Additional Evidence:

Risk of Adverse Behavioral Conditions and Psychiatric Disorders

James A Catreine, ***Risks for Future Depression in Astronauts: A Narrative Review of the Literature***. Behavioral Media Resources, 182 Fisher Avenue, Boston, MA 02120-3340, 2011.

Lawrence A. Palinkas, ***Psychosocial Characteristics of Optimum Performance in Isolated and Confined Environments (ICE)***. School of Social Work, University of Southern California, February 2010.

Camille Shea, Kelley J. Slack, Kathryn E. Keeton, Lawrence A. Palinkas, Lauren B. Leveton, ***Antarctica Meta-analysis: Psychosocial Factors Related to Long-duration Isolation and Confinement***. NASA/TM-2011-216148, June 2011

Gary Strangman, ***Human Cognition and Long Duration Spaceflight***. Produced for NASA's Behavioral Health and Performance (BHP) program element, July 2010.

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Risks for Future Depression in Astronauts:
A Narrative Review of the Literature

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Introduction

Problem

Depression is currently the largest cause of disability worldwide (World Health Organization, 2008). Within the United States, approximately 10.2% of U.S.-born Americans have had major depression within the past 12 months, with a lifetime occurrence rate of 23.8% (Gonzalez, Tarraf, Whitfield, & Vega, 2010). Astronauts are not immune to depression. Symptoms of depression and concerns about crewmates' depression have occurred on prior space missions (Epstein, 2001; Feldman, 1997; Lokeman, 1997; Mullane, 2006; National Aeronautics and Space Administration, 2006). Furthermore, tragic events have recently transpired in which one former astronaut apparently committed suicide due to depression (Chappell, 2006a, 2006b) and another cited depression as a cause of criminal behavior (CNN.com, 2007). A depression-free past does not guarantee a depression-free future, despite careful selection.

Depression can disrupt mission success, safety, individual performance, and morale; at its worst, depression can be fatal, through suicide. Depression on a long-duration mission could be particularly problematic because it could result in an impaired astronaut, thereby having a prolonged and profound effect, and because evacuating an astronaut from an exploration-class mission would generally not be possible. Because the majority of space missions are now long-duration, and because NASA is moving toward exploration missions, it is now more important than ever to be able to estimate an individual's likelihood of developing depression.

Need

There is a need to evaluate the risk of an astronaut developing depression on a space mission. Knowing an individual's risk for depression will be useful in at least three ways: (1) it can be weighed in the decision to assign an astronaut to a particular mission; and (2) it may inform standards of fitness for entrance into the astronaut corps; and (3) it can identify astronauts who, if selected for a long-duration mission, could benefit from enhanced monitoring, prevention, and intervention resources.

Although a voluminous literature is emerging on risk factors for depression, no single review has captured the breadth of variables studied across the fields of medicine, genetics, physiology, psychiatry, psychology, and epidemiology.

Purpose

The purpose of this project is to take a broad inventory of depression risks that may pertain to long-duration flyers, both before and during their missions. The primary application of this inventory is to provide guidance in understanding a given individual's risk for depression, given

that he or she is currently depression-free. Secondarily, it can inform decisions and activities on long-duration missions to reduce the likelihood of depression.

Method

An extensive narrative review of the literature in the fields of medicine, psychiatry, psychology, and epidemiology was conducted. Approximately 260 journal articles were reviewed by a clinical psychologist and an epidemiologist, of which 110 were included in the final review table. The majority of these are referenced in this paper. Several decisions were made to include a risk factor in the review:

- The risk has to have been shown to be valid in at least one well-conducted study. Because the area of depression risk research is relatively new, conflicting results exist and there is not full consensus about every potential risk factor. Conflicting data and opinions are discussed in this whitepaper.
- The risk has to be relevant to astronauts. For example, an astronaut is unlikely to be impoverished, unemployed, or have a low level of education, so even though those problems are risks for depression they are not discussed here.

"Depression" is defined in somewhat different ways across the reviewed studies. Some focus on major depressive disorder specifically, whereas others focus more broadly on depressive symptoms. Because much of this research has been conducted internationally, various diagnostic criteria have been used, and at least 39 measures of depression were employed. The variety of criteria complicates a disjointed field of studies; nonetheless, general themes for risk of depression do emerge.

Note that the populations studied are primarily adults the age of astronauts; however, relevant risks were also identified in younger populations. Furthermore, most studies included nonclinical samples, which further help to draw comparisons to the astronaut population.

At this stage in the science, it is not always possible to tell whether an observed risk factor is a cause or effect of, or marker for depression, or whether it is a covariate caused by a third factor (or in some cases more than one of the above). Practically speaking, the exact relationship is not as important as whether a phenomenon coincides with or precedes depression.

Because the scope of this project is so broad, only risks are discussed. Protective factors and depression prevention strategies are beyond the scope of the review, although they are also important and could inform select-in decisions, organizational policy, and mission design.

Journal articles were primarily identified via the PubMed and PsychInfo databases, as well as the reference lists in other articles. In reviewing journal articles, more recent sources were strongly favored over earlier publications, since they typically reflect advances in knowledge and include the most current information. Additionally, in areas for which recent, high-quality literature reviews or meta-analyses have been published, fewer individual supporting papers were included. In other risk areas, only a handful of studies have been conducted, so those are

included. It should be noted that most of the research studies reviewed did a reasonably good job of isolating risk factors, usually statistically, to appropriately attribute variance to the various risks.

Longitudinal and community sample studies were included whenever possible, since these studies are more capable of identifying predictive variables than smaller, single-time point studies. A list of these follows:

Large-scale Population Studies

- Aberdeen Children of the 1950s (Scotland)
- Australian Longitudinal Study of Ageing
- BeyondBlue National Postnatal Depression Program (Australia)
- British Cohort Study
- Canadian Community Health Survey—Mental Health and Well-being
- Canadian National Population Health Survey
- Cardiff Depression Study
- Children in the Community Study (US)
- Depression Research in European Society (6 European nations)
- Dunedin Multidisciplinary Health and Development Study (New Zealand)
- East Flanders Prospective Twin Survey (Belgium)
- Epidemiologic Catchment Area community survey (US)
- European Study of the Epidemiology of Mental Disorders/Mental Health Disability
- Family Blood Pressure Program, Tecumseh Michigan Site
- Great Smoky Mountains Study
- HUNT-1 & HUNT-2 (Norway)
- Large Analysis and Review of European Housing and Health Status (Various European cities)
- Mater-University of Queensland Study of Pregnancy and its Outcomes
- Medical Research Council National Survey of Health and Development (UK)
- National Collaborative Perinatal Project (US)
- National Psychiatric Morbidity Among Adults Living in Private Households (UK)
- Netherlands Twin Registry
- PATH through Life Project (Australia)
- Project Metropolit (Denmark)
- Renfrew/Paisley Study (UK)
- Screening Across the Lifespan: Swedish Twin Registry
- Sequenced Treatment Alternatives to Relieve Depression (STAR*D; US)
- SUN Project-Seguimiento Universidad de Navarra (Spain)
- Survey of Adolescent Life in Vestmanland—2004 (Sweden)
- Temple-Wisconsin Cognitive Vulnerability to Depression Project
- The Harvard Study of Moods and Cycles
- The Helsinki Study of Very Low-Birth-Weight Adults
- Toronto Mental Health and Stress Study

- US National Comorbidity Survey
- Virginia Adult Twin Study of Psychiatric and Substance Use Disorders
- Virginia Twin Registry
- Whitehall II Study (UK)
- WHO study on Psychological Problems in General Healthcare (International)
- Yale Bereavement Study
- Zurich Cohort Study

Conclusion

Depression is a complex clinical condition that appears to have multiple etiologies. It is likely that multiple factors are involved, each with small but cumulative effects, including vulnerabilities (genetic and physiological), historical events (such as early adversities), and current stressors and health. Moreover, many covariates for depression are not depression-specific; many tend to be associated with multiple behavioral health problems. Nonetheless, identifying the range of possible predictors is a start toward making predictions about future occurrence of depression, with the broad generalization that the more risk factors an individual possesses, the more likely he or she is to develop depression.

Future Directions

This project appears to be the first effort to inventory all of the risks for depression identified across multiple fields. It was a major undertaking, but only the first of several potential steps to improve selection of long-duration crews to minimize the chances of depression occurring. Now that the range of potential risk factors has been identified, the relative strength of each possible factor should be compared, as relevant to astronauts. This can be done through further analysis of the literature and possibly through a meta-analysis. Additionally, the literature on resiliency, depression prevention and protective factors (other emerging bodies of work) should be reviewed to identify both select-in criteria and prevention strategies that can be implemented in space.

Risk Factors for Depression in the Astronaut's Personal History

Birth Weight as a Risk for Depression

Literature Summary: Birth Weight

No comprehensive review of depression risk due to birth weight was identified at the time of this whitepaper. Therefore, a sampling of representative papers on this topic was reviewed. Overall, there is marked disagreement between studies as to whether low birth weight predicts depression.

Several research teams have found that low birth weight (<2.5 kg) is a risk for depression in adulthood (Colman, Ploubidis, Wadsworth, Jones, & Croudace, 2007; Gale & Martyn, 2004) and in adolescence (Costello, Worthman, Erkanli, & Angold, 2007). Moreover, one study found that risk of depression decreases as birth weight increases, up to 4.5 kg but that it then increases as birth weight exceeds that amount (Colman, Ploubidis, Wadsworth, Jones, & Croudace, 2007). Other studies have analyzed results from preterm infants compared to full-term, and found that low birth weight for gestational age is a risk (i.e., persons born prematurely but at appropriate weight for their development are not at increased risk for depression) (Raikkonen et al., 2008; Wiles, Peters, Leon, & Lewis, 2005).

Contrary to the above findings, other research teams have found no relationship between low birth weight and depression (Osler, Nordentoft, & Andersen, 2005; Vasiliadis, Gilman, & Buka, 2008).

Risk Importance: Birth Weight

At present, there appears to be no consensus in the field as to the impact of low birth weight on depression, and there is clearly more research to be done. Those studies that have found a relationship between low birth weight and depression have only found a modest correlation, and somewhat more for women than men. One finding that low birth weight may magnify the impact of other risk factors for females is particularly intriguing. (Costello et al., 2007). Additionally, the most important factor may be low birth weight compared to gestational age (suggesting healthy development up to that point); not weight at birth, alone.

Taken together, the literature suggests that low birth weight be considered a small risk for depression. Low birth weight may increase the astronaut's likelihood of developing depression, and possibly reduce resilience, but it is unknown to what extent. If an astronaut has other risks for depression, low birth weight may be considered to be a more important factor than if he or she has few other risks.

Risk Assessment: Birth Weight

Birth weight and gestational age at birth is one of the few potential risks for depression that can be easily, reliably, and objectively ascertained.

Risk Mitigation: Birth Weight

None.

Family Psychiatric History as a Risk for Depression

Literature Summary: Family History

A moderately strong predictor of first-episode depression in adults is family history. Recent, longitudinal and cross-sectional population studies indicate that psychiatric problems in first-degree relatives and even grandparents place individuals at increased risk for depression. For example, several studies have found that having a parent with depression is a major risk factor for developing depression as an adult (Angst, Gamma, & Endrass, 2003; Kessing, Agerbo, & Mortensen, 2003; Kessler, Davis, & Kendler, 1997; Kessler et al., 2008), and a parental history of generalized anxiety disorder is a similar risk (Kessler et al., 1997; Kessler et al., 2008). Furthermore, persons with a mother, father or sibling who has been hospitalized for any psychiatric reason have been found to be at greater risk for depression in adulthood, with a maternal history of hospitalization being the greatest risk (Kessing, Agerbo, & Mortensen, 2003). Beyond psychiatric conditions, a family history of fatigue also presents an elevated risk of depression (Angst, Gamma, & Endrass, 2003). Finally, being impaired due to depression (versus having depression but functioning adequately) predicted onset in offspring and grandchildren of persons with depression (Weissman et al., 2005).

Despite the strong evidence of family psychiatric problems being a risk for depression, it is important to bear in mind that a family history of depression neither predicts all future cases of depression nor guarantees the onset of future depression. For example, in one study, only 29% of persons with depression had a family history of depression, whereas 21% of persons who did *not* have depression did have a family history of depression (Moffitt et al., 2007).

Risk Importance: Family Psychiatric History

The importance of obtaining a thorough and accurate family psychiatric history cannot be overstated. Based on these studies, it would be important to learn the mother and father's history of major depressive disorder (and any mood disorder), generalized anxiety disorder, and addictions. It would also be useful to know if the astronaut's mother, father, or any sibling had been hospitalized for any psychiatric problem. And, it would be informative to know the grandparents' history of depression. In addition to these, the level of impairment caused by depression in first and second-degree relatives may also be important, with more impairment signaling greater risk. Finally, family history of fatigue should be evaluated.

Family Psychiatric History Risks for Depression

- Maternal or paternal major depression
- Maternal or paternal generalized anxiety disorder
- Maternal or paternal addiction
- Paternal antisocial personality disorder
- Maternal, paternal, or sibling psychiatric hospitalization
- Maternal or paternal chronic fatigue
- Grandparental history of major depression

Risk Assessment: Family Psychiatric History

Several strategies can be used to obtain family history of first and second-degree relatives:

Interviews with the astronaut and his or her parents and grandparents are optimal. However, it is probable that by adulthood some or all of the individual's parents and grandparents will be deceased or unable to provide reliable information due to impairment. Nonetheless, interviews should be conducted whenever possible, using semi-structured formats that ensure that key questions are asked, yet leeway is given for follow-up inquiry. Also, interviewing the same individual on multiple occasions may provide more depth and variety of information, as well as establish the credibility of the informant.

Brief diagnostic testing for current psychiatric disorders can be conducted with parents and grandparents, to the extent that they are available and provide consent. Such testing may not provide data about past episodes of psychiatric illness, but could yield important information if an informant has a current behavioral disorder.

Medical record review of parents and grandparents would be valuable, as would interviews with them, if available. Some informants may wish to present information about their history in a favorable light and may not acknowledge past episodes of mental illness. A medical record review of all parents and grandparents could provide important clues, through diagnoses made, observations noted and interventions prescribed, such as psychotropic medications or psychotherapy, even in the absence of formal diagnoses. As electronic medical records become more commonly used in the U.S., such chart reviews may become easier to conduct and medical data may persist longer.

Third-party interviews with persons who know or knew the astronaut's parents or grandparents well could also provide information about past episodes of mental illness. Examples of these interviewees would be siblings of the descendant, siblings of the parents and grandparents, friends, neighbors, caregivers or sitters, healthcare providers, clergy, nursing home staff, beauticians, shopkeepers, et cetera.

Risk Mitigation: Family History

No direct mitigation of family history is possible, although resilience-building, enhanced monitoring and enhanced support may assist an individual at risk for depression due to family history.

Genetic Factors as Risks for Depression

Literature Summary: Genetic Factors

The literature on potential genetic bases for depression is vast; however, several recent review papers provide an excellent overview of findings to date. Genetic factors are likely to be one of the greatest risks for depression and may explain how individuals differ in response to adversity and stressors. However, it is likely that depression is related to the effects of multiple genes each exerting small effects, combined with gene-gene and gene-environment interactions that cause the development of depression (McCaffery et al., 2006).

Persons with vulnerability, sensitivity, alterations or dysregulations in the serotonergic system may be particularly prone to depression (Jans, Riedel, Markus, & Blokland, 2007). Several factors may be responsible for "serotonergic vulnerability," including genetic variation, personality, gender, stress, immune system functioning, and substance use (Jans et al., 2007). Within the genetic domain, persons with the s-allele of the 5-HTTLPR gene have an elevated risk of depression when faced with life adversity (Jans et al., 2007). Additionally, polymorphisms in the 5-HT_{1A} and TPH2 genes are of interest (Jans et al., 2007). Other serotonergic genes that may relate to depression are 5-HTT, 5-HT2A, and 5-HT2B (McCaffery et al., 2006).

Genes involved in other physiological processes have been implicated in depression. Chronic inflammation is present in many cases of depression (McCaffery et al., 2006), and some of the markers associated with it are found in IL-6, IL-1B and TNFA (McCaffery et al., 2006). Finally, a gene related to the metabolism of folate, MTHFR, has also been linked to depression (Teper & O'Brien, 2008), and polymorphisms in clock genes T3111C and NPAS2 471 may be responsible for sleep disturbance, which has also been identified as a risk factor for depression (Germain & Kupfer, 2008).

Genetic factors have even been identified that relate to suicidal ideation, including markers within the genes GRIA3 and GRIK2. These findings are robust and an allele of GRIK2 is associated with an extremely high risk of suicidal ideation—more than eight times the risk of persons with out it (Laje et al., 2007).

Finally, genetics play a large role in personality, and the BDNF gene has been determined to be partly responsible for variation in neuroticism (Laje et al., 2007). Persons with the Val allele of the BDNF gene score higher on Neuroticism on the NEO-Five Factor Inventory measure of personality than those with the Met allele. Moreover, persons with the Val allele only score high on the Neuroticism facets of "Depression", "Self-consciousness", "Anxiety", and "Vulnerability"—all of which are associated with depression (Laje et al., 2007).

Risk Importance: Genetic Factors

Genetic vulnerability probably underlies all depression risk and is major pathway by which risk is transmitted between familial generations. As such, the theoretical importance of genetic risk factors is profound. However, they are not yet well understood. At present, most research is exploratory and little has been replicated. Therefore, the practical importance of genetic risk factors today is limited. As assays are developed to reliably test for depression vulnerability, this risk factor may ultimately become the most important one for astronaut and crew selection.

Risk Assessment: Genetic Factors

Although no commercially available genetic test for depression susceptibility has yet been created, some genetic testing of astronauts could be conducted that may provide information of potential value. In particular, testing could focus on identifying which variant the astronaut carries of the genes 5-HTTLPR, 5-HTT, 5-HT2A, 5-HT2B, TPH2, IL-1B, TNFA, GRIA3, GRIK2, and BDNF. Results related to any single gene should probably not cause concern; however, if a profile emerged of depression-implicated alleles on many of these genes, some concern could be warranted.

Regarding serotonergic vulnerability, several tests have already been used in research with humans and could be used with astronauts. Jans et al. (Jans et al., 2007) describe testing for this condition in two ways: by use of a serotonin challenge or by an acute tryptophan depletion test (serotonin is synthesized from the amino acid tryptophan). In a serotonin challenge, a serotonin agonist is administered to the person, such as L-TRP, citalopram, fenfluramine, buspirone, or *meta*-chloropenylpiperazine (Jans et al., 2007). Changes in the hormone prolactin are then monitored. A blunted or hypo-active, prolactin response to these substances has been found in persons with a history of depression, even if not currently depressed (Jans et al., 2007). This assessment has the advantage of being objective.

In an acute tryptophan depletion test, an amino acid mixture is administered to the individual and subjective mood states are reported. Persons with serotonergic vulnerability report mood lowering in response to this procedure; whereas, persons without it do not. Of course, this assessment is subjective and is therefore susceptible to an astronaut providing inaccurate reports of mood states. Nonetheless, behavioral observations may be able to detect mood changes.

Risk Mitigation: Genetic Factors

There is no way to mitigate risk of depression due to genetic factors; however, knowing the astronaut's vulnerability to depression based on his or her genetics could lead to enhanced support or monitoring, as needed.

Parental Divorce as a Risk for Depression

Literature Summary: Parental Divorce

There is a rich literature on the effects of divorce, family background and parenting styles on individuals' development, and a few representative studies are described here. Divorce, and to a lesser extent separation, of one's parents in early childhood is a risk for developing depression later in life.

Persons whose parents divorce or separate before their child is 16 years old have a moderately increased risk of developing major depression as adults, compared to those whose families remained intact (Kessler et al., 1997; Pelkonen, Marttunen, Kaprio, Huurre, & Aro, 2008). However, risk of depression was higher if the mother divorced and remarried—more than double the odds of individuals without divorced parents (Gilman, Kawachi, Fitzmaurice, & Buka, 2003a). The risk of depression for persons whose parents separated but did not divorce

was slightly less (Gilman, Kawachi, Fitzmaurice, & Buka, 2003b). These results were found to be consistent, even when adjusted for socioeconomic status (Gilman et al., 2003a).

Persons whose parents had a high-conflict relationship and then divorced had a substantial risk of developing depression (Gilman et al., 2003a). However, if the mother remarried, the risk of depression in adulthood jumps to three-and-a-half times more than an individual whose parents stay married (Gilman et al., 2003a). Fifty-seven percent of those offspring had major depression by age 39. Persons whose mothers were never married but had ongoing conflict with the father are at similarly high risk (Gilman et al., 2003a). Risk of depression for persons whose parents were in conflictual relationships but remained married does not appear to be at substantially higher risk than persons from intact low-conflict families (Gilman et al., 2003a).

Risk Importance: Parental Divorce

A relationship between parental divorce and the likelihood of developing depression in later life has been found by multiple research teams (Gilman et al., 2003a; Kessler et al., 1997; Pelkonen et al., 2008). Across the above studies, persons who experienced parental divorce during their childhood are at a moderately increased risk of depression, compared to persons from intact families. However, Gilman et al.'s 2003 study (Gilman et al., 2003a) found profound risks for persons whose mothers remarried but remained in high-conflict relationships with the father (the effects of fathers' remarriage were not studied). The depression risk for that group (along with persons whose mothers were never married to their fathers but had ongoing conflict with them) is very high. This elevates the potential importance of parental divorce in evaluating an astronaut's risk.

A second study by Gilman et al. (2003b) (Gilman et al., 2003b) suggests that some childhood risks, including parental divorce, may diminish in importance over one's lifetime, meaning that they are more likely to cause depression earlier in life than later. Risk decay is an important concept to consider, and few studies have looked at the declining or increasing importance of risks over time. Until more research is available, the divorce of an astronaut's parents—especially with remarriage of the mother and/or ongoing conflict—should be considered a current depression risk factor. Finally, divorce is a more serious risk than the death of a parent in childhood, although it may be less of a risk for later depression than a family history of psychopathology, or experiencing certain interpersonal traumas or other adversities as a child (Kessler et al., 1997).

Risk Assessment: Parental Divorce

The marital history of an astronaut's parents should be able to be ascertained by legal records (although a nationwide search may be needed to find documentation of marriage and divorce, and older records may not be available electronically). These data may be more accurate than an astronaut's self-report, due to mistaken dates or misunderstood facts.

The level of conflict between an astronaut's parents is more difficult to ascertain. Interviews with the astronaut, his parents and siblings should include questions about conflict. Asking about topics that tend to create conflict in divorced couples may trigger recall, such as finances, visitation schedules, living arrangements, or choice of school or religious institution. Additionally, third-party informants could be valuable, such as the astronaut's teachers (if

available), relatives, family friends, and childhood friends and neighbors. Again, the level of conflict following divorce would be important to ascertain, to estimate risk of depression.

Risk Mitigation: Parental Divorce

It is unknown whether the risk of depression due to parental divorce can be mitigated. Psychotherapy may be helpful, if an astronaut has current, ruminative thoughts about his or her parents' divorce. Additionally, relationship-building with surviving parents and siblings may help to reduce this risk.

Childhood Relationship with Parents as a Risk for Depression

Less research has been conducted about the quality of parent-child relationships as a risk for future depression than about parental relationships and divorce. However, it appears that parenting style and relationships with mothers are critical. Low affection from, rejection by, separation from, and poor relationship with one's mother during childhood are risks for depression in adulthood. The few articles that address this topic are discussed here. Note that abuse and neglect are addressed elsewhere, in the Child Abuse section.

Literature Summary: Childhood Relationship with Parents as a Risk for Depression

Rejection by one's mother during childhood has been found to be a strong risk factor for depression in adulthood followed by mother's lack of affection (Brown, Craig, Harris, Handley, & Harvey, 2007). Additionally, having a poor relationship with one's mother in adolescence predicts depression in adulthood, compared to persons with better relationships (Pelkonen, Marttunen, Kaprio, Huurre, & Aro, 2008).

Having a poor childhood relationship with one's father does not appear to predict future depression (Pelkonen et al., 2008), although affection from either mother or father is protective against depression (Jorm, Dear, Rodgers, & Christensen, 2003). However, persons who received more affection from fathers than mothers as children had significantly more depressive symptoms in both survey groups (Jorm et al., 2003). The authors suggest that either the imbalance in affection, itself, may cause depression or that fathers being more affectionate than mothers may be indicative of other troubles in the home (Jorm et al., 2003).

Regarding parenting style, persons who reported having had "negative parenting" are significantly more likely to have had depression (Gladstone & Parker, 2006). "Negative parenting" in that study was a collapsing of data on three types of parenting: "indifference" (lack of care or neglect), "overcontrol" (overprotection or criticism), and "abuse" (physical or verbal abuse).

Finally, two studies found temporary separation from mother during early childhood to be risks for adult depression. Adults who had been separated from their mother for greater than one month before age four (Gale & Martyn, 2004) or age five (Colman et al., 2007) were found to be significantly more likely to be currently depressed than those who had not.

Risk Importance: Childhood Relationship with Parents

The literature is not yet mature enough to provide a clear sense of how important of a risk factor the astronaut's childhood relationship with parents is. Moreover, three of the studies were retrospective; not longitudinal (Brown, Craig et al., 2007a; Gladstone & Parker, 2006; Jorm et al., 2003), and therefore relied on respondents' remote memories of parenting and relationships. It is conceivable that the experience of having or having had depression influenced recall of those data. The U.K. study (Brown, Craig et al., 2007a; Brown, Craig, Harris, Handley, & Harvey, 2007b; Brown, Craig, Harris, Handley, Harvey et al., 2007) worked to overcome this limitation by interviewing one or more sisters of each person in the study for collateral information (which could also be a good model for obtaining information about astronauts' families of origin).

It is also interesting to note that as brief a separation of one month from one's mother is associated with depression; however, sufficient data was not published to ascertain the gravity of this risk.

Overall, the risk of depression due to relationship with parents should be considered a moderate one. Poor relationships with one's mother as a child may bode ill for the astronaut in multiple ways; however, this risk should probably only be considered to be relevant if other, better established risk factors are also present. Again, this risk is exclusive of child abuse, which is covered separately.

Risk Assessment: Childhood Relationship with Parents

One potential self-report measure of childhood relationship with parents is the Measure of Parental Style (Parker et al., 1997), which was used by Gladstone et al. (Gladstone & Parker, 2006) and was designed for retrospective studies. Additionally, the Parental Bonding Instrument (Parker, 1979) could be considered; a subset of its questions were used by Jorm et al. (Jorm et al., 2003). Finally, the Childhood Experience of Care and Abuse Instrument (Bifulco, Brown, & Harris, 1994) could be considered. Self-report, however, is subject to recall error and bias. Also, since the measures are face valid, it would be easy to present one's parenting history in a favorable light. Other sources of information are needed.

As with other domains of personal history, it would be valuable to interview as many people as possible who could have observed the astronaut's family dynamics as a child. These might include siblings, childhood friends, clergy members, neighbors, and teachers, as available. Additionally, any diaries from childhood or other memoirs or reflections written by astronauts or their siblings could provide clues about family relationships.

Finally, the astronaut's pediatric records may mention family dynamics, as might court records, if any. Of course, if the astronaut or his or her family members have received psychotherapy or counseling at some point (even in adulthood), those records might also provide insight into early family dynamics and parenting.

Risk Mitigation: Childhood Relationship with Parents

Although changing the past is not possible, changing its effects might be. Psychotherapy could be beneficial to address issues that are still salient from early childhood. Moreover, addressing problems and improving relationships with surviving family members may help to mitigate the risk of depression due to childhood relationship with parents.

Childhood Psychiatric Problems as a Risk for Depression

There is mixed opinion about the risk of adult depression being predicted by diagnosed childhood psychiatric problems. Some research has found clear associations, whereas others have found weaker ones or none at all. Below is a summary of the literature based on representative papers.

Literature Summary: Childhood Psychiatric Problems as a Risk for Depression

One longitudinal study found that children with a diagnosis of major depression, overanxious disorder, or "fearful spells" were at very high risk of also being diagnosed with it at age 18 (Pine, Cohen, Gurley, Brook, & Ma, 1998). Interestingly, major depression only predicted future depression when it was present by age nine, although it did predict simple phobia and generalized anxiety disorder (Pine et al., 1998). Another study also found a significant but weak relationship between childhood depression and adult depression: in a multivariate analysis, "childhood depression" dropped out, leaving "parental maltreatment," "conduct problems," and "shame-withdrawal" (all before age 17) as the only significant predictors (Brown, Craig, Harris, Handley, Harvey et al., 2007).

More broadly, internalizing and externalizing problems of childhood have both been linked to adult-onset depression. Childhood conduct problems have been significantly associated with major depression in adulthood (Moffitt et al., 2007), as are greater "negative emotionality" (alienation, irritable-aggressive attributes, and reactivity to stress) at age 18 (Moffitt et al., 2007), This study did not find internalizing problems at ages five to eleven to be significantly associated with later depression (Moffitt et al., 2007). Another longitudinal study found that children who rated themselves as "anxious-depressed," "depressed," or whose mothers rated them as having internalizing or externalizing problems had a greater likelihood of depression at age 26 than those who did not. Finally, another study supported childhood behavioral inhibition as a precursor to adult depression (Gladstone & Parker, 2006). The best-fit path analysis model showed that behavioral inhibition as a child leads to social anxiety which leads to depression in adulthood (Gladstone & Parker, 2006).

Finally, though not psychopathology, one study linked developmental delay in children with future depression (Colman et al., 2007). In particular, delayed age of first standing and delayed age of first walking were found to be significantly associated with adult depression. The pathway proposed by the authors is that these capabilities are linked to cognitive development, and depression is also linked to cognitive capabilities (Colman et al., 2007). Notably, age of first speech was not associated with adult depression.

Risk importance: Childhood Psychiatric Problems

There appear to be measurable psychological factors in one's childhood that have predictive value for the future onset of depression. The challenge is identifying which ones and, especially, how to measure them in an adult astronaut. Although there are mixed results in the literature about the importance of specific behavioral features, knowing the astronaut's child history of psychiatric problems would be valuable for predicting risk of future depression. Nonetheless, Reinherz et al. (Reinherz, Paradis, Giaconia, Stashwick, & Fitzmaurice, 2003) point

out that, in their research, family violence and family composition were stronger predictors of depression than symptoms of childhood psychosocial problems.

The finding regarding delayed developmental milestones (age of first standing and walking) is interesting, but the odds ratios are small enough that they should be considered minor risks. In the context of multiple other risks, these might be considered, but they should not be considered risks for future depression in and of themselves.

Overall, childhood psychiatric problems appear to fall into a high risk category, beneath family history of psychiatric problems. The research also points to the interrelationship between generalized anxiety and depression, the challenge of making accurate diagnoses in children, and the sense that nebulous emotional-behavioral problems in children can subsequently be manifested as specific disorders in adulthood, such as depression.

Risk Assessment: Childhood Psychiatric Problems

Ideally, an assessment should be made for childhood symptoms of depression, symptoms of anxiety, internalization problems, and conduct problems. It is a challenge to obtain an accurate retrospective snapshot of childhood emotional and behavioral problems. The self-report measure used by Gladstone et al. (Gladstone & Parker, 2006; Gladstone, Parker, Mitchell, Wilhelm, & Malhi, 2005), the Retrospective Measure of Behavioral Inhibition, could be completed by astronauts. The same measure could also be completed by surviving older relatives (parents, aunts, uncles, et cetera) about the astronaut's behavior as a child. Obtaining several responses to the same questions might help to triangulate information to achieve a clearer picture. Open-ended interviews could also be useful.

Of course, subjective ratings are prone to recall and desirability bias. Objective sources of information could be pediatric records (especially if the astronaut or his or her parents had complaints about anxiety, depression, or somatization symptoms as a child). Additionally, school records might provide clues to the existence of social withdrawal, and especially conduct problems. If the astronaut saw a counselor in middle or high school, those records would be valuable, if still available. If conduct problems were severe enough to involve law enforcement, those records would be invaluable.

Finally, records created by the astronaut, such as diaries or memoirs could provide evidence about the existence of such problems. Additionally, for upcoming generations of astronauts, large volumes of saved emails, text messages or other electronic communications may be analyzed via computer programs to search for types of content.

Risk Mitigation: Childhood Psychiatric Problems

Although it is not possible to change past events or mental health status, it may be possible to assist the astronaut to prevent future episodes of depression through support, monitoring, and early intervention. Additionally, psychotherapy and skills training may help astronauts with a history of childhood psychiatric problems become more resilient toward future stressors.

Child Abuse as a Risk for Depression

Child sexual, physical, and verbal abuse are some of the worst types of traumas or adversities that a child can experience, and there is strong evidence to link them to depression in adulthood.

Literature Summary: Child Abuse as a Risk for Depression

Most studies collapse various types of child abuse (sexual, physical, and verbal) into a single "abuse" variable, which has been found to be significant, substantial risk factor for depression in adulthood. For example, persons having experienced "maltreatment as a child" have a substantially increased risk of having major depression in adulthood, compared to those who did not experience it (Brown, Craig, Harris, Handley, Harvey et al., 2007; Moffitt et al., 2007). A study of parental verbal, physical, and sexual abuse risks for adult depression found that all three types of abuse are risk factors for depression in adulthood (Sachs-Ericsson, Verona, Joiner, & Preacher, 2006). Nonetheless, one study found that "abuse before age 15" did not significantly predict depression at age 18 or 26, but that "violence in the family" did (Reinherz et al., 2003).

A few studies have looked independently at sexual abuse (Weiss, Longhurst, & Mazure, 1999) and the evidence is strong and results between studies consistent that childhood sexual abuse is a major risk factor for depression in women. A large cross sectional study found that, of all life events, sexual abuse (rape and molestation, isolated or repeated) was the greatest risk factor for future depression (Kessler, Davis, & Kendler, 1997). Characteristics of sexual abuse that predicted greater future depression were its severity, frequency, and duration; age of child was not found to be predictive (Weiss et al., 1999). Only a few studies have looked at child sexual abuse of boys and adult-onset depression, and those data suggested that, although sexual abuse is a risk for depression in men, it less than for women (Weiss et al., 1999). Another study developed a depression prediction model, and both mild/moderate and severe childhood sexual abuse were found to pose similar risks for both males and females for depression in adulthood (Kendler, Kuhn, & Prescott, 2004).

Risk Importance: Child Abuse

The magnitude of child abuse as a risk factor for depression in astronauts is moderate to large, depending on the type and severity of abuse. An astronaut who experienced child abuse is at a substantially greater risk for depression as an adult than one who has not, with recurring child sexual abuse being the greatest risk. Evidence for the long-term deleterious impact of child abuse is strong, and effects are likely to be neurological. Early stressors, both acute and chronic, can result in long-term changes in the activity and regulation of the hypothalamic-pituitary-adrenal axis, and these changes are associated with depression.

Risk Assessment: Child Abuse

As with other child history risk factors, a combination of self-report, third-party report, official records and personal writings (diaries, emails) can help to triangulate facts. Regarding

assessments, the Childhood Experience of Care and Abuse Instrument (Bifulco et al., 1994) could be considered.

Of particular importance regarding abuse would be criminal records if a parent or other were arrested for such, or family court records, if the astronaut were removed from his or her home due to abuse.

Risk Mitigation: Child Abuse

No intervention can change past events; however, psychotherapy may be able to help the astronaut cope with the effects of past abuse. Nonetheless, any neurological harm from abuse or other intense childhood stressors is likely to persist. And, it is unknown how such preexisting neurological effects might interact with microgravity, radiation, and other spaceflight stressors.

Other Childhood Adversities as Risks for Depression

Multiple types of adversity and trauma can be experienced by children, and some of these have been studied in relation to adult onset of depression. Examples are having witnessed or experienced violence (other than abuse, which is covered separately), accidents, bullying or shaming, loss of a parent, and growing up in a low- socioeconomic status household. The research on some of these is more robust than others; nonetheless, if traumas or adversities are noted in the astronaut's childhood history, or if he or she witnessed a trauma in childhood, it could be an indicator of susceptibility to future depression.

Literature Summary: Other Childhood Adversities

Multiple childhood experiences are associated with subsequent major depression in adulthood, including accidents, natural or manmade disasters, being mugged, kidnapped, or physically attacked, being shocked, or witnessing trauma (Kessler et al., 1997). It is particularly noteworthy that having witnessed trauma is an even greater risk than parental aggression or being mugged or kidnapped, and is as severe a risk as being physically attacked as a child (Kessler et al., 1997).

Nonviolent victimization experiences in childhood can also have lasting deleterious effects, for both the victim and the aggressor. For example, persons who experienced weight-related teasing as children were found to have significantly elevated depression scores as adults (Benas & Gibb, 2008). Interestingly, however, two studies of childhood bullying found that frequently being bullied in childhood was *not* directly associated with depression at age 18 (Klomek et al., 2008) or later (Gladstone & Parker, 2006). However, regularly *being* a bully as a child was a risk for future depression, and frequently being both a victim and a bully was an even greater risk (Klomek et al., 2008).

Loss of a parent in childhood has been found to be associated with later depression (Luecken, 2000) if it resulted in worse-quality caretaking. Those who lost a parent but whose caretaking was not substantially affected do not appear to have elevated risk.

Finally, some studies have identified growing up in a low-income household as a risk factor for depression in adulthood (Gilman et al., 2003b). Similarly, having parents employed in a manual labor occupation or unemployed as a child is a moderate but significant risk for depression into adulthood, and it persisted whereas other risks (such as parental divorce) lessened over time (Gilman et al., 2003b). Another study also found that financial hardship in one's family of origin predict adult depression, but that the effects of financial hardship were entirely mediated by parental discord (i.e., families with financial stress are likely to have more parental discord, which produces depression) (Brown, Craig, Harris, Handley, Harvey et al., 2007).

Risk Importance: Other Childhood Adversities

Clearly, some risks in this category are more important than others. Childhood experiences of violence or witnessing traumatic incidents should be taken seriously in estimating an astronaut's likelihood of developing depression. On the other hand, the loss of a parent appears to only be a risk for later life depression if it resulted in poor caretaking. Being bullied, even regularly, does not appear to pose a risk for adult depression, although having been a bully—especially one who is sometimes bullied him or herself—is probably a moderate risk. Finally, growing up in a low-income household is a risk substantiated in multiple studies. Of course few risks for depression exist in a vacuum; many risks can interact with each other—some causing or mediating others, and this appears to be the case for financial hardship as a child. Although there are certainly examples of persons who rise from financial hardship to become an astronaut (or other leader), it is still worth noting this as a potential risk, which would have more importance if other, major risks are present.

Risk Assessment: Other Childhood Adversities

As with other childhood data, the use of multiple sources of information is recommended to obtain as clear and comprehensive a picture as possible. For exposure to traumatic incidents or loss of a parent resulting in poor caretaking, interviews with the astronaut and those who knew him as a child would be valuable. Additionally, periods of absence from school might be clues that a major problem was occurring in his or her life. School records and interviews with former teachers may also be valuable for identifying childhood bullying experiences.

Socioeconomic status as a child could be estimated by descriptions of possessions owned, or photographs of the astronaut's childhood home (inside and out). A notation might be made in pediatrician's or school records (such as eligibility for school lunches). In some cases, objective information may be available, as well. For example, tax returns from the astronaut's family of origin may be accessible via government sources (or the families, themselves), as well as welfare records.

Although many school, medical, and tax records currently exist in paper form and likely are destroyed periodically, they may become more available for future generations of astronauts as records are kept electronically and may not be purged at all.

Factors Specific to Adolescence as Risks for Depression

Although many of the childhood factors described above are also risks if experienced during adolescence, a handful of adolescent-specific risk factors for adult depression have been identified. Each has been shown, in at least one study, to be significantly predictive of later depression, although the risks vary in magnitude.

Literature Summary: Factors Specific to Adolescence

Hours of television use in never-depressed 7th to 12th graders was found to predict depression seven years later (Primack, Swanier, Georgiopoulos, Land, & Fine, 2009). The risk was small but significant above 2.3 hours per day and became greater with more hours watched. The effect of more television was found to be greater for males than females, and no risk was found for viewing pre-recorded videos, video games, or radio (Primack et al., 2009)

Patterns of sexual activity as an adolescent may be indicative of having had depression at that time. Girls and boys age 14-16 who did not use contraception at most recent intercourse were significantly more likely to have current depression (Kosunen, Kaltiala-Heino, Rimpel & Laippala, 2003). Additionally, as the number of sexual partners increased, self-reported depression symptoms increased. Boys who had had five or more partners were more likely to have depression than those with only one partner; girls who had had five or more partners were at similarly high risk for depression (Kosunen et al., 2003). Additionally, a review of the literature on fatherhood and depression noted that becoming a father in adolescence is a risk for future depression (Spector, 2006).

Weight perception in adolescence can also be a risk factor. One study found that mass index at age 14 is not associated with depression at age 21; however, the perception of being overweight at age 14 is. Adults who perceived themselves as being overweight at age 14 are more likely to score higher on both measures of depression than those who did not perceive themselves as being overweight—regardless of actual body mass index (Al Mamun et al., 2007). This effect is stronger for females.

Finally, personality and social anxiety disorder as an adolescent has been linked to depression in adulthood in several studies. For example, elevated negative emotionality and low positive emotionality at age 18 are significantly related to depression at age 32 (Moffitt et al., 2007). A different study found that personality disorders diagnosed in late adolescence predict depression at age 33 (Johnson, Cohen, Kasen, & Brook, 2005). In particular, individuals with a personality disorder by age 22 in Cluster A (Paranoid, Schizoid, or Schizotypal) or Cluster C (Avoidant, Dependent, Obsessive-compulsive) were at elevated risk for depression at age 33 (Johnson et al., 2005). Another study found that over 50% of persons age 14 to 24 with social anxiety disorder developed depression within eight years (Beesdo et al., 2007).

Importance of Factors Specific to Adolescence

This section includes a variety of risk factors, some of which are more substantial than others. Of the studies reviewed here, the findings of social anxiety disorder (Beesdo et al., 2007) and personality disorders (Johnson et al., 2005) being predictors of depression in later life have the greatest importance. It seems unlikely that an individual with these characteristics in adolescence would become an astronaut in later life; however, it is conceivable. The personality

characteristics of negativity and positivity in adolescence could also be important; however they would be difficult to assess retrospectively decades later.

The studies of weight concern (Al Mamun et al., 2007) and television exposure (Primack et al., 2009) did not follow their subjects far into adulthood, but they nonetheless could be considered secondary risk factors for later depression; particularly if more important risk factors are present. Note however, that the magnitude of risk for weight concern (odds ratio) was not reported and that the magnitude of risk for television exposure was low and is likely correlated with other factors (e.g., low socioeconomic status of parents).

Finally, the study of sexual behavior of adolescents did not look at prediction, but correlation with current depression. The importance of this study is that the magnitude of risk of current depression was high for those adolescents, and therefore sexual activity with many partners at a young age, particularly without the use of contraceptives, could suggest the presence of depression at that time point—which would then be a risk for future depression. Although it has not been studied as a risk factor for depression in adulthood, having many sexual partners as an early teen may well indicate the presence of other psychosocial problems during that time.

Risk Assessment: Factors Specific to Adolescence

Measuring behaviors, thoughts, and feelings that occurred decades earlier is a challenge, and is likely to be an estimate, at best. Self-report by the astronaut, as well as interviews with individuals who knew him or her at that time in life are good starting points, provided that recall and social desirability bias can be overcome.

For past psychiatric history (related to diagnoses of personality disorders or social anxiety disorder), medical, psychotherapy, or counseling records would be the gold standard. In the absence of these sources, school records, personal writings (diaries, email, memoirs, even text messages, if available) may provide clues. As content analysis software improves and more of an individual's life writings are kept digitally, it may be possible to review large quantities of material to detect some mental health problems.

Adolescent sexual history can probably only be obtained by interviewing the astronaut. However, there may be a tendency for males to exaggerate and females to underreport their number of partners, and remote memory could be a problem, as well.

Weight concerns as an adolescent would also be best reported by the individual, or perhaps his or her family members. Similarly, hours of television watched may be able to be deduced by reviewing typical days/evenings during the teen years via interviews with the astronaut and those in his immediate family or household at the time.

Risk Mitigation: Factors Specific to Adolescence

Although it is not possible to change the astronaut's history, it may be possible to help him or her manage the effects of that history, to reduce risk of developing depression. For example, an individual who continues to experience social anxiety (which can manifest itself in a fear of evaluation; not just social interactions) could be treated for the problem via psychotherapy; particularly cognitive behavioral therapy. Weight concerns may linger, however irrationally, yet be kept private; in these cases, body image therapy could be of value to prevent depression (and other disorders).

Risk Factors for Depression in the Astronaut's Current Life

Social Support & Relationships as Risks for Depression

Many depression interventions emphasize the importance of building social support and connectedness as a pathway to recovery. However, the literature on inadequate social support and troubled relationships as risk factors for depression is limited. Nonetheless, several studies have pointed to a lack of social support as a risk for depression; particularly in women.

Isolation, resulting in limited social support, is a paramount concern about long-duration missions, so this risk factor is also pertinent to *Mission-specific Risks for Depression.* Nonetheless, an astronaut could experience inadequate social support during long training visits abroad or even in day-to-day life in Houston.

Literature Summary: Social Support & Relationships as Risks for Depression

In one study, it was found that higher levels of global social support predicted lower levels of depression in women but not in men (Kendler, Myers, & Prescott, 2005). Moreover, six of the seven types of social support studied were found to be significant for protecting women from depression, including support from: a sibling (in this study, a twin), other relatives, friends, parents, or spouse; plus overall social integration (Kendler et al., 2005). The researchers suggest that there may be different etiological mechanisms for depression in women and men, and that, whereas women turn to their social networks for emotional support, men turn to them for shared activities that serve as distractions from stress or negative emotions (Kendler et al., 2005)

The majority of other research on social support and depression relates to women. For example, for female clients of a family planning clinic (mean age=25.34 years; SD=7.8) having no social support was a significant predictor of whether they currently had major depression (Lee, 2007). Similarly, a cross-sectional survey found that women who were currently depressed and women who were not depressed but had a previous history of depression both had less satisfying marriages than women who had never been depressed (Hammen, 2003). Finally, in another study, having a high level of support from a new mother's partner was found to be the strongest protective factor against postnatal depression, (Milgrom et al., 2008).

Risk Importance: Social Support and Relationships

Inadequate social support appears to pose a moderate risk for depression for women, but perhaps not for men. However, sufficient research has not yet been conducted to definitively state that social support is irrelevant to men, regarding risk of depression. Nonetheless, it is an interesting finding, particularly in light of mixed versus same-gender space crews. Strictly from the perspective of isolation and severely restricted social opportunities, it may be that men are at less risk of depression than women on long-duration missions. This is one of a small number of risks for which a sex difference has been noted. And, it is unknown how this relates to the incidence of depression being significantly greater in women than in men, overall (Kendler et al., 2005).

Risk Assessment: Social Support and Relationships

Assessment should be made on an ongoing basis of each astronaut's level of social support. This is particularly true for women, but until sufficient evidence exists that social support is *not* important for men regarding depression, they should be assessed, as well. Self-report is probably the most reliable method to assess social support, and several measures have been used in the literature, including the Quality of Relationships Inventory (Pierce, Burleson, Albrecht, & Sarason, 1994) and the Social Provisions Scale (Cutrona & Russell, 1987). It is notable that researchers tended to write their own survey questions about social support; however, it could provide more useful information to administer a measure to astronauts so they can be compared to a normative sample.

Risk Mitigation: Social Support and Relationships

It should be feasible to help astronauts to increase their social support while at home, while traveling abroad, and while in space. This may involve strengthening ties with existing friends and family, developing new ties with new friends and colleagues, or by using social networking technology. This should be a priority for astronauts who appear to be isolated, lonely, or depressed. In some cases, increasing social support may not only depend on expanding social opportunities, but improving social skills. It is conceivable that one's social skills could begin to deteriorate with many hours of isolated activity.

Bereavement as a Risk for Depression

Most research on the effects of bereavement on depression has been conducted with persons who have lost a spouse or a child. One recent review was identified on the psychiatric effects of bereavement (Stroebe, Schut, & Stroebe, 2007), which is supplemented here by several additional studies on the linkage between depression, grief, and loss of a spouse or child.

Literature Summary: Bereavement as a Risk for Depression

Multiple well-controlled studies of persons who have lost spouses or children have supported the differentiation between grief and depression as independent, though related, states that people who have experienced a loss go through; whereas, depression occurs in a smaller portion of persons following a death (Stroebe et al., 2007; Wijngaards-de Meij et al., 2005). Across studies of bereavement, approximately 25-45% of recently bereaved persons have mild levels of depressive symptoms and 10-20% have clinical levels (Stroebe et al., 2007).

Notably, mortality—in large part due to suicide—increases in the first week after losing a spouse. Base rates for death after losing a spouse are low overall; however, across all populations men have a 66-fold risk of death within one week of their spouse and women a 9.6-fold risk (although the likelihood of death in any given week is very low) (Stroebe et al., 2007). These rates may be lower if elderly persons are excluded. Nonetheless, mortality rates remain high in some populations, such as mothers who lose a child. Persons who lose a spouse or a child to suicide are at particularly high risk for suicide, themselves (Stroebe et al., 2007).

Several factors may place persons who are grieving at risk for depression, including factors about the person who died, the circumstances of the death, and the effects of the death. Regarding the person who died, the loss of a spouse is a greater depression risk for men than women and the loss of a child is a greater risk for depression in women (Stroebe et al., 2007). Losing a person with whom one had a troubled relationship is a risk for depression (Stroebe et al., 2007), and loss of a father is a substantial risk for depression in men (Kessing et al., 2003).

The circumstances of the death can pose specific risks for depression, including losing multiple family members in a short period of time (Stroebe et al., 2007), death of a first-degree relative by suicide (Kessing et al., 2003), or death of a person whom the survivor had cared for during a prolonged illness, especially with extreme distress (Stroebe et al., 2007). Additionally, an unexpected death can be a risk for depression (Stroebe et al., 2007).

The effects of the loss can also play a role in the onset of depression. Losing a spouse on whom one was dependent emotionally or instrumentally is associated with greater risk for depression (Johnson, Zhang, & Prigerson, 2008), as is losing a spouse and having low self-esteem (Johnson et al., 2008). When the death of a spouse results in social isolation or the inability to accomplish necessary tasks, depression risk can be elevated (Stroebe et al., 2007). Finally, rumination about the death can be predictive of depression (Stroebe et al., 2007).

Risk Importance: Bereavement as a Risk for Depression

Several astronauts have experienced the loss of a family member, friend, or close colleague while on long-duration missions (Dunn, 2001; Leary, 2007; National Aeronautics and Space Administration, 2001, 2006). Although the loss of a spouse or child during a space mission clearly places an astronaut at risk for developing depression, loss of an astronaut colleague—whether in one's crew or not—could also be a risk for depression, due to the closeness that is fostered between astronauts. If the colleague is a fellow crewmember, his or her death may result in a loss of social support and instrumental support (i.e., performing specialized duties) in a highly interdependent crew. The possibility of bereavement leading to depression might be especially elevated if the death occurred early in the mission and resulting in the crewmember's absence for a longer time.

Risk Assessment: Bereavement as a Risk for Depression

Astronauts who experience the death of a person close to them should be assessed for risk of developing depression. This assessment should include: the relationship of the person to the astronaut (spouse, child, parent, father for men, or close friend/crewmate being greater risk), the relationship the astronaut had with the person (a troubled relationship posing greater risk), the circumstances of the death (suicide, prolonged illness, or unexpectedness posing greater risk), and the effects it has on the astronaut (loss of social or instrumental support; particularly if low self-esteem is a problem, posing a greater risk). Additionally, the stage in the mission may also affect the likelihood of developing depression, with a death earlier on being a greater risk because the death will have a longer impact on it. Finally, a horrifying death of a close relative, friend, or crewmember could pose a risk for posttraumatic stress disorder, as well as depression.

Risk Mitigation: Bereavement as a Risk for Depression

Although deaths cannot usually be prevented, there may be some actions that an astronaut, crew, and the psychosocial support team can take to mitigate their effects. One step is to be aware of who might be at risk for death in the astronaut's life before the mission, such as elderly or seriously ill relatives. If such persons are identified, evaluating the astronaut's level of dependence on, and the quality of his or her relationship with, that person could be indicative of depression risk, should he or she die, and appropriate supportive actions taken. For example, if an elderly parent or grandparent is the astronaut's primary confidant, helping the astronaut develop other significant relationships could be protective. Similarly, if the astronaut has a troubled relationship with a relative who may be at risk for death (or even one who is not), mending fences may help to prevent depression. Astronauts who are at high risk for depression and extreme distress, due to the factors of who died, the circumstances, and/or the effects of the death, should be monitored closely for suicidal ideation or parasuicidal (self-harm without intent of death) or reckless behavior; especially in the weeks immediately following the death.

Grief counseling may be beneficial in some cases. There is no evidence that primary prevention of depression via grief counseling (automatically requiring persons who experience a loss) has any effect on the risk of depression (Stroebe et al., 2007). However, secondary prevention grief counseling (providing it to persons at elevated risk for depression due to bereavement) may provide a benefit, and grief counseling to persons who are experiencing complicated bereavement may indeed reduce risk for depression (Stroebe et al., 2007). Barriers to the astronaut's asking for grief counseling should be minimized; however, grief counseling should not be pushed on the astronaut unless there is a clinical reason for it.

Cognitive Style as a Risk for Depression

Negative cognitive styles are major risks for depression; particularly tendencies toward high achievement, the need for control and autonomy, and a negative attributional style in which the individual deeply believes he or she is in some way flawed and responsible for negative events that occur. Additionally, a tendency to brood about one's own depressed mood is also a risk for future depression.

Literature Summary: Cognitive Style as a Risk for Depression

Three habitual patterns of thinking, or cognitive vulnerabilities, have been demonstrated to predict the onset of depression: dysfunctional attitudes, a negative inferential style, and a ruminative response style. These three cognitive styles have been demonstrated to be unique factors, not facets of a single underlying variable, meaning that they can occur in any combination and that each one carries its own risk for future depression (Hankin, Lakdawalla, Carter, Abela, & Adams, 2007).

Dysfunctional attitudes are based on Beck's work on self-schemas (in Mongrain & Blackburn, 2005). Two types of dysfunctional attitudes have been linked to depression: interpersonal needs for acceptance and nurturance—deriving one's self-esteem and value from others' perceptions and approval—and the need for achievement and independence (Mongrain &

Blackburn, 2005). As the need for achievement, control and independence increases, the individual becomes more perfectionistic and negatively affected by failure experiences. The relationship between the need for achievement and risk for depression appears to be linear, with greater perfectionism more likely leading to depression when the individual does encounter failure experiences (Besser, Priel, Flett, & Wiznitzer, 2007). Similarly, having a high need for approval, acceptance or nurturance carries a higher risk of depression when the individual does not receive that high level of social support (Mongrain & Blackburn, 2005). Interestingly, the relationship between dependency on others and depression appears to be nonlinear, at least for women, with persons who have low or high dependency on others being at a higher risk for depression than persons with moderate levels (Besser et al., 2007).

Inferential styles come from the work of Seligman (in Mongrain and Blackburn 2005; (Mongrain & Blackburn, 2005)) on learned helplessness. Individuals are at risk who interpret negative life events as being out of their control, and attribute them to causes that are stable (ongoing), global (consistent across multiple contexts), and internal (due to flaws of one's own) (Alloy et al., 2006). A study of adult siblings concluded that inferential style is not hereditary, that negative inferential styles may be an effect of existing subclinical depressed mood (rather than a cause), and that internal negative attributions may be a "scar" effect of previous episodes of depression (Ball, McGuffin, & Farmer, 2008). Additionally, another study found that individuals with negative inferential styles indeed experience more negative life events, and posits that a cycle can emerge (Hankin & Abramson, 2001). Negative events strengthen negative inferences, resulting negative expectations that influence individuals' behaviors to make them more likely to experience future negative events (Hankin & Abramson, 2001).

Rumination about one's depressed moods is a third pattern of cognitive behavior that can predict depression (Hankin & Abramson, 2001). Rumination refers to the way one responds to having a depressed mood, such as thinking about why one feels this way (versus engaging in active problem solving) (Mongrain & Blackburn, 2005). The literature on rumination is generally supportive of this cognitive behavior as being predictive of future depressive episodes (Hankin et al., 2007), although studies exist that suggest that it has less predictive value than other cognitive vulnerabilities (Mongrain & Blackburn, 2005). Additionally, rumination has been separated into two components: brooding and reflection (Lo, Ho, & Hollon, 2008). Brooding refers to moody pondering, (e.g., "why do I always react this way") whereas reflection refers to a tendency to "analyze recent events and try to understand why you are depressed" (Lo, et al. 2008, pg. 488 (Lo et al., 2008)). The brooding component of rumination appears to convey the risk for future depressive episodes; the reflection component does not (Lo et al., 2008).

Several studies have compared two or more of these cognitive vulnerabilities (Hankin et al., 2007; Mongrain & Blackburn, 2005). A negative inferential style and greater autonomy (perfectionism and need for achievement) have been shown to be strong predictors of the recurrence of depressive episodes (Mongrain & Blackburn, 2005). Additionally, other studies have looked more broadly at cognitive vulnerabilities (Iacoviello, Alloy, Abramson, Whitehouse, & Hogan, 2006; Ingram, Trenary, Odom, Berry, & Nelson, 2007). One of those studies found that cognitive vulnerability predicts the number of episodes, severity, and chronicity of depression but not the duration of episodes (Iacoviello, Alloy, Abramson, Whitehouse, & Hogan, 2006). Another found a linear relationship between negative automatic thoughts, in general, and depression risk, and that men have fewer of them, over all, than do women (Ingram, Trenary, Odom, Berry, & Nelson, 2007). Importantly, a more objective method of detecting negative

automatic thoughts has been developed (Rude, Durham-Fowler, Baum, Rooney, & Maestas, 2010).

Risk Importance: Cognitive Style as a Risk for Depression

Overall, some cognitive styles pose a high risk for depression. Astronauts are high-achieving individuals who may have a strong need for independence, self-reliance and control. However, these very attributes, which foster success as an astronaut, may put them at elevated risk for depression. Moreover, feelings that one is somehow deeply flawed can exist in high-achieving individuals and may not be obvious to others—or even entirely recognized by the individual. Additionally, it is conceivable that an astronaut could have a tendency to brood about his or her own mood. As a result, these risks are important to evaluate and mitigate, as much as possible.

Risk Assessment: Cognitive Style as a Risk for Depression

Risk assessment for cognitive style is challenging when the outcomes could influence the one's chances of being selected for the astronaut corps or assigned to a mission. This is because nearly all such assessments are face-valid, making it easy to "fake good." Well-validated measures of dysfunctional attitudes, negative inference, and rumination do exist, and candid answers to these questions can help to predict the future onset of depression; however, it is questionable whether persons whose career advancement is influenced by such a test will admit to the negative cognitive behaviors. Nonetheless, some astronauts may recognize the prudence of knowing one's risk factors for depression, and answer such questionnaires honestly. Alternatives beyond self-report may also be considered.

The Scrambled Sentences Test is a new assessment of one's tendency toward negative automatic thoughts that has the unique advantage of being more objective than other tests (Rude et al., 2010). This test requires users to quickly make sentences that could have either a negative or positive message from scrambled words, without having to use all of the words provided. For example, "winner born I am loser a" could be arranged as "I am a born winner," "I am a born loser," or some other combination of words. Individuals are allowed blocks of 3.5 minutes to unscramble as many sentences as they can, and the number of positive-valence sentences are tabulated (Rude et al., 2010). The Scrambled Sentences Test has been shown to be an even better predictor of future depressive episodes than the face-valid Dysfunctional Attitudes Scale (Rude et al., 2010). It could be an excellent measure for NASA to use in astronaut and crew selection.

Third party information about the individual's cognitive style may also be valuable, if it is obtainable and objective. Sources of data that might have this intimate knowledge might be spouses, parents, and persons from other close relationships. It may also be that persons who have worked with the astronaut over time have observations about his or her cognitive behaviors.

Finally, although not ideal from a crew selection perspective, it would be possible for astronauts to self-administer validated assessments and receive feedback and recommendations, either via computer or printed materials. If the astronaut controls his or her data (e.g., takes a test home and does not need to bring back the results), he or she may be more comfortable answering questions candidly. In this way, at least the astronaut could learn his or her own cognitive vulnerability to depression. Mitigation strategies and practical advice could be provided based on scores. This is done in the Virtual Space Station assessments developed by Carter et al., (Carter, Buckey, Greenhalgh, Holland, & Hegel, 2005). It is possible that high-vulnerability candidates

may select themselves out of a mission as a result, or at least seek help to deal with their vulnerabilities.

Risk Mitigation: Cognitive Style as a Risk for Depression

Cognitive style is a risk that can be mitigated, at least to some extent. The best way to change the astronaut's habitual cognitive behaviors is likely to be cognitive therapy or cognitive behavioral therapy. It should be stressed to the astronaut that one does not need to have a mental illness to benefit from psychotherapy, and that learning new cognitive skills to prevent depression is as important as physical fitness, if not more so. If the astronaut is unwilling to enter therapy with a skilled clinician, computer-based therapy, such as offered in the Virtual Space Station (Carter et al., 2005) may be a good alternative.

Skill-building would be another strategy to counteract an identified cognitive vulnerability in an astronaut, particularly if the negative cognitive style were a tendency to ruminate about depressed moods. An alternative to rumination is to actively engage in problem solving. Problem solving treatment can provide a structured means to approach depressed mood in a different way, and is also available via the Virtual Space Station (Carter et al., 2005).

Finally, self-awareness may be a first step toward changing a negative cognitive style. However, without the skills learned in cognitive therapy or problem-solving treatment, it seems unlikely that self-awareness, alone, will reduce the risk of future depression.

Stress as a Risk for Depression

Acute stressful events and chronic stress are both moderate predictors of the onset and recurrence of depression. The current view of this relationship is that persons with histories of depression experience more stressful events, some of which they contribute to, which cause more depression. A major, recent literature review on stress as a risk factor was identified, along with several illustrative papers.

Literature Summary: Stress as a Risk for Depression

It has been well established that stressful events precede depression in many instances (Hammen, 2003). However, the modern view of the relationship is that independent stressful events, such as a death, may lead to the first onset of depression, but that persons who have experienced depression subsequently experience more dependent stressors—ones over which they have some control; particularly interpersonal conflict (Liu & Alloy, 2010). These dependent stressors, such as marital problems (Chen et al., 2007; Hammen, 2003; Milgrom et al., 2008), troubled relationships with one's children (Hammen, 2003), and criticism at work (Chen et al., 2007) are then risk factors for depression (Chen et al., 2007; Liu & Alloy, 2010). Importantly, persons who have experienced prior depression have significantly more dependent stressors in their lives than persons who have not had it (Hammen, 2003; Liu & Alloy, 2010). Indeed, a model of the "stress-depress" cycle is that past stress, negative cognitive styles (discussed above)

and personality and interpersonal vulnerabilities predict stress, which then predicts depression (Liu & Alloy, 2010).

Overall, stressors, both chronic and acute, appear to pose a moderate risk for depression (Milgrom et al., 2008). Besides those noted above, other stressors associated with the onset or recurrence of depression include divorce (Hammen, 2003), having a spouse with a psychiatric disorder (Hammen, 2003), major life events (Liu & Alloy, 2010; Milgrom et al., 2008), and daily hassles (Milgrom et al., 2008). One study found that major life events and daily hassles were not as strong a predictor as lack of partner support, perfectionism, or subclinical signs of depression or anxiety (Milgrom et al., 2008). Finally, one's ability to cope with stress has been found to be negatively related to the recurrence of depression but only marginally (Conradi, de Jonge, & Ormel, 2008).

Risk Importance: Stress as a Risk for Depression

Chronic and acute stressors are moderate risks for depression. However, they may play a somewhat more important role on long-duration missions, in which astronauts are living in a chronically stressful environment, compared to living at home. Therefore, chronic and acute stressors should be tracked and managed by the individual astronaut, the crew, and NASA mission management as much as possible.

Risk Assessment: Stress as a Risk for Depression

Several self-report measures have been validated for the assessment of current stress, the most prominent of which being the Perceived Stress Scale (Schlotz, Yim, Zoccola, Jansen, & Schulz, 2011). However, self-report of stress symptoms may be subject to response bias if the results have bearing on the astronaut's career advancement. Several alternatives are possible.

For current astronauts, it may be possible to track major life stressors of which NASA is aware, such as divorce, or deaths or illness in the family. Dependent stressors, over which the astronaut has some contribution, may be less apparent, such as ongoing marital discord or financial problems.

Finally, self-report measures may be answered more candidly if the astronaut's responses are not conveyed to NASA. Although less useful for purposes of selection, if the astronaut were able to complete a measure and receive feedback and recommendations from it, he or she may at least be able to recognize his or her own risk for depression and take steps to better manage the stress.

Risk Mitigation: Stress as a Risk for Depression

Multiple countermeasures for stress are already available to NASA and others are rapidly coming online. For example, the Virtual Space Station (Carter et al., 2005) suite of interactive media programs will soon include a training course on the management of chronic stress (NASA Research and Education Support Services, 2011). One of the major components of stress management is effective problem solving, and an in-depth treatment of depression is already included in the Virtual Space Station that is based on problem-solving therapy. This intervention may be useful even in the absence of depression to learn more effective approaches to the management of stress both before and during long-duration missions. Additionally, interpersonal

conflict appears to be a major type of chronic stressor that can lead to depression (Liu & Alloy, 2010), and an intervention for ongoing conflicts is currently under development for the Virtual Space Station (Carter et al., 2005), to be completed in 2013.

Finally, NASA management can take steps to help reduce astronauts' level of stress on long-duration missions. Based on this literature review, helping to maintain good family functioning via the psychosocial support team while the astronaut is on travel or in space could prevent family discord. Additionally, minimizing criticisms about job performance from the ground to the crew or between crewmembers—and maximizing praise for jobs well done could reduce stress. Finally, identifying sources of daily hassles for the astronauts and devising organizational systems to minimize them could reduce ongoing stress. Of course, individuals differ in activities they find stress relieving, and conducting a rigorous evaluation of the astronaut's healthy stress management activities and resources could help them find ways to continue them during training and in space.

Alcohol Abuse as a Risk for Depression

Despite the high rates of alcohol abuse and depression in the United States, there have been surprisingly few papers that have studied alcohol use as a risk for depression. Of those that have studied drinking, results are mixed; however, alcohol abuse appears to be a stronger predictor of future depression for women than for men.

Literature Summary: Alcohol Abuse as a Risk for Depression

It has been posited that patterns of alcohol use may predict the onset of depression, and conversely that having depression may predict the problem drinking behavior (Gilman & Abraham, 2001). This bi-directional hypothesis has been partially supported. In an early meta-analysis of eight studies, a positive relationship was found between the number of alcohol dependency symptoms at baseline and the subsequent onset of depression at follow-up (Hartka et al., 1991). This relationship was found to be stronger for females than males. The same meta-analysis found that women with depression at baseline had an increase risk of alcohol abuse at follow-up; no such relationship was found for men (Hartka et al., 1991). A more recent five-year longitudinal study found that both women and men, initial symptoms of alcohol abuse moderately predicted later onset of depression and visa versa (Gilman & Abraham, 2001). However, a stronger relationship was also found for women. Conclusions from that study were that treating depression does not necessarily reduce future alcohol problems, and that alcohol may have depressogenic effects—which suggest that alcohol use may be both a self-medicating behavior and a distinct cause of depression (Gilman & Abraham, 2001). Finally, a more recent study found that alcohol dependence at baseline was not a risk for depression 18 months later; however, men who engaged in binge drinking were at increased risk for depression (Haynes et al., 2005). No depression risk for women who binge drink was found (Haynes et al., 2005). Additionally, persons who had abstained from alcohol during the previous 12 months were at reduced risk for depression 18 months later (Haynes et al., 2005).

Risk Importance: Alcohol Abuse as a Risk for Depression

There is not yet sufficient research to definitively state how strong of a predictor that alcohol abuse is for the later onset of depression, nor what patterns of alcohol use (e.g. bingeing versus dependence) would be most predictive. However, alcohol abuse is clearly a behavioral health problem in its own right that could impair the astronaut's performance both immediately and in the future. As such, it is important to detect the problem and facilitate behavior change in the astronaut. Overall, it would be safe to say that individuals who abuse alcohol and exhibit either patterns of bingeing or symptoms of dependence are at least at mildly elevated risk for depression in the future.

Risk Assessment: Alcohol Abuse as a Risk for Depression

Self-assessment, behavioral observation, third-party informants, and biological markers can all be used to assess for problem drinking. Regarding self-assessment, recent studies have found that a two-item screening for alcohol use disorders is more effective than longer, more common measures (Kelly, Donovan, Chung, Bukstein, & Cornelius, 2009; Vinson, Kruse, & Seale, 2007). The two yes/no questions are based on Diagnostic and Statistical Manual criteria, and are: (1) "In the past year, have you sometimes been under the influence of alcohol in situations where you could have caused an accident or gotten hurt?" and (2) "Have there often been times when you had a lot more to drink than you intended to have?" These questions have demonstrated both good specificity and sensitivity to detect the presence of alcohol use disorders. Of course, these questions are also subject to response bias.

Behavioral observation of the astronaut in social situations where alcohol is available may also provide useful data about drinking behavior. Similarly, third-party informants could provide valuable information, provided that they are objective and do not have an incentive to either minimize or exaggerate their reports of the astronaut's drinking. Additionally, persons who have had neutral or even negative relationships with the astronaut (such as former colleagues, ex-spouses, or ex-lovers) may be more candid in describing observed behaviors.

Finally, several biological markers, other than blood alcohol content, are associated with heavy drinking, although they have varying specificity and sensitivity (National Institute on Alcohol Abuse and Alcoholism, 2002). They include elevated levels of the proteins gamma-glutamyl transferase and carbohydrate-deficient transferrin; increased mean corpuscular volume (i.e., larger red blood cells), and, in mothers, the presence of fatty acid ethyl esters (National Institute on Alcohol Abuse and Alcoholism, 2002).

Risk Mitigation: Alcohol Abuse as a Risk for Depression

Clearly, there are multiple treatments for alcohol abuse, ranging from therapist-directed to self-help. Live therapy would be an excellent choice for treatment of alcohol abuse, provided that the therapist is competent to treat it, and individual, rather than group, therapy may be more acceptable to an astronaut who places a premium on confidentiality. Treatment via self-help modalities, such as internet sites, show some evidence of efficacy (Bewick et al., 2008). Examples of online interventions with some clinical validation are www.drinkerscheckup.com and www.moderatedrinking.com. These have the advantage that treatment can be accessed entirely anonymously by the astronaut. Despite their ubiquity, peer-support 12-step programs, such as Alcoholics Anonymous, have not been studied in sufficiently controlled trials to indicate

that they are effective; however, they may be better than no treatment (Ferri, Amato, & Davoli 2006). Also, it seems likely that astronauts would be unwilling to present at a community-based peer-support program, regardless of assurances of anonymity.

Psychiatric History as a Risk for Depression

Although results vary between studies, individuals who have had some level of psychiatric problems in the past appear to be at increased risk for depression in the future.

Literature Summary: Psychiatric History of Depression as a Risk for Depression

Several studies have examined the effect that a history of depression (clinical or subclinical) has on an individual's likelihood of developing future depression. A longitudinal study found that having symptoms of depression at age 16 or 22 produced a nine-fold risk of having depression at age 32, and symptoms of depression at age 22 produced a ten-fold risk of depression at age 32 (Pelkonen et al., 2008). Similarly, another study found that women who had previously been treated for depression had a five-fold risk of having future depression (Lee, Casanueva, & Martin, 2005). However, an individual's risk for future depression is only moderately associated with the number of depressive episodes he or she has had in the past (Conradi et al., 2008; Giles, Jarrett, Biggs, Guzick, & Rush, 1989).

Several studies from the maternal literature have examined risk factors for women during the antenatal and postnatal periods. A study of antenatal risk factors found that women with a history of minor depression or anxiety were at a moderate risk of developing depression; women with a history of major depression had an even greater risk, and women with a history of both depression and anxiety problems were at the greatest risk (Milgrom et al., 2008). A study of postnatal depression similarly found that a history of depression put women at an increased risk, and that this was partially mediated by the presence of dysfunctional cognitions (Church, Brechman-Toussaint, & Hine, 2005).

Other psychosocial problems associated with the onset of future depression include social anxiety (Gladstone & Parker, 2006), agoraphobia (Barkow et al., 2003) and suicidal ideation (Barkow et al., 2003), and the presence and extent of either substantially increases the likelihood that the individual will develop depression in the future (Barkow et al., 2003; Gladstone & Parker, 2006).

Risk Importance: Psychiatric History of Depression as a Risk for Depression

A positive history of depression is a major risk for future depression, and a history of other psychiatric conditions, particularly anxiety or social anxiety, is a moderate risk for depression.

Risk Assessment: Psychiatric History of Depression as a Risk for Depression

Astronauts may be unaware that they have had an episode of depression or may be reluctant to acknowledge one. As such, historical data should be sought from as many third-party sources as possible. Sources could include individuals, such as family members, ex-spouses or ex-lovers (who may provide a different viewpoint) long-term professional acquaintances, friends, or professors. And, a medical records review focusing on complaints, symptoms and medications would be invaluable to uncovering signs of past episodes of depression or anxiety, whether diagnosed or not.

Risk Mitigation: Psychiatric History of Depression as a Risk for Depression

Although it is not possible to change the astronaut's psychiatric history, it is possible to provide support to attempt to prevent future episodes of depression.

Personality Traits as Risks for Depression

Some personality traits and tendencies are moderately predictive of the onset of depression in adulthood. Neuroticism (a tendency to experience negative affect), a high need for autonomy, approval and perfectionism; low self esteem; and characteristics of some personality disorders are moderate risks for depression.

Literature Summary: Personality Traits as Risks for Depression

Neuroticism is one of the Big Five personality traits (McCrae & Costa, 1989) and refers to the propensity to experience adverse emotional states such as sadness, anger, and anxiety. Multiple studies have associated elevated neuroticism with depression, and two longitudinal studies have found that neuroticism is a predisposing risk for depression, rather than an effect of prior depression (Kendler, Gatz, Gardner, & Pedersen, 2006; Krueger, 1999). A large-scale longitudinal study that looked at the absence of positive emotionality found similar results, with persons who experience fewer positive emotions being at greater risk for developing depression (Moffitt et al., 2007). Similarly, a study of multiple cognitive, behavioral, and emotional risk factors found that elevated ongoing levels of anger and hostility were the strongest predictor of depression (Ingram 2007). Although studies have generally found neuroticism to be equally predictive of depression for men and women, one study found that level of neuroticism to be a stronger predictor for men (Kendler et al., 2006).

In general, studies have found that level of neuroticism is a small but significant risk factor for future depression, although one study found that it was only associated with prior episodes of depression (Mongrain & Blackburn, 2005). Additionally, several studies have found the trait of neuroticism to be less predictive of future depressive episodes than other psychosocial risk factors. For example, autonomous personality style (Mongrain & Blackburn, 2005), negative attribution style (Mongrain & Blackburn, 2005), "frequent ups and downs" in emotion (Angst et al., 2003), job stress (Paterniti, Niedhammer, Lang, & Consoli, 2002), and family history of

depression (Moffitt et al., 2007) were all found to be stronger predictors of future depression than neuroticism.

Aside from neuroticism, several other personality traits have been found to be moderate risks for depression. These include perfectionism (Milgrom et al., 2008; Mongrain & Blackburn, 2005), having an autonomous personality style (highly valuing self-reliance) (Mongrain & Blackburn, 2005), and having a high need for control combined with having few achievement events (Mazure & Maciejewski, 2003). These closely relate to the negative cognitive styles discussed earlier. Additionally, hostility and low self-esteem have been found to be associated with future depression (Paterniti et al., 2002). Finally, traits associated with antisocial, borderline, dependent, depressive, histrionic, schizotypal personality disorders, as an adolescent have been found to be risks for depression as an adult (Johnson et al., 2005).

Risk Importance: Personality Traits as Risks for Depression

Although the literature is mixed, depending on the personality trait studied, the traits of autonomy, perfectionism, and the need for achievement appear to be high risks for depression; whereas neuroticism appears to pose a lower risk. As such, personality traits vary from large to small as magnitude predictors of future depression. Although neuroticism is often associated with depression in the field of mental health, studies have repeatedly found other factors than neuroticism to be more important. Nonetheless, personality risks should not be overlooked; particularly because they are a risk that has some potential to be mitigated.

Risk Assessment: Personality Traits as Risks for Depression

Applicants to the astronaut corps are routinely assessed via measures of the Big Five personality traits (Musson & Helmreich, 2005) and, at least in the past, have completed the Minnesota Multiphasic Personality Inventory (Santy, 1994). However, answers to self-report measures may be skewed due to social desirability biases, and one study of successful and unsuccessful applicants found no difference in Big Five personality profiles (Musson & Helmreich, 2005). Therefore, observations of astronauts' behavior over time and across situations could be useful to obtain valid indications of personality traits. Interviewing persons who have had positive, negative and neutral interactions with the astronaut may provide data on his or her tendency to experience negative affect under various circumstances.

Risk Mitigation: Personality Traits as Risks for Depression

Although personality cannot be altered per se, much research has been conducted on the treatment of perfectionistic and neurotic features, such as anger and sadness. For persons high in perfectionism and autonomy, cognitive restructuring may be a valuable intervention. For neuroticism, therapies that focus on increasing positive emotionality may be of substantial value, since the experience of positive emotions has been found to buffer against a genetically-based propensity toward negative emotionality (Wichers et al., 2007). Newer cognitive behavioral therapies and mindfulness interventions are also promising approaches (Wichers et al., 2007).

Nutritional Deficiencies as Risks for Depression

The literature on nutritional deficiencies as risks for depression is in its infancy; however, there already appears to be support for low folate and vitamin B_{12} as small to moderate risks for depression.

Literature Summary: Nutritional Deficiencies as Risks for Depression

Although only a small number of studies have been conducted on the risk of depression due to nutritional deficiencies, several nutrients have been associated with depression. In a study of a large cohort (N=9,670), men with higher levels of folate and women with higher levels of vitamin B12 were found to have the lowest levels of depression (Sanchez-Villegas et al., 2009). Analyses of persons with depression in that sample were more complicated: women with current depression were more likely to have low levels of B_{12}, but among depressed men only current smokers or those with low levels of anxiety had low folate levels (Sanchez-Villegas et al., 2009). No relationship was found between depression and vitamin B_6. A meta-analysis of 11 studies that reported folate and depression levels found that persons with decreased levels of folate were significantly more likely to have depression (Gilbody, Lightfoot, & Sheldon, 2007). That meta-analysis identified only one prospective study of folate and depression found that persons with low folate at baseline were more likely to be treated for depression during the next 15 years (Tolmunen et al., 2004).

A review of the literature on nutrition and depression points out that fish oil and folic acid have demonstrated some benefit for the treatment of depression; that folate deficiency reduces individuals' response to antidepressants; and that people with depression are more likely to have deficiencies in folate, vitamin B_{12}, iron, zinc, and selinium (Bodnar & Wisner, 2005). They also suggest that, although not yet sufficiently studied, decreased intake of antioxidants may present a risk for depression. Those authors note that the typical Western diet of processed food is low in all of these nutrients. That review also suggests that nutrition may be involved in depression in three ways: 1) a nutritional deficiency may be causative of depression; 2) a metabolic abnormality may be present; and 3) nutritional therapies may improve the effectiveness of antidepressant medications (Bodnar & Wisner, 2005). Finally, it should be noted that, although there has been much discussion in the press of a possible link between vitamin D and mood disorders, few studies have examined this relationship, and results are inconclusive (Murphy & Wagner, 2008).

Risk Importance: Nutritional Deficiencies as Risks for Depression

Although nutritional risks for depression are not yet as well understood and may not be as great as other factors, they should not be overlooked; especially because they may be able to be mitigated. It is important to recognize, however, that nutrition is not only dependent on diet and consumption of nutrients but their bioavailability. Bioavailability may be influenced by the astronaut's genetics, the presence or absence of other nutrients, pharmaceuticals, or by factors unique to microgravity, radiation and other unique environmental factors. It has already been found that astronauts return from the International Space Station with approximately 20% lower folate than before launch; possibly due to reduced overall food consumption (Smith, Zwart,

Block, Rice, & Davis-Street, 2005). Therefore, this risk for depression also falls into the category, Mission-specific Risks for Depression.

Risk Assessment: Nutritional Deficiencies as Risks for Depression

Nutrients in the body can readily be measured via serum tests, and this is already done on long-duration space missions (Smith et al., 2005). Additionally, food diaries and other records of food consumption can provide data about the intake of nutrients.

Risk Mitigation: Nutritional Deficiencies as Risks for Depression

Countermeasures to reduce the risk of depression due to nutritional deficiencies can focus on diet, nutritional supplements, and factors affecting the bioavailability and metabolism of nutrients. Pre-mission screening for nutrient deficiencies should also be conducted.

Health Factors as Risks for Depression

Some health factors have been found to elevate risk for depression. In this section, only factors that may apply to astronauts are reviewed. Health-related risk factors that are unlikely to be apply to astronauts assigned to missions were not reviewed, including smoking, chronic illness, long-term disability, and obesity. Only a handful of risks were identified, which represent small to moderate risks for depression.

Literature Summary: Health Factors as Risks for Depression

Several studies have measured the relationship between depression and global health and self-perceived health, utilizing prospective longitudinal designs. A study of persons who experienced first-episode depression between the ages of 50 to 59 found that poor health was a stronger predictor than neuroticism or psychosocial factors (Sneed, Kasen, & Cohen, 2007). Another study found a small but significant risk for impaired physical functioning, with greater physical impairment resulting in less depression-free time over three years (Conradi et al., 2008). That study did not, however, find a relationship between physical impairment and severity of depression (Conradi et al., 2008). A study that followed a cohort over 16 years found that poor self-perceived health at age 16 was a moderate risk for having had episodes of depression by age 32 (Pelkonen et al., 2008). Finally, presenting for treatment of abdominal pain in a primary care setting was found to be a moderate risk for having depression one year later (Barkow et al., 2003). This may be due to somatization of psychiatric symptoms, and may be culturally-based (Barkow et al., 2003).

Being underweight has also been found to be a risk for depression (Lawlor, Hart, Hole, Gunnell, & Smith, 2007). In a large 29-year study, persons who were underweight by the World Health Organization's definition (body mass index $<18.5 kg/m^2$) were at moderate risk for developing depression later in life (Lawlor et al., 2007). Notably, persons who were overweight had reduced risk for depression (Lawlor et al., 2007).

Periods of hormonal fluctuation in women have also been found to be associated with higher risk for depression. A literature review concluded that the period after giving birth (postpartum) is a period of high risk for women to develop depression (Soares & Zitek, 2008). The premenopausal period and the year following frank menopause were found to be moderate to high risk periods for depression (Soares & Zitek, 2008).Women with surgically-induced menopause were at the highest risk (Soares & Zitek, 2008). That research team proposed that some women are predisposed to a heightened sensitivity to hormonal fluctuations, which share common pathways and receptor sites with neurotransmitters in the mood regulation system (Soares & Zitek, 2008). Once a women has settled in to menopause, however (approximately one year after her last menstrual cycle), risk for depression is no longer elevated (Soares & Zitek, 2008). Another study examined the ages at which women entered menopause and found that younger age imparts a moderate risk of depression (Cohen, Soares, Vitonis, Otto, & Harlow, 2006). Moreover, women who experience hot flushes are at even higher risk, although it may be that depression is a result of these flushes (Cohen et al., 2006). However, women who use hormone replacement therapy are only at a slightly elevated risk for depression (Cohen et al., 2006).

Risk Importance: Health Factors as Risks for Depression

Although it is unlikely that an astronaut would begin a mission in poor health, over the course of a long-duration mission health problems could develop, which might put the astronaut at secondary risk for depression. Health problems may pose a greater risk for depression in astronauts in their 50’s and older, compared to younger ones. Of particular interest is the finding that low body mass index is a risk for depression. The loss of body mass is well-documented in long-duration flyers, likely due to low caloric intake (Drummer et al., 2000). In addition to nutritional problems, this could pose a risk for depression that increases over time. Finally, the risk of depression for female astronauts who enter menopause just before, during, or after their mission may be substantially elevated.

Risk Assessment: Health Factors as Risks for Depression

There are objective measures of most of the above health risks, with the exception of perceived health and abdominal pain.

Risk Mitigation: Health Factors as Risks for Depression

Although it may not be possible to prevent health problems during long-duration missions, persons who experience them should be monitored for symptoms of depression. Similarly, as crewmembers experience a decrease in body mass, they should also be monitored for depression. Finally, hormonal therapy may be considered for perimenopausal or menopausal women, although more research is needed to determine whether this is protective against depression.

Neurological and Vascular Factors as Risks for Depression

Multiple neurological and vascular irregularities and derivative behaviors have been associated with depression or proposed as causative factors, sequelae, or both. The presence of any of these problems is a concern for astronauts, given the potential for further neurological insults on long-duration missions.

Literature Summary: Neurological and Vascular Factors as Risks for Depression

A growing literature now supports several neurological and vascular abnormalities as being associated with previous or future depression. A recent review of the literature (Savitz & Drevets, 2009) describes eight such irregularities: (1) elevated amygdala reactivity to negative stimuli; (2) loss of gray matter in the hippocampus; (3) hypometabolism/reduced blood flow, and loss of gray matter in the basal ganglia; (4) ventricular enlargement and white matter hyperintensities or lesions; (5) hypermetabolism and volume loss in the occipital frontal cortex; (6) damage to the ventromedial prefrontal cortex; and (7) hypoactivity of the dorsolateral prefrontal cortex; and (8) white matter abnormalities in the corpus callosum. Of these physiological phenomena, increased amygdala reactivity to negative stimuli may be one of the most stable (i.e., trait-like, versus state-like during episodes of depression), and most predictive of depression. However, there exist many contradictory findings, possibly due to differences in sampling and imaging procedures (de Geus et al., 2007; Savitz & Drevets, 2009). Regarding the etiology of depression, that review proposes that a combination of genetic predisposition plus environmental stress lead to altered neural circuitry which leads to depression (Savitz & Drevets, 2009).

Asymmetry of frontal lobe activity has also been associated with risk of depression (Coan & Allen, 2004; Smit, Posthuma, Boomsma, & De Geus, 2007), although results of studies have been mixed. Greater activity in the left hemisphere is associated with "approach" behaviors, whereas greater activity in the right is linked to "withdrawal" behaviors, and depression has been associated with greater right-side activity (Smit, Posthuma, Boomsma, & De Geus, 2007). In one Electroencephalogram (EEG**)** study of 732 twins, data was analyzed by sex, depression risk based on familial history, and age group, with a middle-aged group's mean age being 49 and a younger group's being 26 (Smit et al., 2007). It was found that EEG frontal asymmetry was predictive of family history of depression for women in the younger group, but not for men or for middle-aged persons (Smit et al., 2007). A slightly earlier literature review proposed that asymmetrical frontal lobe activity both moderates and mediates emotion, with elevated right-side activity being associated with withdrawal behaviors and depression (Coan & Allen, 2004). It is unclear how stable a trait frontal lobe asymmetry is, however (Coan & Allen, 2004), and it may decrease over time (Smit et al., 2007).

A heightened state of sympathetic nervous system arousal and/or inadequate parasympathetic nervous system activity may also be predictive of depression (Forbes, Miller, Cohn, Fox, & Kovacs, 2005; Grillon et al., 2005; Mannie, Harmer, & Cowen, 2007; Teper & O'Brien, 2008). Chronic activation of the hypothalamic-pituitary adrenal axis could produce this state, in which glucocorticoids, such as cortisol, are released (Teper & O'Brien, 2008). The chronic presence of cortisol can have deleterious effects and may cause depression (Teper & O'Brien, 2008). In one illustrative study, 49 young people (mean age 19) with no personal history of depression but who had a first-degree relative with depression were compared to 55

controls with no personal or familial depression history (Mannie et al., 2007; Teper & O'Brien, 2008). Persons with a family history of depression were found to have a significantly higher level of cortisol (measured daily) on both workdays and non-workdays (Mannie et al., 2007).

A general state of heightened arousal has also been identified in persons at risk for depression via experimental psychology methods; particularly in response to startling stimuli (Forbes et al., 2005; Grillon et al., 2005). One study enrolled three groups of subjects: those who had parents with a history of depression or those whose grandparents had a history of depression (based on clinic data; not self-report) and those with no family history of depression (Grillon et al., 2005). The level of startle response in reaction to an acoustic stimulus and a blast of air to the face was assessed by physiologic and self-report measures. Overall, the startle response of persons with parents who have had depression was significantly higher than persons without a family history of depression, and was most elevated for women with a parental history of depression (Grillon et al., 2005). This effect was independent of subjects' lifetime history of psychopathology and use of medication (Grillon et al., 2005). Among persons with only a grandparental history of depression, only females demonstrated elevated startle response compared to females without a familial history of depression; no difference was found for males (Grillon et al., 2005). A similar study, of adults who had experienced childhood depression, found that persons with that history demonstrated a greater startle response than persons with no history of depression (Forbes, Miller, Cohn, Fox, & Kovacs, 2005).

Risk Importance: Neurological and Vascular Factors as Risks for Depression

The findings reported here are experimental, and further research is needed to determine the magnitude of risk (if any) that each abnormality poses. Taken together, an astronaut who has several of the neurological or vascular abnormalities mentioned above, or an elevated cortisol level or startle response may be at a moderate risk for depression.

Risk Assessment: Neurological and Vascular Factors as Risks for Depression

Several methods can be used to assess for the presence of the neurological and vascular problems described in this section. Functional MRI has been used to detect irregularities in brain function and structure (de Geus et al., 2007) and EEG has been used to assess for frontal lobe asymmetry (Coan & Allen, 2004; Smit et al., 2007). Level of physiological arousal can be measured by heart rate variability, with less variability indicating more constant sympathetic nervous system activity, and therefore elevated arousal (Savitz & Drevets, 2009). Salivary and plasma samples can be used to measure cortisol levels (Mannie et al., 2007) and such measurement is already done on astronauts (Stowe, Sams, & Pierson, 2003). Additionally, stimuli such as abrupt loud noises and blasts of air to the face can be used to measure startle response (Forbes et al., 2005; Grillon et al., 2005). Finally, hypermetabolism of the occipital frontal cortex has been detected via the Stroop task and Go/No-go Tests (Savitz & Drevets, 2009).

Risk Mitigation: Neurological and Vascular Factors as Risks for Depression

Some neurological phenomena, such as hypermetabolism of the occipital frontal cortex, have been found to be changed via treatments for depression, such as psychotherapy and medication (Savitz & Drevets, 2009). Moreover, there is uncertainty to what extent some

phenomena are traits of persons at risk for depression versus states of having depression that improve once the episode has passed. (Savitz & Drevets, 2009). Therefore, treating the symptoms of depression and increased monitoring to detect depression early on may impact some of these markers.

Mission-specific Risks for Depression

Although many of the risks described above could be present during a mission, some risks are more unique to mission activities, the space environment, and living and working as a crew.

Sleep and Circadian Rhythm Disturbances as Risks for Depression

Primary and secondary insomnia have been found to be moderate risks for depression, as has the use of hypnotics for sleep.

Literature Summary: Sleep and Circadian Rhythm Disturbances as Risks for Depression

Primary insomnia refers to insomnia that is not due to another disorder, and the inability to sleep becomes a chronic stressor, in itself (Riemann & Voderholzer, 2003). Although many earlier studies did not separate primary from secondary insomnia, enough studies have done so to clearly demonstrate that it is a risk for depression (Riemann & Voderholzer, 2003). In a review of eight longitudinal studies, seven were found to provide strong support that the presence of insomnia for at least two weeks predicts depression one to three years later (depending on each study's follow-up window) and even decades later (Riemann & Voderholzer, 2003). The risk for depression due to insomnia appears to be high—more than three times greater than persons without insomnia—as recently found in a large –sample study (Jansson-Frojmark & Lindblom, 2008). It is possible, however, that insomnia is a prodromal symptom of developing, subclinical depression, and the presence of depression also predicts new cases of insomnia (Jansson-Frojmark & Lindblom, 2008). Finally, secondary insomnia—insomnia due to other medical or psychosocial problems—has also been found to predict the future onset of depression (Morgenthaler et al., 2006).

Unfortunately, the use of hypnotics to treat insomnia, itself increases risk of depression (Kripke, 2007). In a review of data published by the U.S. Food and Drug Administration on studies of eight common hypnotics (all that the researcher could locate), the risk of depression in persons taking hypnotics for sleep was found to be more than double that of persons taking placebos (Kripke, 2007).

Finally, it is well-documented that circadian rhythms are different in persons with depression compared to those without it (Germain & Kupfer, 2008). Natural cycles and rhythms that are disturbed in depression include sleep-wake, diurnal mood variation, core temperature, glucose metabolism, cortisol secretion, and melatonin secretion (Germain & Kupfer, 2008). There is not yet sufficient research to predict the future onset of depression based on circadian rhythm disturbance, however, although several theories suggest how depression and circadian rhythm disturbance are linked (Germain & Kupfer, 2008).

Risk Importance: Sleep and Circadian Rhythm Disturbances as Risks for Depression

Sleep and circadian rhythm disturbance is a major concern on long-duration space missions. Overall, the presence of primary insomnia was found to be moderately to highly predictive of the future onset of depression. Many astronauts report having difficulty sleeping and many take hypnotics as a therapy (Shi, Garcia, & Meck, 2003). In the case of long-duration space crews, insomnia may be secondary to the effects of microgravity, radiation, job stress, lighting, or environmental toxins. Nonetheless, both primary and secondary insomnia have been found to predict future depression (Morgenthaler et al., 2006), and need to be addressed to maintain good performance, safety, and health status.

Risk Assessment: Sleep and Circadian Rhythm Disturbances as Risks for Depression

To identify cases of chronic insomnia in the general population, self-report is probably the most commonly used method, and several good measures have been developed, such as the Pittsburgh Sleep Quality Index (Carpenter & Andrykowski, 1998), the Stanford Sleepiness Scale (Bailes et al., 2006), and the Epworth Sleep Scale (Bailes et al., 2006). However, wrist-worn actigraphs offer another option for tracking sleeping in space and on the ground, and can provide an objective record of sleep and wakefulness (Dijk et al., 2001), provided that the sleeper comply with wearing it. Additionally, devices such as the Night Cap have been developed for home use to record sleep behavior (Jacobs, Pace-Schott, Stickgold, & Otto, 2004).

Risk Mitigation: Sleep and Circadian Rhythm Disturbances as Risks for Depression

Cognitive-behavioral therapy has been found to be more effective for the treatment of insomnia than medication (Jacobs et al., 2004) and has no side-effects. As noted above, the use of hypnotics more than doubles the individual's risk of developing future depression (Kripke, 2007). Moreover, it is possible that a course of cognitive-behavioral therapy for insomnia may help prevent future depression. As such, this should be the first choice for the treatment of insomnia on long-duration space missions. At least two self-guided internet-delivered interventions have been developed to provide cognitive behavioral therapy for depression: www.cbtforinsomnia.com and www.SHUTi.net. These resources could be used during a long-duration space mission.

Aspects of the Physical Environment as Risks for Depression

Some aspects of a spacecraft's physical environment could pose risks for depression, including malfunctions, crowding, and exposure to toxins.

Literature Summary: Aspects of the Physical Environment as Risks for Depression

Although spacecrafts are unique environments, they do share commonalities with other built environments insofar as they must accommodate the activities of daily living. A small body of research exists on the connection between housing quality and mental health. One recent study

found several housing problems that are small risks for having a positive lifetime history of depression: having a nonfunctional kitchen, inadequate heating of the living space, and peeling paint (Galea, Ahern, Rudenstine, Wallace, & Vlahov, 2005). (Malfunctioning toilets and water leaks were not found to be significant predictors.) This finding is consistent with another study that found housing quality to be positively associated with mental health, as defined by the characteristics of cleanliness/clutter, indoor climactic conditions, privacy, hazards, and structural quality, among others (Evans, Wells, & Moch, 2003).

Crowding in the household (and perhaps in a spaceship) also has deleterious mental health effects. A large-sample study with one-year follow-up examined the connections between the number of persons per room in one's home to mental health problems (Regoeczi, 2008). Housing density ranged from -1 to +3 or more persons per room (with negative scores indicating more than one room per person). Significant sex differences for crowding were found, with women experiencing significantly higher levels of depression as number of persons per room increased, and so did women's tendency to withdraw from interacting with others, but not to act aggressively (Regoeczi, 2008). Men did not demonstrate any increase in depression as density increased; however they did have a tendency toward aggression plus withdrawal behavior (versus simply withdrawing from interactions) (Regoeczi, 2008). Crowding was also noted to be associated with worse mental health in a large multi-city study (Shenassa, Daskalakis, Liebhaber, Braubach, & Brown, 2007).

Finally, several papers have linked toxins to depression, even after controlling for confounding factors. Importantly, these studies propose that the toxins cause depression; not just mimic its symptoms (Bouchard et al., 2009; Levine & Chengappa, 2007; Shenassa et al., 2007). For example, a large-sample study of residents in eight European cities found that the presence of mold and dampness in the home was a small but significant risk for depression (Shenassa et al., 2007). Persons with less perceived control over their home and persons with health problems; particularly respiratory conditions, were at the highest risk for depression (Shenassa et al., 2007).

Another study examined lead levels in the blood of a large sample of healthy young adults (Bouchard et al., 2009). Persons with the highest levels of lead were excluded from the analysis, as were smokers, and statistical methods to control for socioeconomic status were used. Persons in the highest quintile of the "normal" range were found to be at more than double the risk for having major depressive disorder (Bouchard et al., 2009).

Finally, a clinical case was reported of a female dentist who experienced recalcitrant depression for ten years (Levine & Chengappa, 2007). Multiple attempts to treat the depression failed, although she reported feeling better when she took vacations. A careful review of her work history found that she began to experience depression after starting to use nitrous oxide with her patients, and that the nasal mechanism of delivery permitted a substantial amount of gas to escape into the air-which she breathed(Levine & Chengappa, 2007). It was supposed that inhaling the nitrous oxide for several hours per day caused an increase in homocystine levels and a deficiency in vitamin B_{12}. Once an intervention was introduced of vitamin B_{12} therapy plus reduced use of nitrous oxide and increased air exchange in the office, her depression remitted within ten days (Levine & Chengappa, 2007).

Risk Importance: Aspects of the Physical Environment as Risks for Depression

Although the research in this section was conducted in a variety of settings, it reports problems that could occur on a spacecraft and that could lead to depression. For example,

malfunctions or deterioration of the living space and facilities could, over the course of many months, become a stressor that contributes to depression. Furthermore, exploration-class space missions will inevitably involve travel in a small, confined environment where crowding will occur. Finally, toxins are a particular problem in a closed-atmosphere environment where fresh air is in limited supply. At least one leak was reported on the Mir space station, in which coolant entered the living space and was being inhaled by crewmembers (Associated Press, 1997). Furthermore, mold has been a problem on both Mir and the International Space Station (Bell, 2007; Vesper, Wong , Kuo, & Pierson, 2008). These physical environment problems appear to pose small to moderate risks for depression, although layered on top of other stressors and depression risks, they may increase an astronaut's likelihood of developing depression.

Risk Assessment: Aspects of the Physical Environment as Risks for Depression

Each of the above risks related to the physical environment on a long-duration mission can be assessed, although it may not be possible to do so during the mission (i.e., to identify the specific toxins or types of mold present). However, to the extent that these problems can be detected, they can be addressed. Crowding may be perceived differently by astronauts from different national cultures, although some level of privacy will likely be required by all fliers.

Risk Mitigation: Aspects of the Physical Environment as Risks for Depression

Clearly, some aspects of the physical environment can be altered to address the above risks, whereas others cannot. To the extent that changes can feasibly be made, whether via repairs to equipment or via advance planning, they may reduce the risk of depression on long-duration missions.

Occupational Factors as Risks for Depression

Several factors related to job stress have been demonstrated to be risks for future, depression; particularly performing demanding work with little control over the job, and expending a large amount of effort with insufficient reward.

Literature Summary: Occupational Factors as Risks for Depression

Most research on the association between mental health and occupational factors is cross-sectional, which reduces the ability to draw cause-and-effect inferences. However, a recent review identified ten prospective epidemiological studies about workplace factors as risks for depression. These studies found consistent evidence to support two models of occupational factors being related to depression: the "job demand-control" model and the "effort-reward imbalance model" (Siegrist, 2008). The job demand-control model, in various studies, refers to having low control over one's work, low social support, low decision latitude, and low skill discretion (Siegrist, 2008). Skill discretion refers to the opportunity to learn new things and develop one's abilities, the requirement to perform repetitive work, and variety on the job. The

reward imbalance model compares job rewards (money, career advancement opportunity, job security, and esteem) with the demands of the work (Siegrist, 2008). The ten studies that met inclusionary criteria examined one or both of these models, and both were found to predict depression. Across all studies, persons who work in a job with high demands and low control, or high demand and low rewards were found to have an 80% higher risk for depression. The studies had large numbers of participants; however, they were all conducted with European, not American populations.

Several other job-related factors have also been associated with depression and other mental health problems, though they have not all been evaluated in longitudinal studies. These include injustice in the workplace (Head et al., 2006; Siegrist, 2008), work-home interference (Siegrist, 2008; Wang, Lesage, Schmitz, & Drapeau, 2008), troubled social relationships at work (Melchior, Niedhammer, Berkman, & Goldberg, 2003), criticism about job performance (Chen et al., 2007), overcommitment (Dragano et al., 2008), high psychological demands (Head et al., 2006; Melchior, Berkman, Niedhammer, Zins, & Goldberg, 2007; Melchior, Caspi et al., 2007; Paterniti et al., 2002), and high physical demands (Melchior, Berkman, et al., 2007).

Risk Importance: Occupational Factors as Risks for Depression

Taken together, this literature suggests that many types of stress on the job can pose a moderate the risk of depression. Some of the stressors described here may occur on space missions; particularly on missions where the crew has limited decision-making authority and control over their work and activities. Additionally, crewmembers who perceive an imbalance between the demands of the mission (or of being an astronaut unassigned to a mission) and the rewards may also be at risk for depression. Finally, career advancement may be inherently limited for astronauts.

Risk Assessment: Occupational Factors as Risks for Depression

Several self-assessments have been used to assess job stress in studies of occupational risks for depression (Siegrist, 2008). Although self-report on an individual basis may not be reliable, due to social desirability bias, an anonymous survey using validated measures across multiple crews of long-duration flyers could provide an indication of overall job stress, including effort-reward and job demand-control imbalance. Occasional checks on these areas during missions may also help to uncover developing problems before they become risks for depression.

Risk Mitigation: Occupational Factors as Risks for Depression

Some aspects of the work on long-duration missions may be malleable in such a way as to increase the crew's control over the work flow and maintain a positive effort-reward balance. The movement toward crew autonomy is an example of efforts to provide crews with increased control. Other suggestions might best be provided by crewmembers, themselves.

Risk Summary Checklists

Two summary checklists are provided here: one relevant to the selection of astronauts or crews, and a briefer one pertinent to risks for depression on space missions. The selection checklist (Table 1) may provide value in estimating an individual's likelihood of developing depression in the future and the mission checklist (Table 2) may provide value for estimating the risk factors idiosyncratic to a particular mission.

The checklists broadly summarize the findings of this report in descending magnitude of risk. Risks predictive markers for depression categorized as small, moderate, or large, compared to persons who do not possess that risk factor. Where available, odds ratios (ORs), relative risks (RRs), or hazard ratios (HRs) were used to rank these factors. Although these three types of ratios can differ substantially when they become large, ORs and RRs are reasonably similar to each other at the low (single digit) levels pertinent to depression risk (Agresti, 1996), and HRs are an estimates of RRs (Spruance, Reid, Grace, & Samore, 2004). However, for some risks, no papers reported probability ratios; in those cases the author made a judgment of the risk based on information available.

The studies in this report were conducted with many populations and the magnitude of a given risk could vary from population to population. Therefore, this ranking of risks represents only a rough approximation of magnitude. As such, the following checklists are not intended to be a formal instrument, but only guides.

Magnitudes estimated by the author (versus those for which ORs, RRs, or HRs are available) are indicated with an asterisk. Finally, two risks pertained to having had depression in adolescence; not adulthood, and those risks are indicated with a double-asterisk. Future research could evaluate the accuracy of the selection checklist for predicting depression in astronauts and others.

Table 1: Risks for Depression in Adulthood Related to Selection of Crews

Risks for Depression in Adulthood Related to Selection of Crews	Magnitude of Risk Small *OR, RR, or HR = 1.0-1.49*	 Moderate *OR, RR, or HR =1.5-2.49*	 Large *OR, RR, or HR ≥ 2.5*
Psychiatric history of depression			☐
Autonomous personality style (perfectionism, high need for control, high need for approval)			☐
High need for control combined with few achievement events			☐
Periods of hormonal fluctuation in women (pregnancy, menopause)			☐
Being a bully, as a child			☐
Parental divorce, if mother remarried *or* had ongoing conflict with father			☐
Mother was never married, but had ongoing conflict with father			☐

Childhood maltreatment, in general		☐
Social anxiety disorder, as an adolescent		☐
Insomnia (primary or secondary)		☐
Child sexual abuse: Molested or raped repeatedly		☐
Childhood (pre-adolescent) psychiatric history		☐
Psychiatric history of agoraphobia in adulthood		☐
Having > 5 sexual partners, as an adolescent**		☐
Witnessing trauma, as a child		☐
Being physically attacked, as a child		☐
Genetic factors	*unknown but probably large*	
Family psychiatric history	☐	
Death of spouse (other than by suicide)	☐	
Dysfunctional attitudes, negative inferential style, or ruminative response style	☐	
Personality disorder by age 22 in Cluster A or C	☐	
Blood lead level in high-normal range ($\geq$ 2.11 µg/dL)	☐	
Being mugged or kidnapped, as a child	☐	
Rejection by, or lack of affection from, mother, as a child	☐	
Chronic stress, from various causes	☐	
Use of hypnotics for sleep	☐	
Being shocked, as a child	☐	
Child sexual abuse: Molested or raped once	☐	
Being in a serious accident, as a child	☐	
Inadequate social support, for women	☐	
Suicide of parent, child, or sibling	☐	
Troubled relationship with parents, as a child	☐	
Growing up in a low-income or impoverished household	☐	
Not using contraception during intercourse, as an adolescent**	☐	
Child physical abuse	☐	
Child verbal abuse*	☐	
Low self-esteem*	☐	

Poor self-perceived health*		☐	
Being underweight		☐	
Parental divorce, as a child		☐	
Folate or vitamin B_{12} deficiency		☐	
Chronic hostility*		☐	
High negative and low positive emotionality, as an adolescent*		☐	
Being in a natural or human-caused disaster, as a child	☐		
Binge drinking of alcohol, for men	☐		
Personality traits of neuroticism	☐		
Delayed standing and walking in early childhood	☐		
Loss of a parent as a child, if resulted in worse caretaking*	☐		
Poor self-perceived health*	☐		
Perception of being overweight, as an adolescent*	☐		
Low birth weight	☐		
Separation from mother for > 1 month, as a child*	☐		
Asymmetry of frontal lobe activity*	☐		
Chronically high levels of cortisol*	☐		
Exaggerated startle response*	☐		
Television viewing > 2.3 hours/day, as an adolescent	☐		

* Based on author's assessment of literature
** Risk for having had depression during adolescence (a risk for adult depression)

Table 2: Risk for Depression Related to Mission Factors

Risk for Depression Related to Mission Factors	Magnitude of Risk		
	Small *OR, RR, or HR = 1.0-1.49*	**Moderate** *OR, RR, or HR =1.5-2.49*	**Large** *OR, RR, or HR ≥ 2.5*
Jobs with high demands but low control		☐	
Jobs with demand-reward imbalance		☐	
Poor quality or condition of living quarters	☐		
Dampness and mold	☐		
Crowding in the living space, for women*	☐		
Environmental toxins		*variable*	

* Based on author's assessment of literature

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Psychosocial Characteristics of Optimum Performance in Isolated and Confined Environments (ICE)

Final Report

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Introduction

The Behavioral Health and Performance (BHP) Element addresses human health risks in the NASA Human Research Program (HRP), including the Risk of Behavioral Health and Psychiatric Conditions. BHP supports and conducts research to help characteristics and mitigate the Behavioral Medicine risk for exploration missions, and in some instances, current Flight Medical Operations.

BHP has identified research gaps within the Behavioral Medicine Risk. Gap BMed6: What psychosocial characteristics predict success in an isolated, confined environment (ICE)?, as defined in the BHP Integrated Research Plan (IRP), outlines a research strategy that primarily incorporates identifying the most malleable psychosocial characteristics in isolated, confined, and extreme environments in order to develop and/or strengthen these characteristics to serve as countermeasures of possible decrements in behavioral health and performance success. A first step to address this gap is to conduct an extensive and exhaustive literature review to identify the most malleable psychosocial characteristics that predict success when considering the context of an ICE environment.

This report addresses two specific aims:

- Identify psychosocial characteristics that predict success in ICE environments
- Identify those characteristics that are most malleable

Methods

The review of the literature on isolated and confined environments was modeled after the format used by the Cochrane collaborative in preparing systematic reviews of the literature (Higgins & Green, 2006). This format includes details on the search strategy, description of selection criteria for studies to review, and review methods.

Searches of published and unpublished studies were then conducted using the following sources of information: electronic data bases, including the National Library of Medicine's PubMed Central, PsycINFO, Social Sciences Citation Index, and Sociological Abstracts; specialist bibliographies such as the Antarctic Bibliography; unpublished technical reports and manuscripts; and library catalogs for books on isolation and confinement in extreme environments. Search terms included isolation, confinement,

extreme environments, human behavior, and performance. These materials were then reviewed to identify studies that described specific psychosocial characteristics as being associated with one or more measures of behavior and performance. Studies that included outcome measures of behavior and performance in isolated and confined environments but did not include psychosocial characteristics as potential predictors of these outcomes (e.g., studies that examined whether duration of exposure to isolation and confinement or changes in circadian rhythms were associated with behavior and performance) were excluded from further review.

Studies were assigned values based on whether they were anecdotal or reviews (score = 0) or whether they reflected quasi-experimental (cross-sectional or longitudinal observational designs) (score = 1) or experimental (randomization of participants or conditions of isolation and confinement) designs (score = 2). Quasi-experimental and experimental designs were combined because there was no evident theoretical model or conceptual framework for hypothesizing the direction of causality from performance to psychosocial characteristics, in contrast to several theoretical models and conceptual frameworks that view performance as an outcome and psychosocial characteristics as predictors of performance (Shadish, Cook & Campbell, 2002).

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. Demographic characteristics included age, gender, education and socioeconomic status (measured by number of years of school, occupation, or family income), work experience, birth order, military or civilian status, place of residence (urban or rural), marital status (married or unmarried), record of truancy or delinquency, cultural background (nationality), and cultural orientation (individualistic vs collective). Clinical evaluations included the results of a clinical assessment by a psychiatrist and/or clinical psychologist, and results from any standardized clinical assessment tools like the Minnesota Multiphasic Personality Inventory (MMPI: Tellegen et al., 2003) or screening instruments like the Center for Epidemiologic Studies – Depression Scale (CES-D; Radloff, 1979), Positive Affect Negative Affect Scale (PANAS; Watson et al., 1988), and Subjective Health Complaints (SHC) Inventory (Eriksen et al, 1999). Coping skills were assessed using standardized measures of coping such as the Social Support Questionnaire (SSQ: Sarason et al., 1983) and the Utrecht Coping List (UCL: Schrueurs et al, 1993). Other characteristics of individuals included number of previous expeditions in isolated and confined extreme environments, interests in hobbies or other leisure activities, religiosity (i.e., participation in religious activities), reaction to environment, and

perceived work-related stress. Personality characteristics were based on use of standardized instruments such as the NEO Five Factor Inventory (NEO-FFI: Costa & McCrae, 1991), the 16 Personality Factor Questionnaire (16PF: Cattell, 1946), Personality Characteristics Inventory (PCI: Musson, Sandal & Helmreich, 2004), Edwards Personal Preference Schedule (EPPS: Edwards, 1959), Minnesota Multiphasic Personality Inventory (MMPI: Tellegen et al., 2003), and FIRO-B (Schutz, 1957), and were grouped into the following categories: global personality traits, motivational indicators, cognitive indicators, mood indicators, self efficacy indicators, interpersonal indicators, and attitudes and perceptions. Group indicators included group size; homogeneity or heterogeneity with respect to demographic characteristics, culture, and personality; and crew cohesiveness with respect to status, roles and leadership. Leadership indicators were grouped into categories of style and skills.

Due to the large number of characteristics identified in these studies, several were grouped together into clusters based on similarity of constructs or presence of common themes. These included demographic characteristics reflecting age, experience and maturity (Demographic Cluster A), or cultural background (Demographic Cluster B); personality characteristics that reflected global traits (Personality Cluster A), motivation (Personality Cluster B), mood (Personality Cluster C), self-efficacy (Personality Cluster D), cognition (Personality Cluster E), interpersonal needs and skills (Personality Cluster F), and perceptions and attitudes (Personality Cluster G); group characteristics that reflect size of crew (Group Cluster A), homogeneity or heterogeneity (Group Cluster B), and crew cohesion (Group Cluster C); and leadership styles (Leadership Cluster A) or skills (Leadership Cluster B).

Measures of performance were grouped into five categories, task ability, emotional stability, social compatibility, leadership, and overall performance. Task ability or performance of assigned duties was generally evaluated on the basis of supervisor ratings or peer nominations (Gunderson, 1974). Emotional stability was measured using standardized psychometric instruments (e.g., Centers for Epidemiologic Studies – Depression Scale, Profile of Mood States [POMS: McNair, Lorr & Droppleman, 1992]], clinical evaluations based on DSM criteria, or supervisor ratings or peer nominations (Gunderson, 1974). Social compatibility was measured using standardized sociometric instruments (e.g., SYMLOG Adjective Rating Form, Bales, & Cohen, 1979), or supervisor ratings or peer nominations (Gunderson, 1974). Behavior reflecting leadership was assessed on the basis of supervisor ratings or peer nominations (Nelson, 1963a). Overall performance was measured on the basis of supervisor ratings and peer nominations of single items (e.g., ideal winter-over, would winter-over again with) Gunderson, 1974).

The malleability of a psychosocial predictor was determined on the basis of whether the characteristic could somehow be changed, or whether it could be eliminated from consideration as a potential risk to less than optimum performance if it could not be changed. For instance, demographic characteristics such as age and gender, for example, cannot be changed, but can be eliminated from consideration as a Behavioral Medicine Risk through programs of screening and selection.

When available, data contained in the papers were used to identify correlation coefficients (Pearson's or Spearman's r), odds ratios, and effect sizes (Cohen's d) for all associations reported to be statistically significant. Nevertheless, a previous review of this literature (Shea et al., 2009) noted substantial variation in measurement of both psychosocial characteristics and performance, making it impossible to conduct a traditional meta-analysis. To address this limitation, study associations reported to be statistically significant were rated as small, medium or large effect based on a schema proposed by Hopkins (2002). Using criteria proposed by Cohen (1988), correlation coefficients between 0.1 and 0.3 reflect a small effect; correlations between 0.3 and 0.5 represent a medium effect; and correlations larger than 0.5 represent a large effect. Effect sizes between 0.2 and 0.6 represent small effects; effect sizes between 0.6 and 1.2 represent medium effects; and effect sizes larger than 1.2 represent large effects. Odds ratios between 1.5 and 3.5 represent small effects; odds ratios between 3.5 and 9.0 represent medium effects; and odds ratios larger than 9.0 represent large effects.

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 by summing the scores of 4 variables. Each variable had a range from 1 to 3, resulting in a fidelity score that ranged from 4 to 12. The 4 variables are as follows:

A. Similarity to spaceflight
    1. Analogue setting (polar, undersea)
    2. Space simulation
    3. Spaceflight
B. Similarity of study participants to long-duration expedition astronauts
    1. Possibly similar with respect to age, but not gender, education, or cultural diversity
    2. Similar with respect to age and education, but not gender or cultural diversity
    3. Similar with respect to age, gender and education, and possibly cultural diversity
C. Similarity with respect to duration of mission
    1. 30 days or less

    2. 31 – 364 days
    3. 365+ days
D. Similarity to Crew size
    1. Large (16+) crews
    2. Moderately small (9-15) crews
    3. Small (1-8) crews

Fidelity scores were calculated only for studies that used a quasi-experimental or experimental design; any study that relied upon anecdotal evidence or was a review of the literature was eliminated from further analysis. Each psychosocial predictor identified in a particular study was assigned a fidelity score calculated for the study as a whole. For instance, a study that identified older age and introverted personality as being significantly associated with emotional stability might have a fidelity score of 8. Both of these psychosocial characteristics that were found in that study to be statistically significantly associated with one or more performance outcomes were then assigned a fidelity score of 8. An average fidelity score was calculated for each psychosocial predictor based on the total fidelity score of the reference or references that specified the psychosocial characteristic as a significant predictor of performance divided by the number of references (studies).

We should note that although current plans for extended missions call for crews of no greater than 4 individuals, only 4 of the 31 studies examined that used a quasi-experimental or experimental design were based on crews of 2-4 individuals (Kahn & Leon, 1993; Leon & Scheib, 2007; Atlis et al., 2004; Kanas et al., 1996). Hence, crews of 8 or less were given the highest fidelity score in the crew size category.

Finally, psychosocial characteristics identified from studies with quasi-experimental or experimental designs were prioritized based on three variables: 1) the number of studies reporting a statistically significant association or associations between a particular characteristic or cluster of characteristics and one or more indicators of performance; 2) the average fidelity score of these studies; and 3) the magnitude of the statistical effect reported for these associations in these studies. Magnitude of statistical effects for a particular psychosocial characteristic was calculated by summing the number of studies that reported data that could be used to calculate a small (assigned a value of 1), medium (assigned a value of 2) or large (assigned a value of 3) statistical effect. 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 3 or more studies reporting statistically significant

associations; and 3) less important predictors that were based on 1 or two studies reporting statistically significant associations.

Results

A summary of the information extracted from reviews of 120 articles that met our screening criteria is found in Appendix A of this report. This table provides information on study citation, type of study, performance type, and psychosocial characteristics examined.

Characteristics Associated with Performance Category

Predictors of Task Ability. Psychosocial characteristics within four of the seven categories were identified as being significantly associated with task ability. Demographic characteristics included older age (Sarris, 2006), male gender (Sarris, 2006), military (Palinkas et al., 2000b) or civilian (Doll & Gunderson, 1969) status, education/socioeconomic status (Sauer et al., 1999, Sarris, 2006), years of work experience (Palinkas, Gunderson, Johnson et al., 2000), no record of delinquency/truancy (Nelson & Gunderson, 1963a), and being unmarried (Owens, 1975).

Personality characteristics that predicted for high task ability included the following: low neuroticism (Owens, 1975); high (Sarris, 2006) or low (Rosnet et al., 2000) extroversion; high PCI measures of positive instrumentality/expressivity (McFadden et al., 1994) and low measures of negative instrumentality (Rose et al., 1994); high emotional (self) control (Gunderson & Kapfer, 1966); high need achievement (Gunderson, 1974); low motivation, a representation of a high ability to adapt motivation to circumstances (McFadden et al., 1994); low boredom (Palinkas, Gunderson, Johnson et al, 2000); low hypo or hyperinvestment in work (Rivolier et al., 1999); low hostility against the self and ritualization of activities (Rivolier et al., 1999); high alertness (Gunderson & Kapfer, 1966) and few difficulties with concentration (Rivolier et al., 1999); high PCI measures of negative expressivity – community (supposedly reflecting willingness to assert oneself) (Rose et al., 1994) and low discordance between the real and ideal self (Rosnet et al., 2000); low FIRO-B measures of expressed inclusion (Gunderson, 1973, Nelson & Gunderson, 1963), expressed (Gunderson, 1973) and wanted affection (Palinkas, Gunderson, Johnson et al., 2000); high role clarity and low role conflict (Sarris, 2006); high perceived fit with station culture (Sarris, 2006); and low assertiveness (Rosnet et al., 2000).

Clinical characteristics included high positive affectivity (Kahn & Leon, 1993).

Other individual characteristics included a high degree of religiosity (Nelson & Orvick, 1964) and number of previous expeditions (Sarris, 2006).

Group characteristics included large group size (Doll & Gunderson, 1967); crew homogeneity related to urban-rural residence and number of hobbies and some personality characteristics such as FIRO-B wanted control and, EPPS measures of autonomy, motivation, and describing friends as efficient (Gunderson & Ryman, 1967), or measures of dogmatism, achievement, affiliation, dominance) (Altman & Haythorn, 1967b); crew heterogeneity related to other personality characteristics (FIRO-B expressed inclusion and expressed control) (Gunderson & Ryman, 1967); and membership in crews with high cohesiveness as reflected in measures of group identity and affiliation (Altman & Haythorn, 1967b), compatibility of dyads (Haythorn & Altman, 1967), and team preference for its leader (Kanki & Gregorich, 1992).

Predictors of Emotional Stability. Psychosocial characteristics within all seven categories were identified as being significantly associated with high task ability. Demographic characteristics included older age (Gunderson & Arthur, 1966; Gunderson & Nelson, 1965a; Nelson & Gunderson, 1964; Nelson & Orvick, 1964; Ikegawa et al., 1998; Taylor, 1993; Palinkas et al., 1989; Taylor & McCormick, 1985), male gender (Palinkas, Glogower et al., 2004), work experience (Biersner & LaRocco, 1987), socioeconomic status and education (Gunderson & Arthur, 1966; Gunderson & Nelson, 1965a; Popkin et al., 1974; Weybrew & Noddin, 1979; Palinkas, Glogower et al., 2004; Biersner & LaRocco, 1987; Godwin, 1985), military (Gunderson & Nelson, 1965a) or civilian status (Doll & Gunderson, 1971b; Gunderson & Arthur, 1966; Gunderson, 1968; Palinkas, Glogower, Gunderson, Holland et al., 2000; Palinkas, Glogower et al., 2004; Palinkas et al., 1989), being unmarried (Palinkas et al., 1995; Godwin, 1985; Weybrew et al., 1961) first-born (Gunderson & Arthur, 1966),having no record of delinquency or truancy (Nelson & Gunderson, 1963a), urban residence (Nelson & Orvick, 1964), and cultural background (Palinkas, Johnson et al., 2004; Kanas, Salnitskiy, Gushin et al., 2001). It should be noticed that the association between civilian status and emotional stability reported in several studies may have been confounded by the fact that civilians were often scientists or skilled technicians and most of the military were enlisted personnel. One study of polar expeditioners (Gunderson & Nelson, 1965a) found the association between age, military rank, and years in the military and emotional stability to be linear at large stations but nonlinear at small stations.

Global personality characteristics that predicted for high emotional stability included the following: low NEO scores and other measures of neuroticism (Palinkas, Gunderson, Holland et al., 2000) and

extroversion (Strange & Youngman, 1979; Biersner & LaRocco, 1987) and high measures of conscientiousness (Eilbert & Glaser, 1959); high PCI scores for positive instrumentality/expressivity (Sandal et al., 1996) and low equivalents of negative instrumentality/expressivity (Gunderson & Arthur, 1966); and high 16PF scores and other measures of emotional (self) control (Gunderson & Kapfer, 1966; Leon et al., 1989). Predictive motivational indicators included high achievement motivation (Pope & Rodgers, 1968; Leon et al., 1989) and low boredom (Palinkas, Gunderson, Johnson et al., 2000; Rivolier et al., 1999). Mood indicators associated with emotional stability included Low hostility against self (Gunderson & Kapfer, 1966; Rivolier et al., 1999), low EPPS scores on aggression (Wright et al., 1963), low sexual preoccupation (Rivolier et al., 1999), low pessimism (Rivolier et al., 1999), and low susceptibility to anxiety (Leon et al., 2002; Mocellin et al., 1991; Rivolier et al., 1999). Predictive indicators of cognitive function included high alertness (Gunderson & Kapfer, 1966). Predictive indicators of self-efficacy included high self-concept (Pope & Rodgers, 1968) and ability to make one's self-concept more like the concepts of other crew members (Gushin et al., 1998) and high (Wright et al., 1963) and low (Palinkas, Gunderson, Johnson et al., 2000) EPPS scores on need for orderliness. Predictive indicators of interpersonal needs include low EPPS scores on autonomy and nurturance (Palinkas et al., 1989); low FIRO-B scores on wanted control (i.e., wanting to be controlled by others) (Gunderson, 1973), expressed control (i.e., wanting to control others) (Palinkas, Gunderson, Holland et al., 2000), wanted affection (i.e. wanting affection from others) (Palinkas, Gunderson, Johnson et al., 2000), expressed affection (i.e., expressing affection to others) (Gunderson, 1973), and want inclusion (i.e., wanting to be included by others) (Palinkas, Gunderson, Holland et al., 2000); high EPPS scores on deference (Wright et al., 1963); high interpersonal sensitivity and socialization (Biersner & LaRocco, 1987); a low need for efficiency but a high need for optimism in friends (Palinkas, Gunderson, Johnson et al., 2000); a low preference for friends who are sympathetic, sentimental, confiding, praising, and warm (Gunderson & Arthur, 1966); and good role specificity or ability to program self into role (Pope & Rodgers, 1968).

Clinical characteristics that predicted for high emotional stability included predeployment clinical evaluations (Doll et al., 1969); low MMPI scores on hypochondriasis, psychopathic deviate, psychoasthenia, schizophrenia, and hypomania (Wright et al., 1963); and low baseline depressive symptoms (Palinkas & Browner, 1995; Palinkas et al., 1995).

Coping resources and strategies that predicted for high emotional stability included high satisfaction with social support (Palinkas & Browner, 1995) and a low UCL score on acceptance (Barbarito & Peri, 1999).

Other individual characteristics that predicted for high emotional stability included number of previous expeditions (Taylor & McCormick, 1985), and high (Evans et al., 1987) or a low (Doll et al., 1969; Slater, 1969) interest in hobbies/activities (Doll et al., 1969; Slater, 1969), a low level of religiosity (Gunderson & Nelson, 1965a), and enjoyment and awe of environment (Atlis et al., 2004).

Group characteristics that predicted for high emotional stability included large group size (Gunderson, 1968; Smith, 1969), small group size (Palinkas, 1991; Palinkas et al., 1989), crew homogeneity related to demographic characteristics (Altman & Haythorn, 1967a) and personality (low dominance and need for achievement (Haythorn et al., 1966)), and compatibility and cohesiveness (Altman & Haythorn, 1967a; Palinkas, Gunderson, Johnson et al., 2000; Johnson et al., 2003; Haythorn & Altman, 1967).

Characteristics of team leaders that predicted for high crew member emotional stability included older age (Smith & Haythorn, 1972) and high levels of support to subordinates (Kanas et al., 1996).

Predictors of Social Compatibility: Psychosocial characteristics within all seven categories were identified as being significantly associated with high social compatibility. Demographic characteristics included older age (Gunderson & Nelson, 1965a; McGuire & Tolchin, 1961; Gushin et al., 1996), male gender (Schmidt et al., 2005), socioeconomic status and education (Gunderson & Nelson, 1965a; Natani, 1971), military service (Palinkas, Gunderson, Johnson et al., 2000), first born individuals (Radloff & Helmreich, 1968), being unmarried (Weybrew et al., 1961), rural residence (Nelson & Orvick, 1964), cultural background (Leon et al., 1994; Palinkas, Johnson et al., 2004), and collective cultural orientation (Palinkas, Johnson et al., 2004). One study of polar expeditioners (Gunderson & Nelson, 1965a) found the association between age, military rank, and years in the military and social compatibility to be linear at large stations but nonlinear at small stations. Another study reported differences by occupation in preference for privacy/interaction (Weiss et al., 2007).

Global personality characteristics that predicted for high social compatibility included the following: low NEO scores and other measures of openness to experience and high measures of agreeableness (Rose et al., 1994); high PCI scores for positive instrumentality/expressivity (McFadden et al., 1994; Sandal et al., 1998) and low scores for negative instrumentality/expressivity and impatience/irritability (Rose et al., 1994); and high 16PF scores and other measures of emotional (self) control (Gunderson & Kapfer, 1966).

Predictive motivational indicators included high achievement motivation (Sandal et al., 1999; Sandal et al., 1995), ability to adapt motivation or need for achievement to circumstances (Sandal et al., 1998; Palinkas, Gunderson, Johnson et al., 2000), low boredom (Palinkas, Gunderson, Johnson et al., 2000), and a balance of motivational factors (WHO, 1985). Predictive mood indictors included low hostility against the self (Gunderson & Kapfer, 1966), low aggressiveness (Rivolier et al., 1999), and low withdrawal to oneself (Rivolier et al., 1999). Predictive indicators of cognitive function included high alertness (Gunderson & Kapfer, 1966). Predictive indicators of self-efficacy included high assertiveness (Sandal et al., 1995), tolerance (WHO, 1985), flexibility (WHO, 1985; sense of humor (WHO, 1985), and ability to make one's self-concept more like the concepts of other crew members (Gushin et al., 1998); and low self-centeredness (Rivolier et al., 1999). Predictive indicators of interpersonal needs includes low FIRO-B scores on expressed (Gunderson, 1973) and wanted (Palinkas, Gunderson, Johnson et al., 2000) affection; high wanting optimism in friends (Palinkas, Gunderson, Johnson et al., 2000); mutual respect, emotional support, ability to confide in partner, and motivation to maintain positive and supportive relationships (Leon & Sandal, 2003); high interpersonal sensitivity (Sandal et al., 1999), a low need for dominance (Sandal et al., 1995), low levels of criticism of others (Rivolier et al., 1999), and low levels of distrust of others (Rivolier et al., 1999).

Clinical characteristics that predicted for high social compatibility included predeployment evaluations by psychiatrist and psychologist (which were found to vary by occupation) (Doll et al., 1969), and high positive affectivity (Kanas, Salnitskiy, Weiss et al., 2001).

Coping resources and strategies that predicted for high social compatibility included high satisfaction with social support (Sandal et al., 1998), and high problem-solving strategies (Sandal et al., 1999).

Other characteristics of individuals that predicted for high social compatibility included a low interest in hobbies/activities at small stations (Gunderson & Nelson, 1965a); high levels of religiosity (Nelson & Orvick, 1964); the shared experience, excitement of spaceflight, close quarters, and isolation from Earth (Kelly & Kanas, 1992; Kelly & Kanas, 1993); a lack of recent life event changes (WHO, 1985); and low perceived work-related stress (Kanas, Salnitskiy, Gushin et al, 2001).

Characteristics of groups that predicted high social compatibility included large group size (Doll & Gunderson, 1971a; Harrison, 1980; Kanas & Fedderson, 1971; Smith, 1969) and crew homogeneity related to culture (Kanas, 1998; Oberg, 1981; Chaikin, 1985; Bluth, 1981; Bluth, 1984), demographic characteristics (Nelson, 1964b; McGuire & Tolchin, 1961; Gunderson, 1966; Law, 1960; Kanas, 1998),

personality (Gunderson & Ryman, 1967; Leon & Scheib, 2007; Gunderson & Ryman, 1967; Leon & Scheib, 2007; Altman & Haythorn, 1967a), interest in hobbies/activities (Gunderson & Ryman, 1967), expedition goals (Leon & Scheib, 2007), work experience (Kanas, 1998), and preference for type of leadership (Kanas, 1998). Crew homogeneity related to culture included similar personal hygiene standards and grooming habits, verbal and nonverbal patterns of communication, gender roles, norms and stereotypes, professional background, and decision-making processes (Sandal, 2004; Lozano & Wong, 1993); similar attitudes toward the experiment, privacy, emotional expressiveness, appropriate gender behavior, and coping in relation to conflict and housekeeping (Sandal, 2004); language and dialect (Sandal, 2004; Kanas, 1998; Oberg, 1981; Chaikin, 1985; Bluth, 1981; Bluth, 1984); and values or beliefs (Sandal, 2004; Chaikin, 1985; Bluth, 1981; Bluth, 1984; Gushin et al., 1997). Crew homogeneity related to demographic characteristics included age (Nelson, 1964b), socioeconomic status and education (McGuire & Tolchin, 1961; Gunderson, 1966; Law, 1960; Natani et al., 1974), and urban-rural residence (Gunderson & Ryman, 1967). One study (Kanas, 1998) found that homogeneity related to gender was associated with high social compatibility, while another study found heterogeneity with respect to gender to be associated with high social compatibility (Rosnet et al., 2004). Problems in sample size and strict comparison between same-gender versus mixed gender crews, however, preclude meaningful interpretation of the results of either study. Crew homogeneity related to personality included describing friends as efficient (Gunderson & Ryman, 1967), EPPS measures of need for affiliation and achievement (Altman & Haythorn, 1967a), and autonomy, motivation, and nurturance (Gunderson & Ryman, 1967). However, another study (Altman & Haythorn, 1967a) reported that crew heterogeneity related to an EPPS measure of the need for dominance and the Rokeach scale measure of dogmatism predicted for high social compatibility. Specific characteristics of crews, including team preference for its leader (Kanki & Gregorich, 1992), perceptions of similarity and equality (Atlis et al., 2004; Gushin et al., 1996), and high role complementarity, consensus, redundancy, latency, and isomorphism (Johnson et al., 2003), were also associated with high social compatibility.

Characteristics of team leaders that predicted high social compatibility included older age (Smith & Haythorn, 1972), a participative/supportive style of leadership (Blair, 1992; Weybrew, 1991), and ability to adapt leadership style to context (Blair, 1992).

Predictors of Leadership. Predictors of high leadership performance included both demographic and personality characteristics, but also characteristics of style and skills associated with leadership. Demographic characteristics associated with high leadership performance included older age (Smith &

Haythorn, 1972), work experience (Smith & Haythorn, 1972), high education/socioeconomic status (Miller et al., 1971), and being married (Palinkas, Gunderson, Johnson et al., 2000).

Personality characteristics associated with high leadership performance included being emotionally controlled, stable, adaptable, accepting of authority, and motivation to be efficient and part of a group (Nelson, 1963a); high levels of self-confidence, alertness, and motivation (Nelson, 1964a); a low PCI score on Negative instrumentality- communion (Rose et al., 1994), low EPPS scores on motivation and orderliness (Palinkas, Gunderson, Johnson et al., 2000), and low FIRO-B measure of expressed control (Palinkas, Gunderson, Johnson et al., 2000).

Style characteristics associated with high leadership performance included soliciting advice of subordinates (Gunderson & Nelson, 1965a; Nelson, 1962; Nicholas et al., 1988), relate to men as individuals and not as subordinates (Nelson, 1962), giving personal praise to members and rewarding them whenever opportunities arise (Sells, 1965; Nelson, 1962), ruling by consensus (Taylor, 1993), not being soft or easy going but emphasizing discipline and adherence to regulations (Sells, 1965), keeping informed about station activities at all times (Nelson, 1962), maintain daily contact with subordinates (Nelson, 1962), stick by decisions once they are made (Nelson, 1962), and being highly task-oriented to the goals of the group, delegating and seek advice of members, being highly people-oriented, and showing concern about team members (Nicholas et al., 1988).

Skills associated with high leadership performance included the ability to exercise a participative/ supportive style in routine situations and authoritarian style in emergencies (Nelson, 1962; Weybrew, 1991), ability to exercise versatility regarding responsibilities, readiness to discuss issues, desire and skills in resolving issues (WHO, 1985), ability to maintain group harmony (Nelson, 1963a; Nicholas & Penwell, 1995; Nelson, 1962), watching for clique rivalries and not aligning with any one subgroup (Law, 1960), and the ability to delegate authority and maintain positive contacts with other officers and men (Campbell, 1953), and ability to set work face and establish expectations for performance (Nelson, 1962).

Predictors of Overall Performance. Psychosocial characteristics within six of the seven categories were identified as being significantly associated with overall performance. Demographic characteristics associated with high overall performance included older age (McGuire & Tolchin, 1961; Draggan, 1987; Gunderson et al., 1964), female gender (Grant et al., 2007), high socioeconomic status and education (Gunderson & Nelson, 1965a; Nelson & Gunderson, 1963a; Miller et al., 1971; Crocq et al., 1974;

Gunderson et al., 1964), military service (Palinkas, Gunderson, Johnson et al., 2000; Palinkas, Gunderson, Holland et al, 2000), civilian status (Natani, 1971), rural residence (Radloff & Helmreich, 1968), no history of truancy or delinquency (Gunderson et al., 1964), and being unmarried (Owens, 1975) or married (Gunderson et al., 1964). One study of polar expeditioners (Gunderson & Nelson, 1965a) found the association between age, military rank, and years in the military and overall performance to be linear at large stations but nonlinear at small stations.

Global personality characteristics that predicted for high overall performance included the following: high NEO and other measures of agreeableness (Rose et al., 1994) and low measures of neuroticism (Owens, 1975), extroversion (Palmai, 1963; Draggan, 1987; Palinkas, Gunderson, Holland et al., 2000; de Montchaux et al., 1979), openness to experience (Rose et al., 1994) and conscientiousness (Palinkas, Gunderson, Holland et al., 2000; Rose et al., 1994); low emotional expressivity and self-reflection (Biersner & Hogan, 1984); high 16PF measures of toughness/poised (Taylor, 1974) and emotional stability (Draggan, 1987; de Montchaux et al., 1964; Nelson & Gunderson, 1962; Nelson & Gunderson, 1963; Sandal et al., 1998; Taylor, 1974) and low measures of imaginative and careless (Taylor, 1974). Predictive motivational indicators included high motivation and need for achievement (Biersner & Hogan, 1984; Kahn & Leon, 1993; Taylor, 1987; Gunderson & Nelson, 1965b; Nelson & Gunderson, 1962; Nelson & Gunderson, 1963b) and ability to adapt motivation to circumstances (Barbarito & Peri, 1999; Weybrew et al, 1961; Nelson & Gunderson, 1962), high industriousness and job satisfaction (Nelson & Gunderson, 1962; Nelson & Gunderson, 1963b), and low boredom (Gunderson & Nelson, 1965a; Gunderson & Nelson, 1965b; Nardini et al., 1962; Palinkas, Gunderson, Johnson et al., 2000). Predictive mood and neurotic traits included low bodily concerns (Kahn & Leon, 1993); a low score on 16PF measure of anxiety (Taylor, 1987); high MMPI score on responsibility and low scores on repression-sensitization, control, and heterosexual aggression (Taylor et al., 1969); and low ratings of tension (Gunderson & Kapfer, 1966). Predictive indicators of cognitive function included high alertness (Nelson & Gunderson, 1963b), low divergent thinking (Biersner & Hogan, 1984), and exercising reasonable goal formation and implementation strategies (Draggan, 1987). Predictive indicators of self-efficacy included high self-confidence (Kahn & Leon, 1993; Nelson & Gunderson, 1963b), low EEPS score on need for orderliness (Palinkas, Gunderson, Johnson et al, 2000), and high ratings of self-reliance and adaptability (Gunderson & Kapfer, 1966). Predictive indicators of interpersonal needs included low FIRO-B measures of wanted control (Gunderson, 1973), expressed inclusion (Gunderson, 1973), and wanted affection (Palinkas, Gunderson, Johnson et al., 2000); low 16PF measures of group dependent (Taylor, 1974; de Montchaux et al., 1979); low competitiveness (Kahn & Leon, 1993); high interpersonal sensitivity

(Nardini et al., 1962); high ratings of being friendly (Gunderson & Nelson, 1965b); motivation to be part of the group (Nelson & Gunderson, 1962; Nelson & Gunderson, 1963), willingness to accept authority (Nelson & Gunderson, 1963), and low ratings of mistrust of others (de Montchaux et al., 1979). Predictive indicators of attitudes and perceptions include high perceptions of the job as important and providing personal gain from participation, and of the group as well organized, having definite goals and scheduled activities (Gunderson & Nelson, 1965b).

Clinical characteristics that predicted for high overall performance include predeployment evaluation by a psychiatrist and psychologist (Nelson, 1963b), high levels of positive affectivity (Kahn & Leon, 1993), and few subjective health complaints (Grant et al., 2007)

Coping resources and strategies that predicted for high overall performance included high satisfaction with social support (Sandal et al., 1998), low demands for social support (Nardini et al., 1962), and high emotion-focused coping (Grant et al., 2007).

Other individual characteristics that predicted for high overall performance included high religiosity (Gunderson et al., 1964) and an interest in hobbies or leisure activities that was high at large stations (Gunderson & Nelson, 1965a; Gunderson et al., 1964) and low at small stations (Gunderson & Nelson, 1965b; Draggan, 1987).

Characteristics of team leaders that predicted for high overall performance included being positive about the job and having pride in organizations and personnel (Sells, 1965), adapting style of leadership to context (Nicholas & Penwell, 1995), using delegation effectively (Sells, 1965; Kinsey, 1959), using recognition and reward, giving frequent complements to individuals, and accepting each individual crewmember's personal problems (Sells, 1965), and the ability to set work pace and establish a social atmosphere (Sells, 1965).

Prioritization of Psychosocial Characteristics

Characteristics of the quality and fidelity of reported associations from the study references are described in Tables 1 and 2 below. Table 1 indicates which of the 120 studies utilized a quasi-experimental or experimental design and which contained data that could be used to calculate a statistical effect (a correlation coefficient, effect size, or odds ratio). Table 2 contains information on the four criteria of study fidelity to long duration missions and the fidelity score of each reference.

The psychosocial characteristics for each of the five measures of performance identified from studies with an experimental or quasi-experimental design is presented in Tables 3-9 below. For each characteristic, the number of studies reporting a statistically significant association, followed by the average fidelity score of these studies and the summed statistical effect measure is presented.

The most important predictor of task performance in isolated and confined extreme environments appears to be the cluster of global personality traits that include low levels of neuroticism, extraversion and openness to experience and high levels of agreeableness as measured by the NEO-FFI; high positive instrumentality and low negative instrumentality as measured by the PCI; and high self control. This cluster accounted for 9 studies with statistically significant associations, an average fidelity score of 9.1, and a statistical effect score of 11. The second most important predictor is crew homogeneity related to demographic characteristics, interest and hobbies and crew homogeneity related to some personality characteristics and heterogeneity related to other characteristics. This cluster accounted for 5 studies with statistically significant associations, an average fidelity score of 7.8, and a statistical effect score of 11. The third most important predictor was the cluster of personality characteristics relating to interpersonal needs and skills. These characteristics included low levels of wanted and expressed affection as measured by the FIRO-B, high role clarity and low role conflict, low assertiveness, and a high perceived fit with the organizational culture of the crew or station. This cluster accounted for 5 studies with statistically significant associations, an average fidelity score of 7.6, and a statistical effect score of 9.

Other predictors of importance included the cluster of demographic characteristics reflecting maturity, experience and skills including older age, occupation, work experience (4 significant associations, fidelity score = 7.3, effect score = 5), and the cluster of group characteristics reflecting cohesion (3 significant associations, fidelity score = 7.3, effect score = 0).

Less important predictors included the clusters of personality characteristics reflecting high self efficacy and high motivation, high alertness, low hostility against the self, large groups, high positive affectivity, number of previous expeditions, high levels of religiosity, being unmarried, male gender, military service, civilian status, and urban residence.

The most important predictor of emotional stability identified in the studies reviewed was the cluster of demographic characteristics that included older age, work experience, occupation, first-born, and no record of truancy or delinquency. This cluster accounted for 20 studies with statistically significant

associations, an average fidelity score of 7.4, and a statistical effect score of 11. The second most important predictor of emotional stability was the personality cluster reflecting interpersonal needs and skills that included low needs for autonomy and nurturance and a high level of deference to others as measured by the EPPS; low levels of wanted and expressed affection, wanted control and wanted inclusion as measured by the FIRO B; high interpersonal sensitivity; a high need for optimism and low need for efficiency in friends; a low need for interpersonal sensitivity from others, and high role specificity or ability to program oneself into a social role. This cluster accounted for 12 studies with statistically significant associations, an average fidelity score of 7.6, and a statistical effect score of 8. The third most important predictor of emotional stability was the cluster of personality characteristics reflecting global personality traits that included low levels of neuroticism and extraversion as measured by the NEO-FFI; low levels of repression and high levels of responsibility as measured by the MMPI; high positive instrumentality as measured by the PCI; low emotional expressivity; and high self control. This cluster accounted for 8 studies with statistically significant associations, an average fidelity score of 6.9, and a statistical effect score of 5.

Other important predictors of emotional stability included civilian status (5 associations, fidelity score = 8.0, effect score = 4); clinical characteristics (4 associations, fidelity score = 8.8, impact score = 5); the cluster of psychological characteristics reflecting mood (4 associations, fidelity score = 8.8, effect score = 3); the cluster of personality characteristics reflecting motivation (4 associations, fidelity score 8.3, effect score = 1); the cluster of group characteristics reflecting cohesion that included high crew identity/affiliation, compatibility of social dyads, and high role complementarity, consensus, redundancy, latency, and isomorphism (4 associations, fidelity score = 7.5, effect score = 0); being unmarried (3 associations, fidelity score = 7.3/ effect score = 2); and the cluster of personality characteristics reflecting self-efficacy (3 associations, fidelity score = 8.0, effect score = 1), and cultural background (2 associations, fidelity score = 9.5, effect score = 5). Civilian status, however, is confounded by higher levels of education and occupational status in civilians compared to enlisted military personnel who participated in most of the studies of polar expeditions.

Less important predictors included the cluster of group characteristics related to homogeneity or heterogeneity, male gender, military service, urban residence, high alertness, a high need for orderliness as measured by the EPPS, high level of conscientiousness as measured by the NEO-FFI, high satisfaction with social support, low use of acceptance as a coping strategy, number of previous expeditions, enjoyment and sense of awe from the environment, high and low interest in hobbies and leisure

activities, low levels of religiosity, large and small crew sizes, and a participative/supportive style of leadership.

The most important predictors of social compatibility were crew homogeneity related to demographic characteristics, culture and personality. This cluster of characteristics accounted for 14 statistically significant associations with a mean fidelity score of 7.9 and an effect score of 11. The second most important predictor of social compatibility was the cluster of personality characteristics reflecting global traits. This cluster of characteristics accounted for 18 statistically significant associations with a mean fidelity score of 9.3 and an effect score of 10. The third most important predictor was the cluster of personality characteristics reflecting interpersonal needs and skills. This cluster of characteristics accounted for 7 statistically significant associations with a mean fidelity score of 8.1 and an effect score of 15.

Other important predictors of social compatibility included the cluster of demographic characteristics reflecting age, maturity, experience and skills (7 associations, fidelity score = 9.0, effect score = 0); the cluster of group characteristics reflecting cohesion (6 associations, fidelity score = 8.0, effect score = 0); the cluster of personality characteristics reflecting motivation (5 associations, fidelity score = 8.0, effect score = 3); and the cluster of associations reflecting cultural background (3 associations; fidelity score = 8.0, effect score = 5).

Less important predictors of social compatibility included the cluster of clinical characteristics, the cluster of coping characteristics, enjoyment and awe of the environment, low interest in hobbies and leisure activities, high levels of religiosity, low work-related stress, less hostility against the self, high alertness, large crews, high positive affectivity, rural residence, military service, male gender, being unmarried, a participative/supportive style of leadership, and a leader's ability to adapt style to context.

The most important predictor of leadership was the cluster of characteristics related to leadership style. These characteristics included a participative/supportive style, emphasis on discipline and adherence to regulations, use of recognition and reward, keeping informed of activities engaged by subordinates, maintaining daily contact with subordinates, and sticking by decisions once they are made. This cluster of characteristics accounted for 9 studies reporting statistically significant associations with an average fidelity score of 7.8 and an effect score of 18. The second most important predictor of leadership was the cluster of personality characteristics reflecting global traits. This cluster accounted for 6 studies reporting statistically significant associations with an average fidelity score of 10 and an effect score of

11. The third most important predictor of leadership was the cluster of personality characteristics reflecting motivation. This cluster accounted for 5 studies reporting statistically significant associations with an average fidelity score of 7.8 and an effect score of 9.

Other important predictors of leadership included the cluster of characteristics reflecting leadership skills (5 significant associations, fidelity score = 7.6, effect score = 9), the cluster of personality characteristics reflecting interpersonal needs or skills (4 significant associations, fidelity score = 8.0, effect score = 10), the cluster of personality characteristics reflecting self-efficacy (4 significant associations, fidelity score = 8.5, effect score = 7), and the cluster of demographic characteristics reflecting age, maturity and experience (3 significant associations, fidelity score = 7.7, effect score = 0).

Less important predictors included high alertness, a high level of expressed control over others, and being married.

The most important predictor of overall performance was the cluster of personality characteristics that reflect motivation, including high motivation and need achievement, high industriousness, high job satisfaction, high adaptability, and low boredom. This cluster accounted for 19 studies reporting statistically significant associations with an average fidelity score of 9.5 and an effect score of 39. The second most important predictor was the cluster of personality characteristics that reflected global personality traits, including low NEO-FFI measures of neuroticism, extraversion, openness to experience and conscientiousness, and high measures of agreeableness; low MMPI measures of control and repression and high measures of responsibility; low emotional expressivity; and high self control. This cluster accounted for 17 studies reporting statistically significant findings with an average fidelity score of 8.1 and an effect score of 17. The third most important predictor was the cluster of personality characteristics reflecting interpersonal needs and skills, including low levels of wanted affection, wanted control and expressed inclusion as measured by the FIRO B; high interpersonal sensitivity, low competitiveness, low level of dependence on groups as measured by the 15PF; motivation to maintain social relations and be a part of the group; friendliness; and a low mistrust of others. This cluster accounted for 12 studies reporting statistically significant findings with an average fidelity score of 7.6 and an effect score of 17.

Other important predictors of overall performance included the cluster of demographic characteristics reflecting age, maturity, experience and skills (8 significant associations, fidelity score = 7.8, effect score = 6); the cluster of personality characteristics that reflect self-efficacy (5 significant associations, fidelity

score = 7.8, effect score = 3); clinical characteristics (4 significant associations, fidelity score = 8.0, effect score = 7); the cluster of personality characteristics that reflect mood (4 significant associations, fidelity score = 8.5, effect score = 4); the cluster of characteristics reflecting leadership skills (4 significant associations, fidelity score = 7.3, effect score = 0), and coping resources and strategies (3 significant associations, fidelity score = 7.7, effect score = 1).

Less important characteristics associated with overall performance included the cluster of personality characteristics reflecting cognition, high or low interest in hobbies of leisure activities, military service or civilian status, female gender, a low family socioeconomic status, being married or unmarried, rural place of residence, a high openness to experience, high levels of religiosity, and use of recognition and reward by leaders.

Prioritization of Psychosocial Characteristics by Category

To assess the important of a set of characteristics for each performance measure, we compared the number of studies reporting statistically significant associations, mean fidelity scores of these studies, and statistical effect scores each performance category or cluster (Table 10). The clusters or categories of variables that predicted all five categories of performance included Demographic Cluster A (age, maturity, experience and skills) and Personality Clusters A (global traits), B (motivation), D (cognition), E (self-efficacy), and F (interpersonal needs and skills). Global personality traits accounted for the most statistically significant associations with performance (n = 44), followed by demographic characteristics reflecting age, maturity, experience and skills (n = 43), and personality characteristics reflecting interpersonal needs and skills (n = 41. Studies documenting associations between global personality traits reported the highest average fidelity score (9.04), followed by cultural background (8.75) and personality characteristics reflecting mood (8.50). Personality characteristics reflecting global traits, motivation, and interpersonal needs and skills represented the highest statistical effect scores (53, 46, and 44).

Evaluation of Potential Countermeasures

Three different types of countermeasures have frequently been recommended for use in optimizing astronaut performance during extended duration missions and minimizing the risk of performance decrements: screening, selection, and training (National Research Council, 1998; Institute of Medicine, OM, 2001). Each of these will be examined in turn with regard to the ICE literature on psychosocial characteristics that predict optimal performance.

Screening. Unlike other countermeasures, the screening of individuals for desirable psychosocial characteristics that predict optimal performance does not result in a change in these characteristics. Rather, psychological screening is focused on psychosocial characteristics that are either not malleable or that would require a greater cost investment to implement countermeasures that change malleable characteristics. Nevertheless, psychological screening is an important component to both selection and to training because it provides information that can be used to identify individuals who should be selected for long duration missions and because it can be used to target specific forms of training countermeasures to be implemented with specific individuals who are selected for such missions. When used, psychological screening is believed to improve the effectiveness of both selection and training as potential countermeasures for enhancing individual and group performance in extreme and isolated environments.

The technique of select-in screening (Palinkas, 1990; Institute of Medicine, 2006) is intended to identify those characteristics that predict for optimal performance under a specific set of conditions, in this case, living and working in extreme, isolated and confined environments. The record of success of such efforts, however, is somewhat mixed. Studies of Operation Deep Freeze candidates by Gunderson and colleagues (Gunderson, 1974) found screening predicts performance, but the same psychosocial characteristic does not predict all forms of performance (ability, stability, compatibility) for a specific individual, and the same psychosocial characteristic does not predict the same type of performance for different groups of individuals (enlisted, vs officers vs civilians). Studies of astronaut personnel by Helmreich and colleagues (Rose et al., 1994; McFadden et al., 1994), found certain psychological characteristics (high positive instrumentality and expressiveness and low negative instrumentality, expressiveness and communion) to predict astronaut assessments of fellow astronaut task effectiveness and social compatibility); similar findings have been observed with submarine personnel and polar expeditioners (Sandal et al., 1996). A more recent study by Grant and colleagues (2007), found no significant agreements between the SOAP psychological screening measures and those actually selected by the British Antarctic survey. Participants characterized as exceptionally well adapted by the station commanders had higher scores on Openness on the NEO-FFI (the “Big Five” personality inventory) and higher levels of Emotion-Focused Coping and fewer subjective health complaints. However, other studies (Rose et al., 1994) have found lower scores on the Openness measure to be associated with performance. Participants rated by station commanders as “poor” had higher levels of Defensive Hostility, and lower levels of Emotion-Focused Coping.

Routine psychological screening has been proposed for prevention of adverse behavioral effects of certain psychosocial characteristics such as neuroticism (Lahey, 2009). Although behavioral interventions designed to reduce levels of neuroticism in individuals seem feasible, to date, no such interventions have been identified. In the absence of such countermeasures, routine screening could be used to identify individuals in need of further individual evaluations and possibly training countermeasures like the cognitive-behavioral therapy interventions discussed below (Lahey, 2009).

Target characteristics for psychological screening would include the following:

- Global personality traits
- Mood
- Interpersonal needs and skills
- Self-efficacy
- Leadership style and skills
- Coping skills and strategies

Selection. Selection of crew members for long-duration missions can occur in two different forms: selection based on individual characteristics and selection based on characteristics of the entire group. Selection based on individual characteristics includes elements of social and demographic background, personality, clinical profile, coping skills and strategies, other characteristics, and leadership styles and skills. Target characteristics for individual selection identified from the ICE literature that would be relevant to extended duration space missions include older age, high levels of education or socioeconomic status, years of experience in a profession, number of previous missions or expeditions, being unmarried, and possession of a sense of enjoyment and awe of the environment. They would also include global personality traits, motivational indicators, mood, cognition, self-efficacy, and interpersonal needs and skills. They would include results from predeployment clinical evaluations, low levels of predeployment depressive symptoms and high levels of positive affectivity, and possession and use of specific coping resources and strategies. Finally, they would include possession and use of specific leadership skills and styles.

However, all of the characteristics found to predict performance in other isolated and confined environments may not be suitable for selection of personnel for long duration space missions. For instance, it is likely that most if not all candidates for extended duration missions will possess similar levels of education/socioeconomic status and sense of enjoyment and awe as such individuals are both

self selected and selected by organizations like NASA because of their scientific and technical skills. Selection could also focus on individual personality, leadership and other traits. Other characteristics identified as being significantly associated with performance may not be suitable for selection as the findings regarding these characteristics are somewhat mixed. For instance, some studies found male gender to be associated with task ability, emotional stability, and social compatibility, while other studies found female gender to be associated with overall performance. Similarly inconsistencies in associations exist with respect to military and civilian status, urban and rural place of residence, high and low levels of religiosity, high and low interest in hobbies and leisure activities, and formation of larger or smaller size crews. Being married was associated with leadership performance, but being unmarried was associated with task ability, emotional stability, and social compatibility. Other predictors like low family socioeconomic status might be eliminated from consideration because of the overwhelming evidence in the opposite direction. Still others like predeployment depressive symptoms and subjective health complaints may be eliminated from consideration due to the low probability of obtaining valid and reliable information from astronauts who are reluctant to provide such information if it minimizes their chances of being selected (National Research Council, 1998).

Selection based on group characteristics includes elements of social and demographic characteristics, personality, and cultural background that reflect homogeneity of individual members of the group or, in the case of certain specific psychological traits such as dominance, heterogeneity of individual members. However, as with the selection of individuals, there exist numerous constraints on the utilization of selection as a countermeasure that should be taken into consideration. For instance, while crewmembers may exhibit significant differences in emotional stability or social compatibility based on cultural background or orientation, decisions as to whom to assign to a mission from what country or organization must also consider the political and financial realities (i.e., what country or organization is providing financial support for the mission), as well as the objectives of the mission and the technical needs required to support those objectives (i.e., exploration, base construction, science, logistical support). Consequentially, the desire to enhance individual or group performance may be one goal of selection procedures, but it must compete with other goals, some of which are likely to be viewed as more important or critical to mission success.

Target characteristics to be considered for selection include the following:

- Demographic characteristics reflecting age, maturity, experience and skills

  - Older age
  - Occupation
  - Years of work experience
- Personality characteristics
  - Global personality traits
  - Motivation
  - Mood
  - Interpersonal needs and skills
  - Self-efficacy
- Group characteristics
  - Homogeneity of demographic and personality characteristics
  - Heterogeneity of selected personality characteristics
  - Group cohesion
- Clinical characteristics
  - Predeployment clinical evaluations
  - High positive affectivity
- Leadership style and skills
- Coping skills and strategies
- Number of previous missions/expeditions

Training. Training-based countermeasures are designed to change behavior. Most of the current evidence-based practices the focus on behavior change are designed to change behaviors that are dysfunctional or maladaptive. These include alcohol, drug abuse and other addictive behaviors, anti-social behavior; and mood disorders such as depression and anxiety. While the effectiveness of these techniques in reducing negative behaviors have been well documented, their effectiveness in preventing the occurrence of these negative behaviors or in promoting positive behaviors is less clear.

Social Skills Training (SST) is one type of countermeasure that has the potential for reinforcing psychosocial characteristics that predict for optimal performance or preventing the occurrence of decrements in social compatibility. SST interventions employ behavioral and social learning principles to teach skills involving medication management, early detection and self-management of symptoms, coping with life stress, grooming and hygiene, interpersonal problem-solving, and conversation skills (Wallace et al., 1992). The goals of treatment are explicit, sessions are clearly planned, agendas are

provided in manuals and workbooks, and homework assignments (in vivo practice) are given. Pre-packaged SST modules are available that include manuals for therapist training, patient workbooks, and demonstration videos (Psychological Rehabilitation. The aim of SST is to improve the patient's social interaction through modeling, rehearsal, feedback and role-play.

Target characteristics for the use of Social Skills Training to enhance performance during long-duration space missions would include the following:

- Interpersonal needs and skills
- Cultural background
- Crew homogeneity related to demographic characteristics, culture and personality
- Group cohesion
- Coping resources and strategies
    - Use of and satisfaction with social support
- Leadership style and skills
    - Participative/supportive leadership style
    - Ability to maintain group harmony and resolve conflicts
- Global personality traits
    - Extraversion

Training based on the principles of Cognitive Behavioral Therapy (CBT) is another potential countermeasure for promoting psychosocial characteristics associated with optimal performance and preventive the risk of performance decrements. CBT was originally developed as an intervention for depressive disorders (Beck et al., 1979) but has been modified to address the needs of patients experiencing a variety of other mental illnesses, including anxiety disorders (Barlow, 1988), substance dependence (Monti et al., 1989), and personality disorders (Linehan, 1993). CBT trains patients to identify problematic thoughts and behaviors and to engage in exercises (both cognitive and behavioral) that help dispute irrational or unhelpful beliefs.

One widely used CBT-based intervention with potential for use with astronaut personnel assigned to extended-duration missions is Problem Solving Therapy (PST). PST uses the behavioral activation (Jacobson et al., 2001) components of CBT, but with less emphasis on changing cognition and greater emphasis on individual assessment of personal contextual problems and skill-building to enhance self-management skills (Nezu et al., 1989). In randomized studies, PST has been found to reduce depressive

symptoms among primary care patients with major depression or dysthymia (Barrett et al., 2001; Catalan et al., 1991; Dowrick et al., 2000; Mynors-Wallis, 1996; Mynors-Wallis et al., 1997, 2000). PST is available in published treatment manuals for depression (Nezu et al., 1989). PST is based on a theoretical framework that incorporates negative life events, current daily problems, immediate and long-term emotional reactions, problem solving coping, and their relationship to depression (Nezu et al., 1989). According to this framework, experiencing negative life events can lead to the occurrence of a wide range of daily problems, which are believed to function as sources of stress. If these stressors are coped with effectively (i.e., the problems are resolved), people are likely to experience only mild or no depressive symptoms. However, if individuals are ineffective in their problem-solving attempts, then the probability of moderate-to-severe depression increases.

A second intervention of potential use for extended-duration missions is Computer-based Cognitive Behavioral Therapy (CCBT). This has been introduced in recent years without the need for a trained therapist, or with their minimal involvement. Various versions of this shift towards technology mediated self-help exist, which range from completely computerized versions, such as *Beating the Blues*, to facilitated self-help by a practitioner and a model with minimal intervention from a non- or minimally trained professional. CCBT is seen as an ‘effective first line tool within a stepped care framework for the management of common mental health problems’ based on self-reported improvements in anxiety and depression (Cavanagh et al., 2006).

A third CBT-based intervention that was deliberately designed to prevent the occurrence of performance decrements in small, isolated groups is a program known as Business in Mind (Martin et al., 2009). This is a DVD program (60 minutes in length) involving skills development of managers operating in remote areas to improve mental health of managers and their employees. The program contains four distinct modules. Module 1 aims to develop participants’ understanding of stress and coping processes, introducing relationships among thoughts, feelings and behaviors. Module 2 is designed to enhance participants’ level of psychological capital (self efficacy, hope resilience, optimism). Module 3 is focused on overcoming barriers to living a healthy lifestyle (diet, exercise) Module 4 focuses on assisting crew leaders to create a positive work environment and overcome interpersonal stressors by developing their emotional intelligence and communication skills. However, despite the program’s face validity for use with astronaut crews, its effectiveness has yet to be evaluated.

Interpersonal Psychotherapy (IPT) is another therapeutic technique with potential for promoting positive behaviors and preventing risks to optimal performance. IPT was developed in the1970’s by

Klerman et al. (1984) as a time-limited, weekly outpatient treatment for major depressive disorder. It have been applied and extended to a variety of other psychiatric diagnoses (dysthymic disorder, bulimia nervosa, recurrent depression, bipolar disorder, substance abuse, social phobia, panic disorder, body dysmorphic disorder, chronic somatization, and borderline personality disorder) (Klerman et al, 1984; Weissman et al, 2000). Current evidence suggests that IPT is an efficacious therapy for depressive spectrum disorders and may be superior to other manualized psychotherapies, including CBT (Feijo de Mello et al., 2005). IPT deals with current, rather than previous interpersonal relationships, focusing on the patient's immediate social context. Moreover, it intervenes in symptom formation and the social dysfunction associated with depression, rather than addressing the enduring aspects of personality (Weissman & Markowitz, 1998). Therapy occurs in three distinct phases. The first phsase usually comprised one to three sessions and included the psychiatric diagnostic assessment. A review of the patient's current social functioning and close relationships, including the habitual patterns and expectations characterizing those relationships and how they influence the patient's mood, is accomplished. This review provides a framework for understanding the social and interpersonal context present at the onset of the depressive symptoms and defines the focus of treatment (Weissman & Markowitz, 1998). Symptoms are then linked to the patient's situation in a formulation (Markowitz 1998) that comprises one (or more) of the following problem areas in the patient's life: a) grief; b) interpersonal role disputes; c) role transitions; or d) interpersonal deficits (Weissman & Markowitz, 1998). The second phase of treatment entails the development of specific strategies for the chosen interpersonal problem area. The last phase of IPT takes place during the concluding 12–16 weeks of treatment and it is aimed at giving support to the patient's renewed sense of independence and competence, by recognizing and consolidating therapeutic gains.

Motivational Interviewing (MI) is another evidence-based practice that has been demonstrated to be effective in changing behavior. MI is a directive, client-centered counseling style for eliciting behavior change by helping clients to explore and resolve ambivalence (Rollnick & Miller, 1995). It is guided by a number of general principles, including: expressing empathy, by use of reflective listening; developing discrepancy between client goals and current problem behavior by use of reflective listening and objective feedback; avoiding argumentation by assuming that the client is responsible for the decision to change; rolling with resistance, rather than confronting or opposing it; and supporting self-efficacy and optimism for change (Miller & Rollnick, 1991). The technical aspects of MI include three elements: Client-centered counseling skills, based on Rogerian counseling; reflective listening statements, directive questions, and strategies for eliciting internal motivation from the client, operationalized in the form of

self-motivating statements from the client, also known as "change talk." These skills are used to encourage the client to explore for ensuring that client resistance is minimized. More than 200 clinical trials of MI have been published, and efficacy reviews and meta-analyses have documented its effectiveness for cardiovascular rehabilitation, diabetes management, hypertension, illicit drug use, disease, infection risk reduction, management of chronic mental disorders, problem drinking, smoking, and concomitant mental and substance use disorders. It has been found to be effective both in reducing maladaptive behaviors (e.g., problem drinking, gambling, HIV risk behaviors) and in promoting adaptive health behavior change (exercise, diet, medication adherence). The clinical style and Moreover, the apparent mechanisms of change in MI thus seem to be related to generalizable processes of human behavior and not limited to specific target problems (Miller & Rose, 2009).

Target behaviors for the use of these psychotherapeutic interventions to enhance performance during long-duration space missions would include the following:

- Motivation
- Mood
    - Anxiety
    - Anger, irritability
    - Depressive symptoms
    - Positive affectivity
- Global personality traits
- Interpersonal needs and skills
- Group cohesion
- Coping resources and strategies

Leadership Training. High performance leadership is defined as leading and managing people and organizational systems to achieve and sustain high levels of effectiveness by optimizing goals, design and management at the individual, process and organizational levels (Holton & Naquin, 2000, p. 1). This leadership can be transactional or transformational. Transactional leadership seeks an exchange between leader and follower in which both achieve some benefit. Transformational leadership seeks to develop the potential of the follower or organization to fulfill higher level needs. According to Bass (1998), the transactional leader works within the organizational culture as it exists; the transformational leader changes the organizational culture. Leadership development is defined as "every form of growth

or stage of development in the life cycle that promotes, encourages, and assists the expansion of knowledge and expertise required to optimize one's leadership potential and performance" (Brungardt, 1996, p. 83). There exist numerous programs for training in leadership styles and skills, in fact, too numerous to adequately review in this report. These programs focus on enhancing knowledge, expertise or behavior, and systems or organizational productivity (Avolio, 1999; Bass, 1990; Conger & Benjamin, 1999). A meta-analyses of different leadership development training programs have found significant effects in subjective and objective learning, subjective behavior, and objective results (Burke & Day, 1986). However, most leadership training programs target interpersonal skills and work performance of individual managers (Moxnes & Eilertsen, 1991); in contrast, relatively few programs target organizational performance (Fiedler, 1996). A meta-analysis performed by Collins and Holton (2004) found the effect size for knowledge outcomes of a range of leadership training programs ranged from .96 to 1.37; expertise outcomes from .35 to 1.01; and system outcomes averaged .39.

Leadership in long-duration missions is expected to be primarily transactional in nature, but may also involve elements of transformational leadership as well. To our knowledge, no studies of existing training programs to promote or enhance either form of leadership have been conducted in extreme and isolated environments. Consequently, research using randomized controlled designs is required to determine whether existing programs or adaptations of existing programs could lead to increased leadership knowledge, behavior or organizational outcomes. Target characteristics for the use of such programs to enhance performance during long-duration space missions would include the following:

- Leadership styles and skills
- Group cohesion
- Crew homogeneity related to demographic characteristics, culture and personality

Cross-cultural training. Cross-cultural training (CCT) has long been advocated as a means of facilitating effective cross-cultural interactions (Brislin, 1981; Landis & Brislin, 1983; Harris & Moran, 1979). As with leadership training, there exist numerous programs designed to facilitate the integration of individuals representing different cultural backgrounds into the same group, organization, or system. These programs are designed to develop three types of skills: self-maintenance (mental health, psychological well-being, stress reduction, feelings of self-confidence), interpersonal, and cognitive/perceptual (Mendenhall & Oddou, 1985). These skills allow individuals to more rapidly adjust to a new cultural environment through development of familiarity, comfort and proficiency regarding expected behavior

and values and assumptions inherent in the new culture, all of which may be different from one's own culture (Black & Mendenhall, 1990). They also presumably lead to increased levels of individual and organizational performance (Black & Mendenhall, 1990).

A systematic review of the literature performed by Black and Mendenhall (1990) found evidence to suggest that cross cultural training leaders to positive outcomes with respect to skills development, adaptation, and individual and organizational performance. However, as with leadership training, there have been no studies to our knowledge of existing cross-cultural training programs to promote or enhance either adaptation or performance in extreme and isolated environments. Consequently, research using randomized controlled designs is required to determine whether existing programs or adaptations of existing programs could lead to increased cross-cultural skills, adaptation or performance. Target characteristics for the use of such programs to enhance performance during long-duration missions would include the following:

- Cross cultural differences in emotional stability and social compatibility
- Crew homogeneity related to culture

Discussion

Most of the 330 associations between individual psychosocial characteristics and one or more measures of performance identified in our review of studies using a quasi-experimental or experimental design were based on the findings of only one or two studies. Of the 120 studies examined, slightly more than one-third possessed data that could be used to identify a statistical effect. The number of associations supported by more than two studies was 15 (4.5% of all associations). One conclusion that may be drawn from this is that despite the wealth of research on psychosocial characteristics in isolated and confined extreme environments, the evidence supporting any one particular characteristic as a predictor of performance is quite limited. The most robust associations, based solely on statistical effects and/or fidelity scores, were between emotional stability and age, education/socioeconomic and civilian status, being unmarried, and compatibility of social dyads; between social compatibility and age, enjoyment and awe of the environment, and crew homogeneity related to demographic characteristics, culture and personality, and between overall performance and education/socioeconomic status, an introverted personality, and high need for achievement and high motivation. The association between older age and emotional stability was found among polar expeditions and crewmembers of polar research stations, while the association between education/socioeconomic status and emotional stability was found in

studies of both undersea (i.e., divers, submariners) and polar expeditioners. The associations between crew homogeneity and social compatibility were observed in space and all types of analogue settings.

A second major observation to be drawn from this analysis is the distinction between characteristics that represent fixed traits and characteristics that are potentially malleable through psychosocial countermeasures. Malleable state characteristics such as depressive symptoms and certain traits such as susceptibility to anxiety and perhaps even introverted personalities may be addressed through cognitive behavioral therapy, interpersonal therapy, and other techniques that are evidence-based. Fixed traits such as age, education/socioeconomic status and marital status are potentially enhanced in crews through programs of screening and selection. However, programmatic constraints such as the demands of participating nations to include one or more crew members from their respective nations and the unlikelihood of selecting single gender crews suggests that other countermeasures will be required to enable individuals with different backgrounds in heterogeneous crews to live and work together for prolonged periods of time.

For the most part, the studies reviewed pointed to an association between certain psychosocial characteristics and performance indicators under any environmental or occupational setting. Individuals who are older and have more experience, emotionally mature, highly motivated, socially adept, skillful in exercising leadership, satisfied with their jobs, highly productive, and who exhibit few symptoms of depression and anxiety and rely on social support networks to cope with stress in general are more likely to perform well under any conditions. 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 to do not share these traits. However, our review also identified certain characteristics that seem to run counter to our understanding of factors associated with successful performance. These include being unmarried, having an introverted personality (or low levels of extraversion), not being particularly conscientious or open to experience, not expressing one's emotion or possessing a capacity for self-reflection, having little interest in leisure activities, and needing little sympathy from others. Although perhaps considered to be maladaptive in normal living conditions, such characteristics may be uniquely suited to living in isolated and confined environments (Palinkas, Gunderson, Holland et al., 2000). Furthermore, the ability to adjust one's level of motivation and need for achievement to avoid frustration when environmental constraints like the lack of replacement parts or competing demands place inherent limitations on motivation and achievement points to the importance of flexibility and adaptability in isolated and confined

environments. Individuals exhibiting such flexibility are most likely to exhibit optimal performance in such environments (Palinkas & Suedfeld, 2008).

In evaluating the results of this systematic review, certain limitations must be kept in mind. First, our prioritization of associations between individual psychosocial characteristics and measures of performance were based primarily on the quality of the research design and the fidelity score assigned to that design. The more traditional approach of evaluating associations based on effect sizes using meta-analytic procedures were not adopted in this review due to the relatively small number of studies providing data reflecting statistical effects. Differences in measurement of both psychosocial characteristics and performance indicators also limit the generalizability of effect sizes. Second, although we had access to several unpublished studies or studies published only as technical reports, unpublished studies tend to have more negative results (Higgins & Green, 2009). Furthermore, our search criteria included only significant associations. Hence our review strategy did not include null findings which would normally also be included in a traditional meta-analysis. This decision was made because of the exploratory nature of this systematic review. Third, our objective was to identify psychosocial characteristics that predicted for optimum performance. In many instances, optimum performance was defined in these studies as the absence of a negative outcome or one a scale where a high score reflected a negative outcome (e.g., a high scores on a depressive symptom scale) and a low score indicated a positive outcome. However, this definition of optimum performance did not always translate or convert well, particularly in studies whose objective was to identify characteristics associated with the risk of poor performance in contrast to characteristics associated with optimum performance. The absence of risk does not necessarily imply the existence of optimum performance. Finally, although we could identify specific countermeasures with potential for enhancing performance, we were limited in our ability to prioritize or recommend specific countermeasures based on evidence of their effectiveness with individuals living and working in isolated and confined extreme environments. To our knowledge, there have been no studies of the effectiveness of training countermeasures on individuals in such environments and the evidence supporting the use of psychological screening and selection is somewhat mixed. Moreover, despite their potential for enhancing performance, most of the research on the effectiveness of psychotherapy-based countermeasures has been focused on the treatment or reduction of problems that constitute negative indicators of performance (e.g., depression, anxiety, substance use, group conflict) rather than the enhancement of positive performance outcomes. Positive performance is not merely the absence of negative performance indicators. Consequently,

further research is recommended to adapt existing countermeasures or to develop, implement and evaluate new countermeasures with the goal of promoting or enhancing positive performance.

Policy and Program Implications

The results of this systematic review suggest that NASA should place greater emphasis on performance enhancement. Current policies and procedures emphasize prevention of performance decrements. This policy is manifested in screening and selection procedures that are designed to "screen out" individuals likely to perform poorly in space and countermeasures designed to prevent occurrences of poor performance due to prolonged separation from family members, interpersonal strain and tension among fellow crew members or between crew and ground-based support personnel, fatigue, or the environmental conditions unique to long-duration spaceflight. However, the results of this study suggest that large improvements in task ability, emotional stability, and social compatibility may result from the application of screening, selection, and training countermeasures addressing specific psychosocial characteristics.

The results also offer programmatic guidance on the prioritization of efforts and resources targeting the application of specific countermeasures to address specific characteristics. Although the studies reviewed here identified several different characteristics, many of which were malleable through the use of training countermeasures and many which are not malleable but may be addressed through specific techniques for screening and selection, both characteristics and the countermeasures designed to address them may be rank ordered on the basis of the quality of the evidence, including the magnitude of effect (small, medium, and large) and fidelity of the analogue (crew size, characteristics of crew, mission duration, and characteristics of environment). Based on the results of this review, he characteristics that should be assigned the greatest priority include global personality traits like self-efficacy and emotional maturity, introversion, and agreeableness; high motivation; interpersonal needs and skills; crew heterogeneity with respect to certain characteristics and homogeneity with respect to other characteristics; and demographic characteristics like age, education, and years of work experience that reflect maturity and experience. The latter characteristics are best addressed through selection procedures, while crew heterogeneity/homogeneity is best addressed by screening and selection and the remaining characteristics may be addressed by training countermeasures as well as screening and selection.

Nevertheless, the decision to address specific psychosocial characteristics with specific countermeasures cannot be made on the basis of effect sizes and fidelity of analogue studies alone. For instance, addressing the relevance of the influence of cultural heterogeneity on crew performance must take into consideration the reality that the political importance of having a multinational crew representing the international partners of a long-duration mission will mitigate against the use of selection procedures to insure cultural homogeneity and favor the use of cross-cultural training programs to enhance awareness and adaptability to cultural differences within a crew.

One important criterion for the prioritization of addressing psychosocial characteristics for performance enhancement is whether the procedures are cost effective. At the broadest level, the determination must be made as to whether performance enhancement is ultimately more cost effective than prevention of performance decrements. Previous research in analogue settings does not permit such a determination. Further, the comparative effectiveness of applying different countermeasures to address the same psychosocial characteristic (for instance, use of psychological screening protocols like the NEO-FFI, selection procedures, or training programs based on principles of cognitive-behavioral theory) must be evaluated through established procedures of Comparative Effectiveness Research (CER) in which the benefits of improved outcomes (in this instance, enhanced task ability, emotional stability, social compatibility, leadership and overall performance) associated with one or more countermeasures (screening, selection, training), relative to the costs associated with countermeasure implementation, are compared between the countermeasure and current procedures or between competing countermeasures within the context of a randomized controlled trial (RCT).

Even under normal conditions, RCTs are expensive to conduct and require sufficiently large samples of participants to insure the likelihood of finding statistically significant results. The small crews aboard the International Space Station and the logistical challenges of implementing an RCT in flight limit the feasibility of this approach to investigate cost effective outcomes during a rotation on the ISS. They are potentially more feasible in analogue settings with easier access for investigators and larger pools of potential study participants. To our knowledge, there have been no RCTs of potential countermeasures designed to enhance performance in isolated and confined environments. However, the results of our systematic review indicate that all analogues are not equally relevant or faithful to the conditions of long-duration space missions and all studies in the same analogue setting are not likely to produce the same or similar results. Assessment of the fidelity of the environment to long-duration missions is especially important in this regard. Such assessment should be based on agreed-upon assumptions,

including similarity of degree of isolation and confinement; similarity of crew members with respect to age, gender and education, and possibly cultural diversity; similarity of mission duration (1 year or longer), and crew size (4-6). Development of standards for assessment of the fidelity of analogue settings is critical as NASA begins to transition from research on psychosocial characteristics as predictors of performance to cost effective practice.

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Table 1. Study Reference Design Criteria

Ref No	Authors	Experimental of Quasi-experimental	Effect Statistics
1	Doll & Gunderson, 1971a	1	1
2	Doll et al., 1969	1	0
3	Doll & Gunderson, 1969	1	1
4	Doll & Gunderson, 1971b	1	0
5	Gunderson & Arthur, 1966	1	1
6	Gunderson, 1968	1	1
7	Gunderson, 1973	1	1
8	Gunderson & Nelson, 1965a	1	0
9	Gunderson & Ryman, 1967	1	1
10	Nelson, 1963a	1	1
11	Nelson, 1964a	1	1
12	Nelson, 1964b	1	1
13	Nelson & Gunderson, 1963a	1	1
14	Nelson & Orvick, 1964	1	1
15	Leon & Sandal, 2003	1	0
16	Biersner & Hogan, 1984	1	1
17	Blair, 1992	1	0
18	Ikegawa et al, 1998	1	0
19	Kahn & Leon, 1993	1	1
20	Palmai, 1963	1	0
21	McGuire & Tolchin, 1961	1	0
22	Nardini et al, 1962	1	1
23	Gunderson, 1966	0	1
24	Law, 1960	1	0
25	Pope & Rogers, 1968	1	0
26	Popkin et al, 1974	1	0
27	Rosnet et al, 2004	1	0
28	Sandal et al, 1996	1	0
29	Sauer et al, 1999	1	1
30	Weiss et al, 2007	1	0
31	Sarris, 2006	1	1
32	Sandal, 2004	1	0
33	Rosnet et al, 2000	1	1
34	Leon & Scheib, 2007	1	0
35	Atlis et al, 2004	1	0
36	Kanas, 1998	0	0
37	Kanas et al, 1996	1	1
38	Kanas, Salnitskiy, Weiss et al, 2001	1	0

39	Oberg, 1981	0	0
40	Chaikin, 1985	0	0
41	Bluth, 1981	0	0
42	Bluth, 1984	0	0
43	Radloff & Helmreich, 1968	1	0
44	Kelly & Kanas, 1992	1	1
45	Kelly & Kanas, 1993	1	1
46	Gushin et al, 1998	1	0
47	Weybrew & Noddin, 1979	1	0
48	Rose et al, 1994	1	1
49	McFadden et al, 1994	1	0
50	Sandal et al, 1999	1	1
51	Sandal, 2001	1	0
52	Sandal et al, 1995	1	0
53	Sandal et al, 1998	0	0
54	Taylor, 1987	0	1
55	Gunderson, 1974	0	0
56	Leon et al, 2002	1	0
57	Mocellin et al, 1991	1	0
58	Palinkas & Browner, 1995	1	1
59	Smith & Haythorn, 1972	1	0
60	Altman & Haythorn, 1965	1	0
61	Altman & Haythorn, 1967a	1	0
62	Altman & Haythorn, 1967b	1	0
63	Sells, 1965	1	0
64	Kinsey, 1959	1	0
65	Nicholas & Penwell, 1995	0	0
66	Nelson, 1962	1	1
67	Campbell, 1953	1	0
68	Weybrew, 1991	0	0
69	Miller et al, 1971	1	0
70	Kanki & Gregorich, 1992	1	0
71	Nicholas et al, 1988	0	0
72	Palinkas, Gunderson, Johnson et al, 2000	1	1
73	Johnson et al, 2003	1	0
74	Gunderson & Kapfer, 1966	1	1
75	Gunderson & Nelson, 1965b	1	1
76	Leon et al, 1989	1	0
77	Stange & Youngman, 1979	0	0
78	Palinkas, Gunderson, Holland et al, 2000	1	1
79	Leon et al, 1994	1	0
80	Schmidt et al, 2004	1	0
81	Schmidt et al, 2005	1	0

82	Palinkas, Glogower et al, 2004	1	1
83	Palinkas, Johnson et al, 2004	1	1
84	Grant et al, 2007	1	1
85	Haythorn & Altman, 1967	1	0
86	Taylor et al, 1969	1	0
87	Haythorn et al, 1966	1	0
88	Palinkas et al., 1995	1	1
89	Biersner & LaRocco, 1987	1	0
90	Palinkas, 1991	1	1
91	Taylor 1993	0	0
92	Palinkas et al., 1989	1	1
93	Gushin et al, 1996	1	0
94	Gushin et al, 1997	1	0
95	WHO	0	0
96	Rivolier et al, 1999	0	0
97	Barbarito & Peri, 1999	1	1
98	Crocq et al, 1974	1	0
99	Natani et al, 1974	1	0
100	Taylor, 1974	1	1
101	Godwin, 1985	1	0
102	Nelson 1963b	1	0
103	Natani, 1971	1	0
104	Harrison, 1980	0	0
105	Kanas & Fedderson, 1971	0	0
106	Smith, 1969	0	0
107	Lozano & Wong, 1993	1	0
108	Evans et al, 1987	1	0
109	Draggan, 1987	0	0
110	Slater, 1969	0	0
111	Eilbert & Glaser, 1959	1	0
112	Wright et al.,	1	0
113	Weybrew et al., 1961	1	0
114	Owens, 1975	1	0
115	Taylor & McCormick, 1985	1	0
116	de Montchaux et al, 1979	1	0
117	Gunderson et al, 1964	1	1
118	Nelson & Gunderson, 1962	1	1
119	Nelson & Gunderson, 1963	1	1
120	Kanas, Salnitskiy, Gushin et al 2001	1	1

Table 2. Fidelity Scores of Study References

Ref No	Authors	Setting	Similarity	Duration	Crew size	Score
1	Doll & Gunderson, 1971a	1	2	3	2	8
2	Doll et al., 1969	1	2	3	2	8
3	Doll & Gunderson, 1969	1	2	3	2	8
4	Doll & Gunderson, 1971b	1	2	3	2	8
5	Gunderson & Arthur, 1966	1	2	3	2	8
6	Gunderson, 1968	1	2	3	2	8
7	Gunderson, 1973	1	2	3	2	8
8	Gunderson & Nelson, 1965a	1	2	3	2	8
9	Gunderson & Ryman, 1967	1	2	3	2	8
10	Nelson, 1963a	1	2	3	2	8
11	Nelson, 1964a	1	2	3	2	8
12	Nelson, 1964b	1	2	3	2	8
13	Nelson & Gunderson, 1963	1	1	3	2	7
14	Nelson & Orvick, 1964	1	2	3	2	8
15	Leon & Sandal, 2003	1	3	2	3	9
16	Biersner & Hogan, 1984	1	3	3	2	9
17	Blair, 1992	1	3	3	1	8
18	Ikegawa et al, 1998	1	2	3	3	9
19	Kahn & Leon, 1993	1	2	3	3	9
20	Palmai, 1963	1	2	3	2	8
21	McGuire & Tolchin, 1961	1	2	3	1	7
22	Nardini et al, 1962	1	2	3	1	7
23	Gunderson, 1966	1	2	3	2	8
24	Law, 1960	1	2	3	2	8
25	Pope & Rogers, 1968	1	2	3	2	8
26	Popkin et al, 1974	1	2	3	1	7
27	Rosnet et al, 2004	1	3	3	1	8
28	Sandal et al, 1996	1	2	2	1	6
29	Sauer et al, 1999	1	2	2	1	6
30	Weiss et al, 2007	1	2	3	1	7
31	Sarris, 2006	1	3	3	1	8
32	Sandal, 2004	2	3	2	3	10
33	Rosnet et al, 2000	1	2	3	1	7
34	Leon & Scheib, 2007	1	2	1	3	7
35	Atlis et al, 2004	1	2	2	3	8
36	Kanas, 1998	3	3	2	3	11
37	Kanas et al, 1996	2	2	2	3	9
38	Kanas et al, 2001a	3	3	2	3	11
39	Oberg, 1981	3	3	2	3	11

40	Chaikin, 1985	3	2	2	3	10
41	Bluth, 1981	3	2	2	3	10
42	Bluth, 1984	3	2	2	3	10
43	Radloff & Helmreich, 1968	2	3	2	3	10
44	Kelly & Kanas, 1992	3	3	1	3	10
45	Kelly & Kanas, 1993	3	3	1	3	10
46	Gushin et al, 1998	2	2	2	3	9
47	Weybrew & Noddin, 1979	1	2	2	1	6
48	Rose et al, 1994	3	3	2	3	11
49	McFadden et al, 1994	3	3	1	3	10
50	Sandal et al, 1999	1	2	1	1	5
51	Sandal, 2001	2	2	2	3	9
52	Sandal et al, 1995	2	3	2	3	10
53	Sandal et al, 1998	1	2	2	2	7
54	Taylor, 1987	1	2	3	2	8
55	Gunderson, 1974	1	2	3	2	8
56	Leon et al, 2002	1	3	3	3	10
57	Mocellin et al, 1991	1	3	1	3	8
58	Palinkas & Browner, 1995	1	3	3	1	8
59	Smith & Haythorn, 1972	2	1	1	3	7
60	Altman & Haythorn, 1965	2	1	1	3	7
61	Altman & Haythorn, 1967a	2	1	1	3	7
62	Altman & Haythorn, 1967b	2	1	1	3	7
63	Sells, 1965	1	2	3	1	7
64	Kinsey, 1959	1	2	2	1	6
65	Nicholas & Penwell, 1995	1	2	2	2	7
66	Nelson, 1962	1	2	3	2	8
67	Campbell, 1953	1	2	2	1	6
68	Weybrew, 1991	1	2	2	1	6
69	Miller et al, 1971	2	3	1	3	9
70	Kanki & Gregorich, 1992	1	3	1	3	8
71	Nicholas et al, 1988	1	1	1	1	4
72	Palinkas, Gunderson, Johnson et al, 2000	1	2	3	1	7
73	Johnson et al, 2003	1	3	3	1	8
74	Gunderson & Kapfer, 1966	1	2	3	2	8
75	Gunderson & Nelson, 1965b	1	2	3	1	7
76	Leon et al, 1989	1	3	2	3	9
77	Stange & Youngman, 1979	1	2	3	2	8
78	Palinkas, Gunderson, Holland et al, 2000	1	2	3	2	8
79	Leon et al, 1994	1	3	2	2	8
80	Schmidt et al, 2004	1	3	3	1	8
81	Schmidt et al, 2005	1	3	3	1	8
82	Palinkas, Glogower et al, 2004	1	3	3	1	8

83	Palinkas, Johnson et al, 2004	1	3	3	1	8
84	Grant et al, 2007	1	3	3	1	8
85	Haythorn & Altman, 1967	2	1	1	3	7
86	Taylor et al, 1969	1	1	1	3	6
87	Haythorn et al, 1966	2	1	1	3	7
88	Palinkas et al., 1995	1	3	3	1	8
89	Biersner & LaRocco, 1987	2	1	1	1	5
90	Palinkas, 1991	1	2	3	2	8
91	Taylor 1993	1	2	3	2	8
92	Palinkas et al., 1989	1	2	3	2	8
93	Gushin et al, 1996	2	3	2	3	10
94	Gushin et al, 1997	2	2	2	3	9
95	WHO	1	1	1	1	4
96	Rivolier et al, 1999	1	2	3	1	7
97	Barbarito & Peri, 1999	1	2	3	1	7
98	Crocq et al, 1974	1	2	3	1	7
99	Natani et al, 1974	1	2	3	1	7
100	Taylor, 1974	1	2	3	1	7
101	Godwin, 1985	1	2	3	1	7
102	Nelson 1963b	1	2	3	2	8
103	Natani, 1971	1	2	3	1	7
104	Harrison, 1980	1	2	1	3	7
105	Kanas & Fedderson, 1971	3	2	1	3	9
106	Smith, 1969	1	1	1	1	4
107	Lozano & Wong, 1993	3	3	1	1	8
108	Evans et al, 1987	1	3	3	2	6
109	Draggan, 1987	1	3	3	1	8
110	Slater, 1969	1	2	2	1	6
111	Eilbert & Glaser, 1959	1	1	3	1	6
112	Wright et al., 1963	1	2	3	3	9
113	Weybrew et al., 1961	2	2	2	1	7
114	Owens, 1975	1	2	3	1	7
115	Taylor & McCormick, 1985	1	2	2	2	7
116	de Montchaux et al, 1979	1	2	3	1	7
117	Gunderson et al, 1964	1	2	3	2	8
118	Nelson & Gunderson, 1962	1	2	3	2	8
119	Nelson & Gunderson, 1963b	1	2	3	2	8
120	Kanas, salnitskiy, Gushin et al, 2001	3	3	2	3	11

Table 3. Demographic characteristic number of associations, fidelity scores and effect statistics by performance measure

Malleable Demographic Characteristics	Countermeasure	Task Ability	Emotional Stability	Social Compatibility	Leadership	Overall
Cluster A: Maturity, experience, skills						
Older Age	Selection	1/8/M	8/7.9/S-M	3/7.3/na	1/7/na	3/7.7/S
Work experience (years)	Selection	1/7/S	1/5/na	1/8/na		1/8/S
Education/socioeconomic status	Selection	2/7/M	9/7.2/S-M	2/7.5/na	2/8/na	3/7.7/S
First-born	Selection		2/8/S	1/10/na		
No record of truancy or delinquency	Selection		1/7/S			1/8/S
Cluster B: Cultural background						
Cultural background	Selection Training		2/9.5/S-L	2/8/S-L		
Collective cultural orientation	Selection Training			1/8/M		
Cluster C: Characteristics specific to isolation and confinement						
Unmarried	Selection	1/7/na	3/7.3M	1/7/na		1/7/na
Other characteristics						
Male gender	Selection	1/8/S	1/8/S	1/8/na		
Female gender	Selection					1/8/S
Low family SES	Selection					1/7/S
Military service	Selection	1/7/S	1/8/na	1/7/S		2/7.5/S
Civilian status	Selection	1/8/S	5/8/S-M			1/7/na
Married	Selection				1/7/S	1/8/S
Rural residence	Selection			1/8/M		1/10/na
Urban residence	Selection	1/7/S	1/8/M			

Number of studies reporting a significant association/average fidelity score of study/magnitude of effect statistics (S = small, M = moderate, L = large)

Table 4. Personality characteristic fidelity scores and impact by performance measure

Malleable Personality Characteristics	Countermeasure	Task Ability	Emotional Stability	Social Compatibility	Leadership	Overall
Cluster A: Global personality traits						
Low NEO Neuroticism	Screening Psychotherapy	1/7/na	1/8/S			1/7/na
Low MMPI control	Screening Psychotherapy					1/6/na
Low MMPI repression-sensitization	Screening Psychotherapy		1/5/na			1/6/na
High MMPI responsibility	Screening Training Psychotherapy		1/6/na			1/6/na
Low NEO Extroversion	Screening Social Skills Training Psychotherapy	1/7/L	1/5/na			3/7.7/S
Low NEO Openness to experience	Screening Training	1/11/M		1/11/S	1/11/M	2/10/S-L
Low NEO Conscientiousness	Screening Training					2/9.5/S
High NEO Agreeableness	Screening Psychotherapy	1/11/S		1/11/M	1/11/M	1/11/S
High PCI Positive Instrumentality/expressiveness	Screening Psychotherapy	1/10/na	1/6/na	3/7.3/M		
Low PCI Negative instrumentality	Screening Psychotherapy	1/11/M		1/11/S	1/11/S	
Low PCI Impatience and irritability	Screening Psychotherapy			1/11/M	1/11/S	
Low emotional expressivity and self-reflection	Screening Psychotherapy		1/8/S			1/9/H
High emotional stability and (self) control	Screening Psychotherapy	1/8/M	2/8.5/L	1/8/M	2/8/M-L	4/7.8/S-L

Cluster B: Motivational indicators						
High motivation and need achievement	Screening Training Psychotherapy		3/8.5/na	2/7.5/S	1/8/M	10/8.1/M-L
High industriousness	Screening Training				1/8/M	2/8/L
High job satisfaction	Screening Training				1/8/M	2/8/M-L
Low motivation/high adaptability	Screening Training	1/10/na		2/7/S	2/7.5/S-M	2/7.5/M
Low boredom	Screening Training	1/7/S	1/7/S	1/7/S		3/7/S-M
Cluster C: Mood indicators						
Low hostility against self	Screening Psychotherapy	1/8/M	1/8/L	1/8/M		
Low aggressiveness	Screening Psychotherapy		1/9/na			
Low anxiety	Screening Psychotherapy		2/9/na			4/8.5/S-M
Cluster D: Cognitive indicators						
High alertness (Cognitive)	Screening Training	1/8/M	1/8/L	1/8/M	1/8/M	1/8/M
Low divergent thinking	Screening Psychotherapy					1/9/M
Cluster E: Self-efficacy indicators						
High self confidence	Screening Training Psychotherapy				1/8/M	2/8.6/S
High self concept	Screening Training Psychotherapy		1/8/na			
High self-reliant	Screening Psychotherapy Training					2/7.5/S

Ability to make self concept more like concept of others	Psychotherapy		1/9/na	1/9/na		
High assertiveness (aggressive, dominant)	Training Psychotherapy			1/10/na	1/8/M	
High PCI Negative expressivity - communion	Screening Psychotherapy	1/11/M			1/11/M	
Concordance between real and ideal self	Psychotherapy	1/7/L				
Low EPPS Need for orderliness	Screening Training Psychotherapy		1/7/S		1/7/S	1/7/S
Cluster F: Interpersonal indicators						
Low EPPS Need for autonomy (from others)	Screening Psychotherapy		1/8/S			
Low EPPS Need for nurturance (from others)	Screening Psychotherapy		1/8/S			
High EPPS Deference (to others)	Screening Selection		1/9/na			
Low FIRO-B wanted affection	Screening Psychotherapy	1/7/S	1/7/S	1/7/S		1/7/S
Low FIRO-B expressed affection	Screening Psychotherapy	1/8/S	1/8/S	1/8/S		
Low FIRO-B wanted control	Screening Psychotherapy		1/8/S	1/8/M		1/8/S
Low FIRO-B expressed inclusion	Screening Psychotherapy					1/8/S
Low FIRO-B wanted inclusion	Screening Psychotherapy		1/8/S			
High interpersonal sensitivity/socialization	Screening Social skills training Psychotherapy		1/5/na			2/7.5/M
High role clarity and low role conflict	Training	1/8/M				
Low assertiveness	Training Psychotherapy	1/7/L				

Low competitiveness	Training					2/8/L
High accepting of authority	Screening Training				2/8/M	
High need for optimism in friends	Training Psychotherapy		1/7/S	1/7/S		
Low need for efficiency in friends	Training		1/7/S			
Low need for sympathy, sentiment, confiding, praise and warmth in friends (need for interpersonal sensitivity from others)	Screening Training Psychotherapy		1/8/na			
Low 16PF Group dependent	Screening Psychotherapy					1/7/M
High role specificity/ability to program self into role	Training		1/8/na			
Ability to confide in partner	Social skills training Psychotherapy			1/9/na		
Ability to provide emotional support to others	Social skills training			1/9/na		
Motivation to maintain social relationships and be part of a group	Social skills training Psychotherapy			1/9/na	2/8/M-L	2/8/M-L
Friendly	Screening Selection					1/8/M
Low mistrust of others	Social skills training Psychotherapy					1/7/na
High perceived fit with station culture	Social skills training	1/8/M				
Other characteristics						
High EPPs Need for orderliness	Screening Training? Psychotherapy		1/9/na			
High NEO Extroversion	Screening Social skills	1/8/S				

	training					
High NEO Openness to experience	Screening Training					1/8/M
High NEO Conscientiousness	Screening Training Psychotherapy		1/6/na			
High FIRO-B expressed control	Screening Psychotherapy				1/7/S	

Number of studies reporting a significant association/average fidelity score of study/magnitude of effect statistics (S = small, M = moderate, L = large)

Table 5. Clinical characteristic fidelity scores and impact by performance measure

Malleable Clinical Characteristics	Countermeasure	Task Ability	Emotional Stability	Social Compatibility	Leadership	Overall
Predeployment clinical evaluations	Screening		1/8/na	1/8/na		2/7.5/M-L
Low MMPI measures of psychopathology	Screening Psychotherapy		1/9/na			
Low baseline depressive symptoms	Screening Psychotherapy		2/8/M-L			
High positive affectivity	Screening Psychotherapy	1/9/S		1/11/na		1/9/M
Low subjective health complaints	Screening Psychotherapy					1/8/M

Number of studies reporting a significant association/average fidelity score of study/magnitude of effect statistics (S = small, M = moderate, L = large)

Table 6. Coping resource and strategy fidelity scores and impact by performance measure

Malleable Coping Characteristics	Countermeasure	Task Ability	Emotional Stability	Social Compatibility	Leadership	Overall
High satisfaction with social support	Social Skills Training/ Psychotherapy		1/8/S	1/7/na		1/8/na
Low demands for social support	Social Skills Training/ Psychotherapy					1/7/na
Low UCL score on acceptance	Psychotherapy		1/7/L			
High UCL score on emotion focused coping	Psychotherapy					1/8/S
High UCL score on problem solving strategies	Social skills training Psychotherapy			1/5/S		

Number of studies reporting a significant association/average fidelity score of study/magnitude of effect statistics (S = small, M = moderate, L = large)

Table 7. Other individual characteristic fidelity scores and impact by performance measure

Malleable Other Characteristics	Countermeasure	Task Ability	Emotional Stability	Social Compatibility	Leadership	Overall
Cluster A: Experiential						
Number of expeditions	Selection	1/8/S	1/7/na			
Enjoyment & awe of environment	Selection		1/8/na	2/10/L		
Other characteristics						
High interest in hobbies/activities	Selection		1/6/na			2/8/M
Low interest in hobbies/activities	Selection Training		1/8/na	1/8/na		1/8/na
High levels of religiosity	Selection	1/8/M		1/8/M		1/8/S
Low levels of religiosity	Selection		1/8/na			
Low work-related stress	Psychotherapy			1/11/na		

Number of studies reporting a significant association/average fidelity score of study/magnitude of effect statistics (S = small, M = moderate, L = large)

Table 8. Group characteristic fidelity scores and impact by performance measure

Malleable Group Characteristics	Countermeasure	Task Ability	Emotional Stability	Social Compatibility	Leadership	Overall
Cluster A: Group Size						
Large groups	Selection	1/8/S	1/8/S	1/8/S		
Small groups	Selection		2/8/S-M			
Cluster B: Group homogeneity/heterogeneity						
Crew homogeneity related to demographic characteristics	Selection Training	1/8/H	1/7/na	4/7.5/S-L		
Crew homogeneity related to culture	Training			4/8.8/M		
Crew homogeneity related to personality	Selection Psychotherapy	2/7.5/M-L	1/7/na	2/7.5/M		
Crew homogeneity related to interest in hobbies/activities	Selection Training	1/8/L		1/8/L		
Crew homogeneity related to expedition goals	Selection Training			1/7/na		
Crew heterogeneity related to gender	Selection			1/8/na		
Crew heterogeneity related to personality	Screening Selection	1/8/M		1/7/na		
Cluster C: Group cohesion						
High crew identity/affiliation	Training	1/7/na	2/7.5/na			
High compatibility of social dyads	Selection Training	1/7/na	1/7/na	2/7/na		
High role complementarity, consensus, redundancy, latency, and isomorphism	Selection Training		1/8/na	1/8/na		
High perceived closeness/similarity/equality	Training			2/9/na		
High crew loyalty to leader	Selection Training	1/8/na		1/8/na		

Number of studies reporting a significant association/average fidelity score of study/magnitude of effect statistics (S = small, M = moderate, L = large)

Table 9. Leadership style and skill fidelity scores and impact by performance measure (1)

Malleable Leadership Characteristics	Countermeasure	Task Ability	Emotional Stability	Social Compatibility	Leadership	Overall
Cluster A: Leadership Style						
Participative/supportive style	Selection Training		1/9/L	1/6/na	2/8/L	
Emphasize discipline and adherence to regulations	Training				2/7.5/L	
Use of recognition and reward	Training				2/7.5/L	1/7/na
Willingness to deal with subordinate's personal problems	Training					
Keep informed	Training				1/8/L	
Maintain daily contact with crew	Training				1/8/L	
Stick by decisions once made	Training				1/8/L	
Cluster B: Leadership skills						
Able to adapt style to context	Selection Training			1/8/na		1/8/na
Able to maintain group harmony and resolve conflicts	Selection Training				2/8/L	1/7/na
Able to delegate authority	Training				1/6/na	1/7/na
Able to set work pace, standards	Training				1/6/na	1/7/na
Abel to respond to emergencies	Training				1/8/L	

(1) Note, Predictors of emotional stability, social compatibility and overall performance relate to characteristics of the team leader. Predictors of leadership relate to characteristics of individual crew members.

(2) Number of studies reporting a significant association/average fidelity score of study/magnitude of effect statistics (S = small, M = moderate, L = large)

Table 10. 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	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	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

		Participative/supportive leadership style	Leader's ability to adapt style to context		

Table 11. Prioritization of psychosocial characteristics based on quantity, quality and fidelity of research findings

Psychosocial Characteristic Category	Performance categories	Statistically significant associations	Mean fidelity score	Small effect X 1	Medium effect X 2	Large effect X 3	Overall effect score
Demographic cluster A (maturity, experience, skills)	5	43	7.53	12	4	0	20
Demographic cluster B (unmarried)	4	6	7.17	0	1	0	2
Demographic cluster C (cultural background)	2	4	8.75	2	1	1	7
Personality cluster A (global traits)	5	44	9.04	13	11	6	53
Personality cluster B (motivation)	5	35	7.83	7	9	7	46
Personality cluster C (mood)	4	10	8.50	2	3	1	11
Personality cluster D (cognition)	5	6	8.17	0	5	1	13
Personality cluster E (self-efficacy)	5	16	8.38	5	4	1	14
Personality cluster F (interpersonal)	5	41	7.56	16	8	4	44
Clinical characteristics	4	11	8.45	1	3	2	13
Coping resources and strategies	3	7	7.14	3	0	1	6
Other characteristics	4	16	8.14	2	3	2	14
Group cluster A (homogeneity/heterogeneity)	3	21	7.10	1	3	5	22
Group cluster B (cohesion)	3	13	7.69	0	0	0	0
Leadership cluster A (style)	4	12	7.00	0	0	7	21
Leadership cluster B (skills)	3	10	7.30	0	0	2	6

Appendix: Review Study Characteristics and Variables

Ref	Citation	Setting	Study type	N	Dependent Variable	Independent Variables
2	Doll, Gunderson & Ryman, 1969	Polar	Longitudinal	240	Emotional	Other: Low number of hobbies
2	Doll, Gunderson & Ryman, 1969	Polar	Longitudinal	240	Emotional	Clinical: Clinical evaluations
4	Doll & Gunderson, 1971b	Polar	Longitudinal	245	Emotional	Demographic: Civilians
5	Gunderson & Arthur, 1966	Polar	Cross-sectional	n/a	Emotional	Demographic: Civilians
5	Gunderson & Arthur, 1966	Polar	Cross-sectional	n/a	Emotional	Demographic: Older age
5	Gunderson & Arthur, 1966	Polar	Cross-sectional	n/a	Emotional	Demographic: Education
5	Gunderson & Arthur, 1966	Polar	Cross-sectional	n/a	Emotional	Demographic: First-born (r = .24 - .30)
5	Gunderson & Arthur, 1966	Polar	Cross-sectional	n/a	Emotional	Personality: Hard, stubborn, blunt, or rough in manner ; Low preference for friends who were sympathetic, sentimental, confiding, praising and warm
6	Gunderson, 1968	Polar	Longitudinal	338	Emotional	Group: Large group size (OR = 1.06 – 1.26)
6	Gunderson, 1968	Polar	Longitudinal	338	Emotional	Demographic: Civilians (OR = 1.43)
7	Gunderson, 1973	Polar	Cross-sectional	139	Emotional	Personality: Low FIRO-B wanted control (r = .25)
7	Gunderson, 1973	Polar	Cross-sectional	139	Emotional	Personality: Low FIRO-B expressed affection (r = .20)
8	Gunderson & Nelson, 1965a	Polar	Longitudinal	142	Emotional	Demographic: Age by group size (linear at large stations, nonlinear at small stations)
8	Gunderson & Nelson, 1965a	Polar	Longitudinal	142	Emotional	Demographic: Rank by group size (linear at large stations, nonlinear at small stations)
8	Gunderson & Nelson, 1965a	Polar	Longitudinal	142	Emotional	Demographic: Military (work) experience by group size (linear at large stations, nonlinear at small stations)
8	Gunderson & Nelson,	Polar	Longitudinal	142	Emotional	Other: Low religiosity

	1965a					
13	Nelson & Gunderson, 1963a	Polar	Longitudinal	64	Emotional	Demographic: Older age (OR = 2.16)
13	Nelson & Gunderson, 1963a	Polar	Longitudinal	64	Emotional	Demographic: No record of delinquency/truancy (OR = 2.61)
14	Nelson & Orvick, 1964	Polar	Longitudinal	48	Emotional	Demographic: Older age (r = .40), education (r = .42), urban residence (large hometowns) (r = .40)
18	Ikegawa et al., 1998	Polar	Cross-sectional	5	Emotional	Demographic: Older age
25	Pope & Rogers, 1968	Polar	Longitudinal	13	Emotional	Personality: Self concept (physical fitness, stamina, professional capability
25	Pope & Rogers, 1968	Polar	Longitudinal	13	Emotional	Personality: Motivation, good role specificity, ability to program self into role
26	Popkin et al., 1974	Polar	Cross-sectional	22	Emotional	Demographic: Education
28	Sandal et al., 1996	Mixed	Cross-sectional	68	Emotional	Personality: High PCI score on positive instrumental/expressive personality
35	Atlis et al., 2004	Polar	Longitudinal	2	Emotional	Other: Enjoyment and awe of environment
37	Kanas et al., 1996	Simulation	Longitudinal	3	Emotional	Leadership characteristics: Supervisor support (r = .71)
46	Gushin et al., 1998	Simulation	Longitudinal	6	Emotional	Personality: Ability to make personal self-concept more like concepts of other crew members
47	Weybrew & Noddin, 1979	Undersea	Cross-sectional	261	Emotional	Demographic: High SES (Occupation)
56	Leon et al., 2002	Polar	Longitudinal	6	Emotional	Personality: Low susceptibility to anxiety
57	Mocellin et al., 1991	Polar	Longitudinal	13	Emotional	Personality: Low susceptibility to anxiety
58	Palinkas & Browner, 1995	Polar	Longitudinal	119	Emotional	Clinical: Low baseline depressive symptoms (r = .31)
58	Palinkas & Browner, 1995	Polar	Longitudinal	119	Emotional	Coping: High satisfaction with social support (r =0.20)
59	Smith & Haythorn, 1972	Simulation	Experimental	56	Emotional	Leadership characteristics: older age
61	Altman & Haythorn, 1967a	Simulation	Experimental	36	Emotional	Group: Crew homogeneity
72	Palinkas, Gunderson, Johnson et al., 2000	Polar	Longitudinal	657	Emotional	Personality: Low need for order (r = .14), boredom (r = .10), wanting efficiency in friends (r = .12), and FIRO B score on affection - wanted (r = .17)

72	Palinkas, Gunderson, Johnson et al., 2000	Polar	Longitudinal	657	Emotional	Personality: Wanting optimism in friends (r = .18)
72	Palinkas, Gunderson, Johnson et al., 2000	Polar	Longitudinal	64	Emotional	Group: Crew cohesion
73	Johnson et al., 2003	Polar	Longitudinal	64	Emotional	Group: Crew cohesion
73	Johnson, et al., 2003	Polar	Longitudinal	64	Emotional	Group: High role complementarity, consensus, redundancy, latency, and isomorphism
74	Gunderson & Kapfer, 1966	Polar	Longitudinal	62	Emotional	Personality: High emotional control, low hostility against self, and high alert (r = .53)
76	Leon et al., 1989	Polar	Longitudinal	8	Emotional	Personality: High achievement motivation, self-control
77	Stange & Youngman, 1979	Polar	Review	n/a	Emotional	Personality: Introversion
78	Palinkas, Gunderson, Holland et al., 2000	Polar	Longitudinal	657	Emotional	Demographic: Civilians (r = .14)
78	Palinkas, Gunderson, Holland et al., 2000	Polar	Longitudinal	657	Emotional	Personality: Low levels of NEO scores on Neuroticism (r = .15), and FIRO-B score on Inclusion - wanted (r = .13)
82	Palinkas, Glogower et al., 2004	Polar	Longitudinal	313	Emotional	Demographic: Male gender (OR = 0.68)
82	Palinkas, Glogower et al., 2004	Polar	Longitudinal	313	Emotional	Demographic: Civilians (OR = 0.30)
82	Palinkas, Glogower et al., 2004	Polar	Longitudinal	313	Emotional	Demographic: Education (OR = 0.80)
83	Palinkas, Johnson et al., 2004	Polar	Longitudinal	217	Emotional	Demographic: Cultural background (Russians report more anxiety (ES = 0.28) but less depression (ES =- 0.14), fatigue(ES = -0.81) and vigor (ES = -0.44) than Americans)
83	Palinkas, Johnson et al., 2004	Polar	Longitudinal	217	Emotional	Demographic: Cultural background (Poles report more anger (ES = 0.20) but less fatigue (ES = -0.37) and vigor (ES = -0.29) than Americans)
83	Palinkas, Johnson et al., 2004	Polar	Longitudinal	217	Emotional	Demographic: Cultural background (Chinese report more depression (ES = 0.30) and confusion (ES = 0.43) but less fatigue (ES = -0.50) and vigor (ES = -0.27) than Americans)
83	Palinkas, Johnson et al., 2004	Polar	Longitudinal	217	Emotional	Demographic: Cultural background (Indians report more depression (ES = 0.44), anger (ES = 0.25), and vigor (ES = 0.80) but less fatigue (ES =- 0.50) than Americans)

85	Haythorn & Altman, 1967	Simulation	Experimental	36	Emotional	Group: Compatible isolated dyads
87	Haythorn et al., 1966	Simulation	Experimental	36	Emotional	Group: Dyads homogeneous in personality (low on dominance)
87	Haythorn et al., 1966	Simulation	Experimental	36	Emotional	Group: Dyads homogeneous in achievement
88	Palinkas et al., 1995	Polar	Longitudinal	119	Emotional	Demographic: Not married (r = .35)
88	Palinkas et al., 1995	Polar	Longitudinal	119	Emotional	Clinical: Low baseline depression (r = .51)
89	Biersner & LaRocco, 1987	Simulation	Experimental	30	Emotional	Demographic: Education and work experience
89	Biersner & LaRocco, 1987	Simulation	Experimental	30	Emotional	Personality: High internality-externality (low extraversion), disinhibition (low repression), and socialization
90	Palinkas, 1991	Polar	Cross-sectional	513	Emotional	Group: Small group size (ES = -0.37)
91	Taylor, 1993	Polar	Review	n/a	Emotional	Demographic: Older age
92	Palinkas et al., 1989	Polar	Cross-sectional	513	Emotional	Demographic: Older age (r = .12), civilians (r = .16)
92	Palinkas et al., 1989	Polar	Cross-sectional	513	Emotional	Personality: Low need for nurturance(r = .12) and autonomy (r = .24)
92	Palinkas et al., 1989	Polar	Cross-sectional	513	Emotional	Group: Small group size (r = .10)
96	Rivolier et al, 1999	Polar	Longitudinal	27	Emotional	Personality: Low sexual preoccupation, boredom, obsessive thoughts, pessimism; high emotional control
97	Barbarito & Peri, 1999	Polar	Longitudinal	8	Emotional	Coping: Low acceptance (r = .70)
101	Godwin, 1985	Polar	Cross-sectional	268	Emotional	Demographic: Unmarried, high SES (occupation)
106	Smith, 1969	Mixed	Review	n/a	Emotional	Group: size
108	Evans et al, 1987	Polar	Longitudinal	9	Emotional	Other: Hobbies, activities
110	Slater, 1969	Polar	Review	n/a	Emotional	Other: Low interest in hobbies and activities
111	Eilbert & Glaser, 1959	Polar	Cross-sectional		Emotional	Personality: High conscientiousness, responsible
112	Wright et al., 1963	Polar	Cross-sectional	197	Emotional	Personality: High EPPS scores on deference and orderliness, low scores on aggression
112	Wright et al., 1963	Polar	Cross-sectional	197	Emotional	Clinical: Low MMPI scores on hypochondriasis, psychopathic deviate, psychasthenia, schizophrenia, and hypomania
113	Weybrew et al., 1961	Undersea	Longitudinal	n/a	Emotional	Demographic: unmarried
115	Taylor & McCormick, 1985	Polar	Longitudinal	12	Emotional	Demographic: older age

115	Taylor & McCormick, 1985	Polar	Longitudinal	12	Emotional	Other: Number of expeditions
120	Kanas et al., 2001	Space	Cross-sectional	14	Emotional	Demographic: Cultural background (ES = 1.85)
8	Gunderson & Nelson, 1965a	Polar	Longitudinal	142	Leadership	Leadership characteristics: Solicit advice of subordinates
10	Nelson, 1963a	Polar	Cross-sectional	67	Leadership	Leadership characteristics: Emotionally controlled, stable , adaptable, accepting of authority, and motivated to be part of a group (ES = 0.86)
10	Nelson, 1963a	Polar	Cross-sectional	67	Leadership	Leadership characteristics: Maintaining group harmony (ES = 1.47)
11	Nelson, 1964a	Polar	Longitudinal	72	Leadership	Leadership characteristics: Self-confident (ES = 0.92), alert (ES = 1.05)), job motivated (ES = 0.85), and aggressive (ES = 0.96)
11	Nelson, 1964a	Polar	Longitudinal	72	Leadership	Leadership characteristics: Job satisfaction (ES = 0.71), industrious (ES = 1.50), emotionally controlled(ES = 1.33), accepting of authority (ES = 1.27), and motivated to be part of a group (ES = 1.33)
24	Law, 1960	Polar	Longitudinal		Leadership	Leadership characteristics: Watch for clique rivalries and do not align themselves with any one subgroup
48	Rose et al., 1994	Space	Cross-sectional	65	Leadership	Leadership characteristics: Low PCI score on Negative instrumentality (r = .25) and Impatience/irritability (r = .24), high PCI score on Negative Expressivity – Negative Communion (r = .38); Low NEO score on Openness (r = .33), high NEO score on Agreeableness (r = .33)
63	Sells, 1965	Polar	Longitudinal	n/a	Leadership	Leadership characteristics: Give personal praise to members and reward them whenever opportunities arise
63	Sells, 1965	Polar	Longitudinal	n/a	Leadership	Leadership characteristics: Not soft or easy going but emphasized discipline and adherence to regulations
65	Nicholas & Penwell, 1995	Mixed	Review	n/a	Leadership	Leadership characteristics: Personal traits, task management style, interpersonal style and group maintenance style
66	Nelson, 1962	Polar	Longitudinal	48	Leadership	Leadership characteristics: Related to men as individuals rather than subordinates (r = .85), prasied men for job well done (r = .85), kept informed about station activities at all

						times (r = .79), maintained daily contact with men (r = .76), ability to plan station activities (r = .85), ability to make emergency decisions (r = .85), participate in group activities (r = .69), solicited advice from subordinates (r = .60), set an example (r = .67), able to maintain discipline (r = .69), stuck by decisions once made (r = .46), demanded good work (r = .46)
67	Campbell, 1953	Undersea	Cross-sectional	n/a	Leadership	Leadership characteristics: Ability to delegate authority and number of positive contacts with other officers and men
68	Weybrew, 1991	Undersea	Review	n/a	Leadership	Leadership characteristics: Participative/supportive style in routine situations and authoritarian style in emergencies
71	Nicholas et al., 1988	Mixed	Review	n/a	Leadership	Leadership characteristics: Highly task-oriented to the goals of the group and delegate and seek advice of members, highly people-oriented, and show concern about team members
72	Palinkas, Gunderson, Johnson et al., 2000	Polar	Longitudinal	657	Leadership	Leadership characteristics: Married (r = .16), low motivation/high adaptability (r = .12), low need for orderliness (r = .12), high expressed control (r = .10)
91	Taylor, 1993	Polar	Review	n/a	Leadership	Leadership characteristics: ruling by consensus
95	WHO, 1985	Polar	Review	n/a	Leadership	Leadership characteristics: versatility regarding responsibilities, readiness to discuss issues, desire and skills in resolving issues
7	Gunderson, 1973	Polar	Cross-sectional	139	Overall	Personality: Low FIRO-B score on Control - wanted (r = .20) and Inclusion – expressed (r = .20)
8	Gunderson & Nelson, 1965a	Polar	Longitudinal	142	Overall	Demographic: age by group size (linear at large stations, nonlinear at small stations)
8	Gunderson & Nelson, 1965a	Polar	Longitudinal	142	Overall	Demographic: rank by group size (linear at large stations, nonlinear at small stations)
8	Gunderson & Nelson, 1965a	Polar	Longitudinal	142	Overall	Demographic: military experience by group size (linear at large stations, nonlinear at small stations)
8	Gunderson & Nelson, 1965a	Polar	Longitudinal	142	Overall	Other: Low interest in hobbies
8	Gunderson & Nelson,	Polar	Longitudinal	142	Overall	Other: Participation in clubs, sports, hobbies by group

	1965a					size: high at large stations, low at small stations)
13	Nelson & Gunderson, 1963a	Polar	Longitudinal	64	Overall	Demographic: Low family socioeconomic status (OR = 2.37)
16	Biersner & Hogan, 1984	Polar	Cross-sectional	25	Overall	Personality: Low scores for emotional expressiveness (r = .61), self-reflection (r = .51), Openness to experience seeking (r = .56), divergent thinking (r = .39), and challenge (r = .44); high scores for status seeking (need achievement)(r = .36)
19	Kahn & Leon, 1993	Polar	Longitudinal	4	Overall	Clinical: High positive affectivity (r = .46)
19	Kahn & Leon, 1993	Polar	Longitudinal	4	Overall	Personality: High achievement motivation and self-confidence; low bodily concern and competitiveness
20	Palmai, 1963	Polar	Longitudinal	14	Overall	Personality: High introversion
21	McGuire & Tolchin, 1961	Polar	Longitudinal	17	Overall	Demographic: Older age
22	Nardini et al, 1962	Polar	Longitudinal	579	Overall	Personality: Sensitive to needs of others, low boredom
22	Nardini et al, 1962	Polar	Longitudinal	579	Overall	Coping: Low demands for social support
22	Nardini et al, 1962	Polar	Longitudinal	579	Overall	Clinical: Predeployment evaluations r = .41 - .66)
23	Gunderson, 1966	Polar	Longitudinal		Overall	Personality: Low motivation
43	Radloff & Helmreich, 1968	Undersea	Cross-sectional	n/a	Overall	Demographic: Rural residence
48	Rose et al, 1994	Space	Cross-sectional	65	Overall	Personality: High NEO scores for agreeableness (r = .29); low openness (r = .28) and conscientiousness (r = .17)
54	Taylor, 1987	Polar	Review	n/a	Overall	Personality: High motivation to achieve, satisfaction with social support
54	Taylor, 1987	Polar	Longitudinal	204	Overall	Personality: High 16PF emotionally stable (ES = 0.40), low 16PF anxiety (ES = 0.41)
63	Sells, 1965	Polar	Longitudinal	n/a	Overall	Leadership characteristics: ability to set work pace and establish a social atmosphere
63	Sells, 1965	Polar	Longitudinal	n/a	Overall	Leadership characteristics: positive about their jobs, used delegation effectively, had pride in organizations and personnel, used recognition and reward, gave frequent complements to individuals, and accepted each individual's personal problems
64	Kinsey, 1959	Undersea	Longitudinal	n/a	Overall	Leadership characteristics: Quality of leadership

66	Nelson, 1962	Polar	Cross-sectional		Overall	Leadership characteristics: Decision-making methods used by leader by context (technical = participatory, emergency = authoritarian)
69	Miller et al., 1971	Undersea	Longitudinal	n/a	Overall	Leadership characteristics: High SES (occupation)
72	Palinkas, Gunderson, Johnson et al., 2000	Polar	Longitudinal	657	Overall	Demographic: Military service (r = .16)
72	Palinkas, Gunderson, Johnson et al., 2000	Polar	Longitudinal	657	Overall	Personality: Low boredom (r = .10), need for orderliness (r = .11), and FIRO-B score on wanted affection (r = .13)
74	Gunderson & Kapfer, 1966	Polar	Longitudinal	158	Overall	Personality: Low ratings of self reliant-dependent (r = .19), and adaptable-rigid (r = .31); high ratings of tense-relaxed (r = .22) and friendly (r = .39)
75	Gunderson & Nelson, 1965b	Polar	Longitudinal	158	Overall	Personality: High social compatibility (ES = 1.10), motivation (ES = 1.59), usefulness (ES = 1.57), teamwork (ES = 1.34, achievement (ES = 1.44), and efficiency (ES = 1.19), low boredom (ES = 1.14)
78	Palinkas, Gunderson, Holland et al., 2000	Polar	Longitudinal	657	Overall	Demographic: military service (r = .11)
78	Palinkas, Gunderson, Holland et al., 2000	Polar	Longitudinal	657	Overall	Personality: Low NEO scores on extraversion (r = .14) and conscientiousness (r = .14)
84	Grant et al., 2007	Polar	Longitudinal	348	Overall	Personality: High NEO scores on openness (OR = 5.2)
84	Grant et al., 2007	Polar	Longitudinal	348	Overall	Coping: higher levels of Emotion-focused coping (OR = 2.7)
84	Grant et al., 2007	Polar	Longitudinal	348	Overall	Clinical: lower subjective health complaints (OR = 0.3)
84	Grant et al., 2007	Polar	Longitudinal	348	Overall	Demographic: female gender (OR = 1.6)
86	Taylor et al., 1969	Simulation	Experimental	168	Overall	Personality: Low MMPI scores of repression-sensitization, control, and heterosexual aggression; high score on responsibility
98	Crocq et al., 1974	Polar	Longitudinal	120	Overall	Personality: Low motivation
98	Crocq et al., 1974	Polar	Longitudinal	120	Overall	Demographic: Occupation (scientists adjusted better than technicians, cooks, radio operators)
100	Taylor, 1974	Polar	Longitudinal	93	Overall	Personality: less group dependent (16PF Factor Q2) (ES = .62)
102	Nelson, 1963b	Polar	Longitudinal		Overall	Clinical Evaluations: Summary assessment
103	Natani, 1971	Polar	Longitudinal	21	Overall	Demographic: Civilians
109	Draggan, 1987	Polar	Review	n/a	Overall	Personality: emotional maturity, reasonable goal

						formation and implementation strategies, introverted
109	Draggan, 1987	Polar	Review	n/a	Overall	Demographic: Older age
109	Draggan, 1987	Polar	Review	n/a	Overall	Other: Few or unspecific hobbies or activities
114	Owens, 1975	Polar	Longitudinal	n/a	Overall	Demographic: Unmarried
114	Owens, 1975	Polar	Longitudinal	n/a	Overall	Personality: Low neuroticism
116	De Monchaux et al., 1979	Polar	Longitudinal	77	Overall	Personality: Introverted, trusting of others, self-reliant, emotionally stable
117	Gunderson et al 1964	Polar	Longitudinal	184	Overall	Demographic: Older age (r = .21), years of service (r = .20), rank (r = .28), education (r = .21), married (r = 21), and no history of delinquency/truancy (r =.27)
117	Gunderson et al 1964	Polar	Longitudinal	184	Overall	Other: High religiosity (r = .23), high hobbies/activities (r = .38)
118	Nelson & Gunderson, 1962	Polar	Longitudinal	18	Overall	Personality: adaptability (r = .50), emotionally controlled (r = .50), job motivation (r = .59), industriousness (r = .66), happiness (r = .52), job satisfaction (r = .61), motivation to be part of group (r = .50).
119	Nelson & Gunderson, 1963	Polar	Longitudinal	139	Overall	Personality: emotionally controlled (r = .68), job motivation (r = .48), industriousness (r = .56), happiness (r = .48), job satisfaction (r = .35), motivation to be part of group (r = .53), accept authority (r = .56), achievement motivation (r = .53), attitude towards project (r = .48), alertness (r = .43), self-confidence (r = .29).
1	Doll & Gunderson, 1971a	Polar	Cross-sectional	245	Social	Group: Station size (ES = 0.52)
2	Doll et al., 1969	Polar	Longitudinal	240	Social	Clinical: Predeployment evaluations by occupation
7	Gunderson, 1973	Polar	Cross-sectional	139	Social	Personality: Low FIRO-B score on expressed affection (r = .20)
8	Gunderson & Nelson, 1965a	Polar	Longitudinal	142	Social	Demographic: Age by group size: linear in large stations, nonlinear in small stations
8	Gunderson & Nelson, 1965a	Polar	Longitudinal	142	Social	Other: Low participation in clubs, sports, hobbies (at small stations)
8	Gunderson & Nelson, 1965a	Polar	Longitudinal	142	Social	Demographic: Rank by group size: linear in large stations, nonlinear in small stations
8	Gunderson & Nelson,	Polar	Longitudinal	142	Social	Demographic: Military (work) experience by group size:

	1965a					linear in large stations, nonlinear in small stations
9	Gunderson & Ryman, 1967	Polar	Longitudinal	270	Social	Group: Crew homogeneity related to urban-rural residence (r = .67)
9	Gunderson & Ryman, 1967	Polar	Longitudinal	270	Social	Group: Crew homogeneity related to hobbies (r = .85)
9	Gunderson & Ryman, 1967	Polar	Longitudinal	270	Social	Group: Crew homogeneity related to personality (need for achievement (r = .40), autonomy (r = .49), nurturance (r = .36), motivation (r = .44), and describing friends as efficient (r = .33)
9	Gunderson & Ryman, 1967	Polar	Longitudinal	270	Social	Personality: Low FIRO-B Control – wanted (r = .49)
12	Nelson, 1964b	Polar	Longitudinal	59	Social	Group: Crew homogeneity related to age
14	Nelson & Orvick, 1964	Polar	Longitudinal	48	Social	Demographic: Rural residence (Small hometown) (r = .49)
14	Nelson & Orvick, 1964	Polar	Longitudinal	48	Social	Other: High religiosity (r = .45)
15	Leon & Sandal, 2003	Polar	Longitudinal	12	Social	Personality: Mutual respect, emotional support, ability to confide in partner, and motivation to maintain positive and supportive relationships
17	Blair, 1992	Polar	Longitudinal	20	Social	Leadership characteristics: Ability to adapt leadership style to context
21	McGuire & Tolchin, 1961	Polar	Longitudinal	17	Social	Demographic: Older age
21	McGuire & Tolchin, 1961	Polar	Longitudinal	17	Social	Group: Crew homogeneity related to income/socioeconomic status
23	Gunderson, 1966	Polar	Review	n/a	Social	Group: Crew homogeneity related to occupation
24	Law, 1960	Polar	Longitudinal		Social	Group: Crew homogeneity related to culture
27	Rosnet et al., 2004	Polar	Longitudinal	52	Social	Group: Crew heterogeneity related to gender
30	Weiss et a., 2007	Polar	Cross-sectional	27	Social	Demographic: Age by occupation (Young scientists expressed a higher need for privacy whereas older technicians preferred places for social leisure)
32	Sandal, 2004	Simulation	Longitudinal	12	Social	Group: Crew homogeneity related to culture (Language, attitudes toward the experiment, privacy, emotional expressiveness, hygiene, appropriate gender behavior, coping in relation to conflict and housekeeping)
34	Leon & Scheib, 2007	Polar	Longitudinal	2	Social	Group: Crew homogeneity related to personality traits and

						expedition goals
35	Atlis et al., 2004	Polar	Longitudinal	2	Social	Group: Equality of dyad
36	Kanas, 1998	Space	Review	n/a	Social	Group: Crew homogeneity related to gender, culture, work experience, language and dialect, and task vs supportive leadership
38	Kanas, Salnitskiy, Weiss et al., 2001	Space	Cross-sectional	71	Social	Clinical: Positive affectivity, low work pressure
39	Oberg, 1981	Space	Anecdotal	3	Social	Group: Crew homogeneity related to language, culture and political orientation
40	Chaikin, 1985	Space	Anecdotal	n/a	Social	Group: Crew homogeneity related to language, culture and political orientation
41	Bluth, 1981	Space	Anecdotal	n/a	Social	Group: Crew homogeneity related to language, culture and political orientation
42	Bluth, 1984	Space	Anecdotal	n/a	Social	Group: Crew homogeneity related to language, culture and political orientation
43	Radloff & Helmreich, 1968	Undersea	Cross-sectional	n/a	Social	Demographic: First born individuals
44	Kelly & Kanas, 1992	Space	Cross-sectional	54	Social	Other: Shared experience (ES = 3.13), excitement of spaceflight (ES = 1.52), close quarters (ES = 1.91) and isolation from Earth (ES = 1.45)
45	Kelly & Kanas, 1993	Space	Cross-sectional	54	Social	Other: Shared experience (ES = 1.90) and excitement of space flight (ES = 1.61)
46	Gushin et al., 1998	Simulation	Longitudinal	6	Social	Personality: Ability to make personal self-concept more like concepts of other crew members
48	Rose et al., 1994	Space	Cross-sectional	65	Social	Personality: Low PCI score on impatience/irritability (r = .32), and negative instrumentality (r = .25); Low NEO score on Openness (r = .22); high NEO score on Agreeableness (r = .41)
49	McFadden et al., 1994	Space	Cross-sectional	66	Social	Personality: High positive instrumentality and expressivity
50	Sandal et al., 1999	Undersea	Cross-sectional	50	Social	Personality: High positive instrumentality and expressivity (r = .32); strong achievement motivation (r = .15)
50	Sandal et al., 1999	Undersea	Cross-sectional	50	Social	Coping: Use of problem-solving strategies (r = .13)
52	Sandal et al., 1995	Simulation	Longitudinal	12	Social	Personality: Dominance and task motivation
53	Sandal et al., 1998	Undersea	Longitudinal	50	Social	Personality: High PCI scores on positive

						instrumental/expressive personality and low motivation
53	Sandal et al., 1998	Undersea	Longitudinal	50	Social	Coping: High social support
59	Smith & Haythorn, 1972	Simulation	Experimental	56	Social	Leadership characteristics: Older age
59	Smith & Haythorn, 1972	Simulation	Experimental	56	Social	Group: Compatible groups
61	Altman & Haythorn, 1967a	Simulation	Experimental	36	Social	Group: Crew heterogeneity related to personality, egocentric characteristics (dominance and dogmatism) and homogeneity on sociocentric characteristics (affiliation and achievement)
68	Weybrew, 1991	Undersea	Review	n/a	Social	Leadership characteristics: Participative/supportive style of leadership
70	Kanki & Gregorich, 1992	Expedition	Longitudinal	n/a	Social	Group: Team preference for its leader
72	Palinkas, Gunderson, Johnson et al., 2000	Polar	Longitudinal	657	Social	Demographic: Military service (r = .13)
72	Palinkas, Gunderson, Johnson et al., 2000	Polar	Longitudinal	657	Social	Personality: Low FIRO-B score on affection wanted (r =.11); low need for achievement (r = .15), and boredom (r = .10); high wanting optimism in friends (r = .14)
73	Johnson et al., 2003	Polar	Longitudinal	64	Social	Group: High role complementarity, consensus, redundancy, latency, and isomorphism
74	Gunderson & Kapfer, 1966	Polar	Longitudinal	62	Social	Personality: High emotional control and alert; low hostility against self (r = .38)
79	Leon et al., 1994	Polar	Longitudinal	12	Social	Demographic: Cultural background (Russians treated women as subordinates; Americans treated them as equals)
81	Schmidt et al., 2005	Polar	Cross-sectional	187	Social	Demographic: Male gender
83	Palinkas, Johnson et al., 2004	Polar	Longitudinal	217	Social	Demographic: Collective cultural orientation (r = .37)
83	Palinkas, Johnson et al., 2004	Polar	Longitudinal	217	Social	Demographic: Cultural background (Russians report more seeking advice (ES = 0.81) and interaction (ES = 0.47) from other crewmembers than Americans)
83	Palinkas, Johnson et al., 2004	Polar	Longitudinal	217	Social	Demographic: Cultural background (Indians report more seeking advice (ES = 0.73) and interaction (ES = 1.67) from

						other crewmembers than Americans)
83	Palinkas, Johnson et al., 2004	Polar	Longitudinal	217	Social	Demographic: Cultural background (Chinese report more interaction (ES = 1.53) from other crewmembers than Americans)
85	Haythorn & Altman, 1967	Simulation	Experimental	36	Social	Group: Compatible isolated dyads
91	Taylor, 1993	Polar	Review	n/a	Social	Demographic: older age
93	Gushin et al., 1996	Simulation	Longitudinal	6	Social	Group: Regarding one another as close or similar
94	Gushin et al., 1997	Simulation	Longitudinal	6	Social	Group: Sharing common values and beliefs
95	WHO, 1985	Polar	Review	n/a	Social	Personality: Tolerance, flexibility, sense of humor, balance of motivational factors
95	WHO, 1985	Polar	Review	n/a	Social	Other: Lack of major recent life event change
96	Rivolier et al., 1999	Polar	Longitudinal	27	Social	Personality: Low self-centeredness, criticism of others, aggressiveness, withdrawal to oneself, distrust
99	Natani et al., 1974	Polar	Longitudinal	62	Social	Group: Crew homogeneity in Occupation
103	Natani, 1971	Polar	Longitudinal	21	Social	Demographic: occupational differences in between group interaction
104	Harrison, 1980	Mixed	Review	n/a	Social	Group: size
105	Kanas & Fedderson, 1971	Space	Review	n/a	Social	Group: size
106	Smith, 1969	Mixed	Review	n/a	Social	Group: size
107	Lozano & Wong, 1993	Space	Cross-sectional	37	Social	Group: Crew homogeneity related to culture (personal hygiene standards and grooming habits, verbal and nonverbal communication, gender roles, norms and stereotypes, professional background, decision-making processes and religious beliefs) (ES = 0.68 - 0.93)
113	Weybrew et al., 1961	Undersea	Longitudinal	n/a	Social	Demographic: unmarried
1	Doll & Gunderson, 1971a	Polar	Longitudinal	245	Task	Group: Group size (ES = 0.49)
3	Doll & Gunderson, 1969	Polar	Longitudinal	195	Task	Demographic: Civilians (ES = 0.44)
7	Gunderson, 1973	Polar	Cross-sectional	240	Task	Personality: Low expressed emotion (r = .25; low FIRO-B score on affection – expressed (r = .20)
9	Gunderson & Ryman,	Polar	Longitudinal	270	Task	Group: Crew heterogeneity related to personality (FIRO-B

	1967					score on inclusion – expressed (r = .45) and control – expressed (r = .42))
9	Gunderson & Ryman, 1967	Polar	Longitudinal	270	Task	Group: Crew homogeneity related to personality (FIRO-B wanted control (r = .49), autonomy (r = .55), motivation(r = .44))
9	Gunderson & Ryman, 1967	Polar	Longitudinal	270	Task	Group: Crew homogeneity related to personality (describing friends as efficient)(r = .54)
9	Gunderson & Ryman, 1967	Polar	Longitudinal	270	Task	Group: Crew homogeneity related to urban-rural residence (r = .62) and number of hobbies (r = .85)
13	Nelson & Gunderson, 1963a	Polar	Longitudinal	64	Task	Demographic: No record of delinquency/truancy (OR = 2.62)
14	Nelson & Orvick, 1964	Polar	Longitudinal	48	Task	Other: High religiosity (r = .46)
19	Kahn & Leon, 1993	Polar	Longitudinal	4	Task	Clinical: Positive affectivity (r = .16)
29	Sauer et al., 1999	Polar	Cross-sectional	16	Task	Demographic: Occupation (Scientists)
31	Sarris, 2006	Polar	Cross-sectional	117	Task	Demographic: Occupation (Scientists) (r = .41)
31	Sarris, 2006	Polar	Cross-sectional	117	Task	Personality: High role clarity (r = .38) and low role conflict (r = .25)
31	Sarris, 2006	Polar	Cross-sectional	117	Task	Personality: Perceived fit with station culture (r = .48)
31	Sarris, 2006	Polar	Cross-sectional	117	Task	Demographic: Male gender (r = .25), older age (r = .41), number of expeditions (r = .20)
31	Sarris, 2006	Polar	Cross-sectional	117	Task	Personality: High extraversion (r = .20)
33	Rosnet et al., 2000	Polar	Cross-sectional	16	Task	Personality: Low assertiveness (ES = -2.07) and extraversion (ES = -2.02), concordance between real and ideal self (r = .55)
48	Rose et al., 1994	Space	Cross-sectional	65	Task	Personality: Low PCI scores on negative expressivity - communion (r = .35); low NEO score on Openness (r = .38), high NEO score on Agreeableness (r = .27)
49	McFadden et al., 1994	Space	Cross-sectional	66	Task	Personality: High PCI scores on instrumentality and expressivity and low levels of motivation/high adaptability
55	Gunderson, 1974	Polar	Review	n/a	Task	Personality: High achievement motivation
62	Altman & Haythorn, 1967b	Simulation	Experimental	36	Task	Group: Crew homogeneity related to personality (dogmatism, achievement affiliation, and dominance)
62	Altman & Haythorn, 1967b	Simulation	Experimental	36	Task	Group: Groups high in affiliation

70	Kanki & Gregorich, 1992	Expedition	Longitudinal	n/a	Task	Group: Team preference for its leader
72	Palinkas, Gunderson, Johnson et al., 2000	Polar	Longitudinal	657	Task	Military (r = .13), years of service (r = .19), low boredom (r = .10) and low FIRO B score of affection - wanted (r = .12)
74	Gunderson & Kapfer, 1966	Polar	Longitudinal	62	Task	Personality: High emotional control and alert; low hostility against self (r = .43)
85	Haythorn & Altman, 1967	Simulation	Experimental	36	Task	Group: Compatible isolated dyads
96	Rivolier et al., 1999	Polar	Longitudinal	27	Task	Personality: Low ritualization of activities, concentration difficulties, hypo or hyperinvestment in work
114	Owens, 1975	Polar	Longitudinal	n/a	Task	Demographic: Unmarried
114	Owens, 1975	Polar	Longitudinal	n/a	Task	Personality: Low neuroticism

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Antarctica Meta-analysis: Psychosocial Factors Related to Long-duration Isolation and Confinement

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Contents

Acronyms

ANARE	Australian National Antarctic Research Expeditions
BHP	behavioral, health, and performance
DSM-IV	Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition
ICE	isolated, confined, and extreme
PANAS	Positive Affect Negative Affect Schedule
POMS	Profile of Mood States
REM	rapid eye movement
16PF	Sixteen Personality Factor Questionnaire
SSAD	subsyndromal seasonal affective disorder

Abstract

The purpose of this study was to examine the psychological effects of wintering-over in Antarctica. We considered the feasibility of a meta-analysis for combining the results of relevant empirical studies in this area. As an ICE [isolated, confined, and extreme] environment, Antarctica provides invaluable opportunities to experience stressors more common to spaceflight than to the average person's everyday life. The increased prevalence of psychological symptoms, syndromes, and psychiatric disorders, as well as positive salutogenic effects, were expected to be associated with various demographic and environmental factors. The great disparity between experimental design, statistical methodology, and reporting details led to the conclusion that a traditional meta-analysis was not feasible. Possible forward work considerations include a systematic literature review, a re-analysis of the data (for certain individual measures) using modern longitudinal techniques, an alternative meta-analysis method (for certain individual measures), and/or a qualitative literature review. NASA's BHP [behavioral, health, and performance] Element is planning to conduct the systematic review in FY10.

Introduction

NASA is committed to longer-duration spaceflight, including astronauts returning to the moon and crewed flights to Mars. All of this requires a deeper understanding of the impact extended missions pose for astronauts. A primary concern is the effect that extended periods of isolation will have on astronauts' psychological well-being. Predicting the psychological impact of longer-duration missions must include a consideration of space environment factors, which will likely intensify feelings of isolation. These factors include: longer periods away from family and friends, absence of earthly conveniences and daily routines, as well as time spent confined in the spacecraft due to living in a potentially dangerous environment. Evidence gathered in space analogs such as the Antarctic provides insight into psychological issues that might arise during such longer-duration missions.

Antarctica as a Space Analog

The Antarctic is physically remote from the rest of the world, and during winter months it is further isolated since the weather precludes travel to and from the continent. Additionally, 24-hour periods of darkness prevent travel on the continent. It is the coldest, windiest, and highest of Earth's continents; therefore, outdoor excursions are limited even when there is daylight. Living and working space also provides relatively small and limited areas in which to live and work. These attributes define the Antarctic as an isolated, confined, and extreme (ICE) environment, thereby making it an important analog for spaceflight because long-duration missions will inherently present similar challenges.

Documentation of psychological effects in Antarctica

Psychological effects of Antarctic expeditions have been well documented from anecdotal accounts recounted by the earliest explorers. Frederick Cook, the physician of the multinational crew aboard the *Belgica,* described the psychological state of his crew as follows: "The curtain

of blackness which has fallen over the outer world of icy desolation has descended upon the inner world of our souls. Around the tables, in the laboratory, and in the forecastle, men are sitting about sad and dejected, lost in dreams of melancholy from which, now and then, one arouses with an empty attempt at enthusiasm" (Cook, 1909). Men from Sir Ernest Shackleton's Imperial Trans-Antarctic Expedition of 1914–1917 were stranded on Elephant Island after their ship, the *Endurance*, was destroyed after it was trapped in ice in the Weddell Sea. The carpenter for the Expedition, Harry McNeish, wrote of being on the island saying, "I don't think there are ever many fine days on this forlorn island... I don't think there will be many survivors if they have to put in a winter here" (American Museum of Natural History, 2001).

It was not until the late 1950s and 1960s, however, that these psychological effects were documented for research purposes by investigators such as Gunderson, Taylor, and Rivolier (Gunderson and Nelson, 1962; Taylor, 1969; Rivolier, 1963). Although research needs began to be addressed by collecting data relating to psychological well-being, the findings from these initial research efforts seem only to raise more questions than answers. Often, data were inconsistently collected and analyzed and research methodologies were not reliably administered. Additionally, due to the specific samples used, it is difficult to generalize results across population groups. In more recent research, an effort has been made to systematically examine psychological effects on well-being. For example, Suedfeld et al. (1992) looked at emotional stability and Mocellin, et al. (1991) examined anxiety in polar environments. Nonetheless, even at the present time, a complete understanding of how (and to what extent) the characteristics of ICE environments impact psychological well-being remains unknown. As Palinkas and Suedfeld (2007) note, "Apart from anecdotal reports of polar madness and cabin fever, little is known about the psychological demands people face on polar expeditions …"

Purpose of the study

The purpose of this study was to examine the effects that wintering-over in Antarctica has on psychological well-being, and to relate the findings to longer-duration spaceflight. The aim was to employ meta-analytic techniques to synthesize existing empirical research, thus affording a more complete understanding of the data than can be provided by one study alone in an effort to apply these findings to astronauts on long-duration missions. The study is addressed by the Behavioral Health and Performance (BHP) Element within NASA's Human Research Program. Specifically, this study addresses the Risk of Behavioral and Psychiatric Conditions; Gap 6: What psychosocial characteristics predict success in an ICE environment?

The hypotheses initially developed for this study were generated based on the authors' intent to account for factors that are directly relevant to spaceflight dynamics (eg, duration of mission, individual selection, harshness of climate, etc.). These hypotheses are supported by the literature summarized below as well as by a *Lancet* article by Palinkas and Suedfeld (2007) in which the authors discussed many of the psychological effects experienced on polar expeditions. Although data limitations in this study prevented hypothesis testing, these hypotheses are provided for background information, as they were foundational to the initial project.

Categorization of psychological effects experienced in Antarctica

Psychological Symptoms

Most of the literature gathered for this study addresses psychological symptoms experienced in the Antarctic. Somatic symptoms such as fatigue, headaches, and weight gain are often listed. Disturbed sleep – including phenomena such as difficulty falling or staying asleep, loss of slow-wave sleep, loss of rapid eye movement (REM) sleep were common problems (Polosatov, 1973; Usui et al., 2000). Expeditioners have also experienced impaired cognition such as: reduced accuracy and short-term memory, increased response time for cognitive tasks and spontaneous fugue states; the latter of which has often been referred to as “the Antarctic stare” (Reed et al., 2001; Sandal, Leon, and Palinkas, 2006) or, more recently, as “toast” (Cravalho, 1996). Other symptoms reported include depressed mood, anger and irritability, and anxiety. Interpersonal tension and conflict toward both group members and non-group members (ie, replacement personnel and support personnel located elsewhere) was reported in much of the literature (Lugg, 1987; Palinkas and Suedfeld, 2007).

Syndromes

Psychological effects experienced on polar expeditions may also be categorized as syndromes; these are often cited within this body of literature. Three syndromes experienced by persons living in the Antarctic are winter-over syndrome, polar T3 syndrome, and subsyndromal seasonal affective disorder (SSAD). Winter-over syndrome consists of impaired cognitive functioning, disturbed sleep, interpersonal tension and conflict, and negative affect. However, this syndrome is not usually severe enough to warrant a DSM-IV [Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition] diagnosis. The term “third quarter effect” is often used because the symptoms associated with the winter-over syndrome appear to peak in the third quarter of the mission. Polar T3 syndrome occurs when long-term exposure to cold temperatures produces changes in thyroid functioning with effects similar to those seen in hypothyroidism (eg, mood disturbances and reductions in cognitive performance). Complaints include fatigue, memory problems, weight gain, dulled thinking, lethargy, and depression. Finally, SSAD is related to variations in the amount of daylight, and is associated with depressive symptoms.

Psychiatric Disorders

The literature also discusses psychiatrics disorders as another type of psychological effect that expeditioners may experience while in the Antarctic. The most common psychiatric disorders reported in the literature that are severe enough to warrant DSM-IV diagnoses include: mood, personality, substance-related, sleep, and adjustment disorders. The incidence rates of all the diagnoses revealed that 5.2% of people wintering-over in Antarctica met criteria for at least one DSM-IV diagnosis (Palinkas et al., 2004). The rate of mental disorders, including depression, was 4.5% according to ANARE [Australian National Antarctic Research Expeditions] and 6.4% at McMurdo Station (Otto, 2007). Based on 12 years of South Pole data, the overall incidence rate for depression that required pharmacological intervention was 2.03% (Otto, 2007). These rates reflect vulnerability to the stress associated with long-duration isolation and confinement in a harsh environment, combined with limitations in screening procedures designed to select-out individuals with such vulnerabilities.

Positive Effects

To depict polar service accurately, it is important to evaluate both positive and negative reactions that expeditioners may experience. Research has been primarily focused on the negative challenges in ICE environments. However, not all effects experienced are negative and, in fact, anecdotal evidence – including diaries, journal entries, and autobiographies – demonstrate salutogenic effects (Palinkas and Suedfeld, 2007). Salutogenic effects enhance rather than challenge psychological well-being. These inherently enjoyable aspects in the Antarctic environment include: success in overcoming the challenges inherent in the situation, in-group solidarity, cohesiveness, shared values, hardiness, resiliency, and coping. Results from one Antarctic survey suggest that positive reactions were experienced more often than negative ones, although the range of negative reactions reported was broader (Wood et al., 2000).

Outcomes of Psychological Effects

In addition to examining the psychological effects experienced by participants in the Antarctic, reviewed studies also included important behavioral outcomes resulting from the changes experienced in the individual's psychological well-being. In particular, evidence suggests that gender and military differences as well as an individual's prior experience in a polar environment and the size of the expedition crew may all relate to the psychological symptoms that are experienced (Gunderson, 1970; Gunderson, 1962). Results also suggest that selection screening, duration, station accessibility, and station latitude are all also related to psychological effects (; Suedfeld and Palinkas, 2007).

Based on this evidence as well as the review by Palinkas and Suedfeld (2007), the following hypotheses were formulated:

Hypothesis 1: Incidence of negative psychological symptoms is positively associated with the duration of residence in Antarctica, third quarter of Antarctic residence, and station latitude. Negative psychological symptoms are higher in women and military personnel. Negative psychological symptoms are negatively associated with size of crew, station accessibility, and prior experience.

Hypothesis 2: Incidence of negative syndromes is positively associated with duration of residence in Antarctica and station latitude and negatively associated with screening processes for selection.

Hypothesis 3: Incidence of psychiatric disorders is positively associated with duration of residence in Antarctica and station latitude. Psychiatric disorders are higher in women and military personnel. These psychiatric disorders are negatively associated with station accessibility, selection process, and prior experience.

Hypothesis 4: Incidence of salutogenic effects is positively associated with station accessibility and severity of station environment.

Methodology

Search Criteria

The authors of this project first attempted to identify and obtain all published and unpublished empirical studies of the psychological effects of Antarctic stays. This search effort resulted in a collection of 516 articles, books, presentations, and papers on psychological effects of Antarctic missions ranging from 1959 through 2007. Of these, 362 articles contained numerical data and were, therefore, chosen for inclusion. Qualifying data constituted any reported numerical findings (ie, means, standard deviations, numerical tables of results, etc.) applicable for a quantitative meta-analysis. Search terms used for the database were: Antarctica, polar, and winter-over. The search locations included: PsycInfo, Medline, and other similar search engines. Prominent researchers in the field were contacted, and the following databases held by countries involved in Antarctic research were explored: Australian Antarctic Division, British Antarctic Survey, New Zealand Antarctic Bibliography, Antarctic Bibliography, and the U.S. Defense Technical Information Center.

Current Status of Meta-analysis

Statisticians[1] evaluated the feasibility of traditional meta-analysis (the measures most frequently used within the 362 articles were chosen: 16PF [Sixteen Personality Factor Questionnaire], POMS [Profile of Mood States], and PANAS [Positive Affect Negative Affect Schedule]) after completing coding, which involved identifying and coding the relevant data found in each study. Based on this evaluation, a traditional meta-analysis was not feasible due to inconsistent measurement of data and a lack of critical information reported in research articles. Although a large number of articles were identified, there was little consistency across the articles; it was thus impossible to generalize across subjects. Differences in the data reported, measures used, and methodological rigor of the studies all contributed to an inability to perform a meta-analysis.

Alternative methodologies to the traditional meta-analysis are being considered for forward work. One possibility is a quantitative literature review. Although the data in these studies do not lend themselves to the stringent requirements of the meta-analysis methodology, a less-formal version of a quantitative literature review remains a possibility. This less-rigorous quantitative literature review would use descriptive statistics (eg, percentile and frequency) to summarize research findings.

Similarly, a qualitative review, which would incorporate the qualitative articles that were originally removed from consideration for the traditional meta-analysis, remains a possibility. Alternatively, a modern longitudinal technique could be conducted whereby the data for the POMS would be re-analyzed. This methodology might be possible if sufficient raw data is obtained from researchers for each measure considered. To this end, discussions are under way with prolific Antarctic researcher(s); if obtained, these data will be reanalyzed in an effort to establish meaningful statistical inferences.

A third alternative is a systematic review and comparison to evaluate both process and content. The content might be evaluated using techniques that attempt to quantify qualitative assessments,

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such as Delphi Technique or Concept Mapping. However, this cannot be approached without caution due to the fact that reported data may contain heterogeneous subsamples.

Without discounting the qualitative review and modern longitudinal technique methodology, NASA's BHP Element is currently planning to conduct the systematic review in fiscal year 2010, which will necessitate an effort to update the literature review subsequent to 2007. This particular methodology was chosen as forward work because it will take into account all of the literature gathered in the database as opposed to furthering examination of a limited number of studies or one particular measure. Additionally, this systematic review is planned to begin after completion of two other NASA literature reviews related to the same risk of behavioral and psychiatric conditions. It is believed that these other literature reviews may assist in informing the risk and aid in focusing the subsequent planned systematic review.

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13. ABSTRACT *(Maximum 200 words)*

The purpose of this study was to examine the psychological effects of wintering-over in Antarctica. We considered the feasibility of a meta-analysis for combining the results of relevant empirical studies in this area. As an ICE [isolated, confined, and extreme] environment, Antarctica provides invaluable opportunities to experience stressors more common to space flight than to the average person’s everyday life. The increased prevalence of psychological symptoms, syndromes, and psychiatric disorders, as well as positive salutogenic effects, were expected to be associated with various demographic and environmental factors. The great disparity between experimental design, statistical methodology, and reporting details led to the conclusion that a traditional meta-analysis was not feasible. Possible forward work considerations include a systematic literature review, a reanalysis of the data (for certain individual measures) using modern longitudinal techniques, an alternative meta-analysis method (for certain individual measures), and/or a qualitative literature review. NASA’s BHP [behavioral, health, and performance] Element is planning to conduct the systematic review in fiscal year 2010.

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Human Cognition and Long Duration Spaceflight

Gary Strangman, PhD

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A literature review on the topic of:

"Changes in Cognition and Psychological Well-being in Isolated, Confined and Extreme Environments"

Produced for NASA's Behavioral Health and Performance (BHP) program element:

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1. Introduction

1.1. Motivation and Overview

Human exploration into remote, unknown environments is inherently dangerous, and this is particularly true for long duration (**LD**) spaceflight. Successful manned space missions are highly dependent on intact cognitive function. However, spaceflight poses numerous potential risks to the brain and cognitive performance. High-energy radiation, toxic gasses, chronic stress, sleep deprivation, hypoxia, temperature extremes, dehydration, fluid shifts, hormone imbalances, and injury were all previously predicted to be critical by Ruff *(1961)*, and are now well-recognized risks of spaceflight *(**Christensen and Talbot, 1986; Grigoriev et al., 2009**)*. Moreover, each such condition—especially in extreme cases—is capable of seriously degrading both brain function and cognitive performance.

Although extreme versions of these conditions are relatively rare, they have occurred in-flight: toxic gasses due to fire, sleep deprivation due to chronic overwork and slam shifting, radiation bursts, dehydration, and more *(Burrough, 1998)*. But even in the absence of extreme events, numerous and ongoing anecdotal reports from spacefarers have described cognitive deficits during flight *(Bluth, 1984; Covault, 1988)*. The cognitive effects are sufficiently commonly reported to engender colloquial monikers such as "space stupids" or "space fog" *(Welch et al., 2009)*. The most regularly mentioned cognitive concerns include difficulty paying attention or concentrating, memory impairments, and generalized mental or motor slowing *(Palinkas, 1992; **Schroeder and Tuttle, 1991**)*. Just over 10 years ago, **Casler and Cook *(1999)*** reviewed the existing experimental literature on cognitive alterations in spaceflight and analogous environments, finding only 10 spaceflight and 19 analog environment experiments that directly address some aspect of cognitive alterations during missions. Of these, only one spaceflight case report and three analog studies were relevant to long duration spaceflight. A substantially larger literature is now available for review, so this paper revisits the topic, focusing primarily on issues relevant to LD missions.

In addition to spaceflight itself, there are numerous isolated, confined and extreme (**ICE**) environments that have been used as experimental analogs of spaceflight. These include Antarctic bases, submarines, various laboratory based isolation chambers, extreme environments (e.g., Mt. Everest, undersea habitats) or voyages of exploration. Each of these environments simulate different aspects of the spaceflight environment: social isolation, confinement with limited recreation options, dangerous ambient or external environments, dramatically altered lighting conditions and circadian cues, sensory restriction, temperature extremes, and so on. Because cognitive performance research conducted in each of these environments has the potential to provide additional insights into the cognitive consequences of LD spaceflight, these environments will also be considered herein.

As an overview, following some introductory remarks, the current findings on cognitive alterations in spaceflight will be reviewed and summarized, followed by relevant analog environments. The review covers English language articles found through electronic searches in PubMed, PsycInfo, Inspec, the NASA Technical Report Server, and the Defense Technical Information Center through January 2010. Search terms included the word cognition, cognitive, or performance along with spaceflight, flight, mission, Antarctica, submarine, deprivation, radiation, stress or closely related terms. Once first-pass articles were identified, relevant studies found in the reference lists of these papers were recursively

included. Separate, more restricted searches were conducted on specific spaceflight stressors (radiation, chronic stress, noise, vibration, toxicology), as these have been identified by multiple researchers as key components to consider regarding cognition in spaceflight. The findings are then summarized according to classic dimensions of cognition (perception, attention, memory, executive function, and so on).

For consistency with previous reviews and reports, long duration missions will be defined as those lasting more than 3 weeks (21 days). However, it must be emphasized that this represents an extremely short time in comparison to proposed spaceflight missions of two to three years duration. As will be seen, there is only limited data from a single individual examining a spaceflight lasting more than 1 year in duration. We sought to broadly construe cognitive performance, to include complex perceptual and motor performance. Treatment of simpler perceptual or motor findings is limited to summaries and references to existing sensorimotor reviews. Throughout the review, key references or reviews appear **in bold**, and findings are specifically interpreted in the context of LD missions. Following the review and summary of findings by cognitive domain, gaps in the existing literature are identified, followed by a series of research recommendations to help fill in these gaps.

1.2. Cognitive assessment approaches

Before reviewing existing studies, the measurement tools used in such work should be discussed. A particularly wide variety of tasks and measures have been utilized for cognition experiments in ICE environments, including spaceflight studies. These measures break down into two broad categories: (1) elemental cognitive tasks, and (2) complex/operational tasks. Elemental cognitive tasks represent a reductionist scientific approach and are intended to identify alterations in specific cognitive abilities as a result of ICE environments—perception, motor control, memory, attention, language, executive function, emotional, or social processing. Example tasks include perceptual discrimination, simple or choice response time (RT), verbal working memory, grammatical reasoning, cognitive set switching, dual-task performance, or facial emotion identification. Because such tasks are designed to identify specific cognitive alterations, they can be quite sensitive. They can also help identify the mechanisms underlying any observed cognitive or performance changes in spaceflight by more narrowly identifying the source deficit. For example, impaired operational performance on the robotic arm could result from basic problems with perception, difficulties with motor control, deficits in working memory, complex reasoning difficulties, or any combination of these. Identifying one or two specific deficit(s) can accelerate the development of targeted countermeasures. Since the precise elemental processes affected by spaceflight are still in the process of being identified, a common approach has been to select a battery of tasks that spans a reasonably large portion of cognitive capabilities. In this way, the suite of cognitive tasks allows one to separate out the relative contributions of each elemental cognitive function.

While clearly of benefit, there are two primary challenges to such a reductionist approach. First, when humans enter poorly understood and dangerous environments, it is unknown at the outset what cognitive functions might be affected and to what degree. This puts significant pressure on test selection for an assessment battery: one must reasonably span the full range of human cognitive abilities, in a sensitive way, and ideally requiring minimal testing time. Numerous attempts have been made at this *(Gawron, 2008)*, including a particularly large, distributed and ongoing effort by the U.S. military ***(Reeves et al., 2007)***. Beginning in the early 1980s, researchers at Walter Reed Army Institute of Research

developed a Performance Assessment Battery (WRPAB), designed to assess the negative impact of sleep *(Thorne et al., 1985)*. Soon after, the Navy developed the Performance Evaluation Tests for Environmental Research (PETER), specifically for applications requiring repeated measurements *(Bittner Jr. et al., 1986)*. The Navy also developed its own performance assessment battery (NMRI-PAB), based on PETER and WRPAB *(Thomas and Schrot, 1988)*. During this same period, the Air Force developed the Criterion Task Set, CTS *(Schlegel and Gilliand, 1990)* followed closely by the NATO-STRES battery (also called the AGARD-STRES battery), a set of seven tasks specifically selected for aerospace and environmental medicine applications *(AGARD, 1989)*. Three other efforts include the Automated Performance Testing System, or APTS *(Kennedy et al., 1985)*, the Performance Assessment Work Station, or PAWS *(Shehab et al., 1998)*, which was flown on space shuttle missions in 1994 and 1996, and the Spaceflight Cognitive Assessment Tool (SCAT), which was converted to a Windows operating system platform for NASA operational use and is now called WinSCAT *(Kane et al., 2005)*. The Automated Neuropsychological Assessment Metrics (ANAM) is essentially, but not precisely, the culmination of these efforts *(Reeves et al., 2007)* and is the primary collection from which more specialized task batteries are often generated. For example, ANAM-ICE is a selection of 6 tests specifically chosen for ICE environment research: immediate and delayed code substitution, logical reasoning, match to sample, continuous performance task, and Sternberg memory scanning *(Palinkas et al., 2007a)*. The WinSCAT is a particularly important ANAM-like sub-battery, incorporating five tasks (mathematical processing, continuous performance test, delayed match to sample, immediate and delayed code substitution) and which is currently in operational use onboard the Shuttle and International Space Station *(**Kane et al., 2005**)*.

After more than 25 years of work, the ANAM continues to be developed and refined. In its current state, each test has multiple parameters to choose for each component test, and tests can be combined "as the application demands". While this provides flexibility, it has two notable drawbacks. First, even some of the default parameter settings are not identical to the settings used when the tests were normed or evaluated for stability, validity and reliability, reducing confidence in test suitability. Second, and as a consequence of the flexibility, selection of an appropriate set of tasks, and parameters for each task, remains part art, part science, and thus puts at risk efforts to combine datasets—such as meta-analyses—that could otherwise boost confidence in findings from multiple research studies completed on small numbers of subjects.

While identifying cognitive deficits using the cognitive/reductionst approach is generally easier than doing so in complex or real-world settings, the reductionst approach has a second fundamental drawback for many observers. In particular, identifying a modest decrement in, for example, verbal working memory, does not provide any useful information about the potential magnitude of deficits in terms of practical, operational performance capability. For example, how serious is a 20% decrement in working memory? It may not affect docking or landing performance at all because of other on-line compensatory mechanisms, continuous visual feedback, or reliance on highly trained motor control capabilities. At the same time, a 5% decrement in simple response time may translate into a 40% decrement in docking or landing accuracy. Hence, for those where the concern about cognition is specifically its effect on *operational* performance, then operational tasks may make a more appropriate performance measure.

Indeed, because of the difficulties in translating elemental cognitive impairments to operational performance, a few researchers have chosen to investigate more complex, operationally relevant tasks. These have included simulated docking *(Savilov et al., 1997; Strangman et al., 2005)*, cabin air management *(Sauer, 2004)*, map reading and coordinate computation *(Haslam, 1984)*, and a variety of other operational tasks *(Gawron, 2008)*. Performance on these tasks is presumed to transfer directly to real operational performance—or at least more directly than elemental cognitive tasks. However, as with elemental cognitive tests, almost no effort has been made to establish any such direct link between test performance and spaceflight operational performance. Moreover, because complex tasks tend to obscure the core source of a deficit—by providing multiple avenues for compensatory behavior—such tasks are considerably less effective pointing the way towards specific countermeasures.

A third alternative is to develop secondary tasks that can be embedded in operational processes *(Christensen and Talbot, 1986; Gawron, 2008)*. The goal here is to enable ongoing, unobtrusive monitoring of cognitive performance in parallel with actual operational performance. While a particularly laudable goal, and of tremendous value from a compliance point of view, such tasks are especially difficult to design to avoid interference with the primary operational activity, and are equally difficult to norm. Hence, no major inroads have been made on this front, either for spaceflight or military operations research.

Today, cognitive assessment methods remain an active topic of discussion: should they be based on elemental cognitive tasks, more operationally relevant tests, actual operational performance, embedded secondary task performance, or some combination of these? As a result, and given that different research questions demand different task types, the studies reviewed below have employed a wide variety of tasks. Both elemental cognitive tests and operational tests have their roles, as well as their drawbacks. These pros and cons need to be kept in mind when evaluating the associated research.

Finally, there are a few additional key considerations for any test or test battery. Optimal tests will (1) have no ceiling or floor effects *(Cowings et al., 2007)* which, importantly, can occur at points well away from 100% or 0% accuracy, (2) have high test-retest reliability, (3) have high construct validity (i.e., the test measures the intended cognitive capability), (4) have high responsiveness (i.e., sensitivity to the variables relevant to spaceflight), and (5) have minimal sensitivity to learning effects, or an exceptionally well understood learning curve. Most of these issues have been considered in the process of selecting and developing ANAM tests. Nevertheless, learning confounds are still commonly observed. Tests outside the ANAM set—particularly the more complex, operational style tests—often have not been fully evaluated on these key considerations. Finally, even optimal tests need to be coupled with proper experimental design and include appropriate control groups. As will be seen below, even when well-characterized and understood tests are used, learning confounds and control group considerations plague numerous spaceflight and analog studies.

2. Early Adaptation Effects

Transitions to and from microgravity are associated with numerous adaptive processes. Excellent reviews have been written about these early sensorimotor adaptation effects—collectively known as space adaptation syndrome (SAS)—which include space motion sickness *(Lackner and Dizio, 2006;* ***Reschke et al., 1996****; Slenzka, 2003)* as well as vestibular and proprioceptive sensory alterations, compensatory eye movements including the vestibulo-ocular reflex, the otolith-ocular response, optokinetic nystagmus, visual-vestibular interactions associated with posture and locomotion, and the resultant effects on perceptuomotor performance *(Bock, 1998; Fowler and Manzey, 2000; Oman, 2002; Reschke et al., 1998; Reschke et al., 1996)*. Adaptation effects tend to be most prominent on the first day after liftoff and generally represent the physiological response to dramatically altered input to the vestibular and proprioceptive systems, as well as the altered forces on the body. Space motion sickness is generally viewed as the most operationally disruptive of these effects, producing symptoms of malaise, loss of appetite, lack of initiative, nausea, vomiting and drowsiness over the first several days in space. These effects are related to the individual adapting to the loss of linear vestibular input and the altered physical forces on the astronaut's body *(Kanas and Manzey, 2008; Reschke et al., 1996)*. One exception that has been noted is a 5-30% decline in visual function and an up to 40% decline in visual contrast sensitivity in flight *(Nicogossian and Parker, 1982)*.

In most cases, SAS alterations appear to dissipate after 1-3 weeks in space *(Reschke et al., 1998; Reschke et al., 1996)*, suggesting minimal concern for long-duration spaceflight. However, there appears to be considerable inter-individual variability in adaptation. Moreover, there have been reports where flyers have had continued alterations after 30 days in space. Examples include visual illusions (in up to 7% of flyers throughout 96-365 days of flight), anomalous spontaneous and evoked eye movement reactions beginning after 30 days in flight, altered perception of the subjective vertical, and sensitization of the vestibulospinal tendon reflex in up to 241 day missions *(Reschke et al., 1996)*. In addition, vection (the perception of body motion from visual input) was altered in 145 and 175 day flights *(Reschke et al., 1996)*. While these effects appear to represent changes primarily in basic perceptual input or motor output—and hence are outside the scope of this review—they need to be considered when evaluating performance on cognitive tasks that depend on such inputs or motor outputs.

Returning to a gravitational environment re-starts the adaptation process, roughly in reverse. Thus, adaptive processes similar to SAS also occur following landing, including intense dizziness and queasiness with head motions, particularly following long-duration (176-438 day) flights *(Reschke et al., 1996)*. In this case the time constant of recovery is generally related to the duration of the stay in space, with longer duration flights generally associated with longer recovery periods *(Reschke et al., 1996)*. Unfortunately, it is not known how to extrapolate from our current datasets to the postflight effects of exceptionally long duration missions such as a two and a half year mission to Mars.

3. Spaceflight Studies

3.1. Overview

Table 1 lists the 31 spaceflight studies that included cognitive performance measures, sorted from longest duration to shortest. The longest duration study to date was a case study conducted as part of the record holding 438-day flight of Dr. Vasily Polyakov. Including that case study, only 6 cognitive studies with a duration exceeding 90 days have been published, and a total of only 10 with durations exceeding 21 days. Included in the table is a level-of-evidence rating. This rating is based on Department of Health and Human Services publications and are characterized as follows:

Level IA: evidence from a meta-analysis of randomized controlled trials (RCTs)

Level IB: evidence from at least one RCT

Level IIA: evidence from a controlled study without randomization

Level IIB: evidence from a quasi-experimental study

Level III: evidence from descriptive, correlation, case-control studies, and case reports

Level IV: evidence from expert committee reports or opinions

Based on these levels of evidence, levels IA and IB are particularly difficult to achieve in spaceflight, since random assignment in spaceflight is difficult. Level IV evidence is excluded from the tables in this review, though such evidence is cited as appropriate. The ratings provided in the tables were based on the study design and hence do not attempt to reflect the importance or influence of potential confounder variables. Thus, the ratings can generally be considered best case or optimistic ratings.

Table 1: Spaceflight studies involving cognitive performance measures.

Duration (days)	Subjects	Controls	Repetitions	Level of Evidence	Cognitive measures	Early Impairment	Late Impairment	Other measures	Findings	Reference
438	1 cosmonaut	None	4 preflight, 29 inflight, 6 postflight	III	Grammatical reasoning, Sternberg memory search, unstable tracking, dual-task	yes	no	mood, workload	Poor performance in first 2-3 weeks after launch and after landing; otherwise quite stable	*(Manzey et al., 1998)*
194	8 cosmonauts	3 backup crew, plus 1 more	2-4 preflight, 3-6 inflight, 1-5 postflight	IIA	Mental rotation	yes	yes	n/a	Flight participants more variable than controls; no facilitation; learning effect in evidence	*(Leone et al., 1995b)*
189	5 astronauts plus 8 cosmonauts	58 mission controllers	weekly sessions pre-, in- and post-flight	IIB	POMS (self-report)	no	no	n/a	Flyers gave low ratings to forgetful and unable to concentrate; no 3rd quarter effect, or evidence of asthenia	*(Kanas et al., 2001)*
180	5 cosmonauts	15 subj, tilt chair	3 preflight, 1-8 inflight, 3 postflight	IIA	Oriented line memory	no?	no	n/a	Visual orientation uses multiple frames of reference (retinal, head/body, gravity); adaptation over time in 0g (variable across cosmonauts)	*(McIntyre et al., 2001)*
172	3 cosmonauts (missions: 9-d, 144-d, 172-d)	None	3-7 preflight, 2-9 inflight, 2 postflight	IIB	Pointing arm movements (accuracy and kinematics), AFTER adaptation to microgravity	motor	motor	n/a	Accuracy maintained but movement durations increased significantly in all flight sessions compared to preflight; argues against visual-guidance hypothesis (acceleration & velocity slowed)	*(Berger et al., 1997)*
180	3 astronauts	2 ground controls	3 preflight, 3-6 inflight, 3 postflight	IIA	Timing (continue tapping a steady rhythm)	perception, motor	perception, motor	n/a	Undershot target timing intervals in flight; variability increased; no trends over time in-flight	*(Semjen et al., 1998a)*
84	2 astronauts	None	performance of 120 tasks inflight	IIB	Crew efficiency rating (tasks accomplished / man hours available)	yes	no?	n/a	Relatively stable increases over mission days; probable learning effect	*(Garriott and Doerre, 1977)*

84	6 astronauts (two per Skylab crew)	None	31,900 feet of preflight film; 10,650 feet of inflight film	IIB	Duration to complete repeated tasks (food prep, EVA suit don/doff, experiment M092, etc)	yes	no	n/a	Behavioral performance (time on task) improved through each mission; no evidence of performance deterioration; first in-flight performance took longer than last pre-flight performance	*(Kubis et al., 1977)*
27	2 astronauts	1 backup crewmember	3 preflight, 5-6 inflight, 3 postflight	IIB	Timing (continue tapping a steady rhythm)	motor	motor	n/a	More variable timing in one, trend in second subj. (timekeeper variability increased)	*(Semjen et al., 1998b)*
26	3 astronauts	3 backup crew, plus 6 more	3 preflight, 5-6 inflight, 3-4 postflight	IIA	Mental rotation	no	no	n/a	No change, or even /facilitated/ rotation; probable learning effect	*(Matsakis et al., 1993)*
21	1 cosmonaut	None	7 preflight, 6 inflight, 6 postflight	III	Step-tracking kinematics	motor	----	n/a	Kinematic changes of small finger movements in microgravity	*(Sangals et al., 1999)*
20	1 astronaut	None	6 preflight, 6 inflight, 6 postflight	III	Manual tracking	motor	----	n/a	Impaired accuracy (early= adaptation, late assumed to be attention/workload/fatigue); Heuer did model-based analysis, "stiffness" parameter lower in spaceflight (slower movements)	*(Heuer et al., 2003; Manzey et al., 2000)*
18	4 astronauts	None	24 preflight, 9 inflight, 5 postflight	IIB	PAWS: unstable tracking, spatial matrix rotation, Sternberg, continuous recognition memory, directed attention, Fittsberg	memory	----	mood, fatigue	No main-effect impairments; two astronauts impaired on math processing, one on spatial memory; circadian effects?	*(Eddy et al., 1998)*
18	1 cosmonaut	None	6 preflight, 7 inflight, 5 postflight	III	Unstable tracking	motor	----	n/a	Model-based analysis; "stiffness" parameter lower in spaceflight, meaning slower movements in-flight	
16	6 astronauts	None	7 preflight, 3 inflight, 3 postflight	IIB	Pointing, unstable tracking	motor	----	n/a	Pointing slowed even without hand vision (not a visual feedback problem), relatively little change in tracking	*(Bock et al., 2001)*

16	4 astronauts (plus 2 partial datasets)	None	7 preflight, 3 inflight, 3 postflight	IIB	Pointing, grasping, unstable tracking and RT tasks	perception, motor	----	n/a	Slowing for pointing and grasping tasks (no change in accuracy); no slowing for RT or tracking (but both of those demanded speed and may have had larger errors)	*(Bock et al., 2003)*
16	3 cosmonauts	None	3 preflight, 3 inflight	IIB	Face perception and learning	no	----	n/a	Gravity not relevant to inversion effect (retinal basis)	*(de Schonen et al., 1998)*
16	6 astronauts	None	3 preflight, 3 inflight, 3 postflight	IIB	Dual-task: unstable tracking + RT task	motor	----	n/a	More variability in RT and errors	*(Fowler et al., 2000)*
13	3 astronauts	None	24 preflight, 13 inflight, 3 postflight	IIB	PAWS: unstable tracking, spatial matrix rotation, Sternberg, continuous recognition memory, directed attention, Fittsberg	motor	----	n/a	Compared to pre-flight learning curve predictions: degradations of tracking, dual-task and attention-switching in 2 of 3 subjects; effects associated with fatigue (beginning/end)	*(Schiflett et al., 1995)*
13	4 astronauts	96 ground subj	24 preflight, 9 inflight, 4 postflight	IIA	PAWS: unstable tracking, spatial matrix rotation, Sternberg, continuous recog memory, directed attention, Fittsberg	attention	----	n/a	Compared to pre-flight learning curve predictions (based on controls): degradations of attention-switching in 2 subj; tracking OK or improved (in 1 subj)	*(Schiflett et al., 1998)*
11	2 astronauts	13 pilots	2 preflight, 2 inflight, 2 postflight	IIA	Color-word Stroop, general emotional Stroop, specific emotional Stroop	emotion	----	n/a	Accuracy drop on emotional material; attributed to high workload	*(Pattyn et al., 2005)*
10	4 astronauts	None	5-6 preflight, 5-6 inflight, 6-9 postflight	IIB	Time estimation, sequence learning, symbol substitution, number recognition	perception, memory	----	POMS	Digit-symbol substitution and number recognition response rates slowed … no other cognitive effects; BUT subjects both fatigued *and* aroused	*(Kelly et al., 2005)*
10	8 cosmonauts	None	1-4 preflight, 1-4 inflight, 1-4 postflight	IIB	Polygon symmetry detection, mental rotation	no	----	n/a	Mental rotation unchanged, symmetry estimation slightly changed	*(Leone et al., 1995a)*
10	1 astronaut	None	7 inflight	III	Observe movement & orientation	perception, motor	----	n/a	Perceptual disturbances, compensated for by sensorimotor learning	*(Tafforin and Lambin, 1993)*

8	1 astronaut	None	6 preflight, 13 inflight, 4 postflight	III	Grammatical reasoning, Sternberg, unstable tracking	motor	----	n/a	Fine motor control problems, no cognitive decrements (despite sensitivity)	*(Manzey et al., 1993)*
8	1 astronaut	None	6 preflight, 13 inflight, 4 postflight	III	Unstable tracking, Sternberg, dual-task (tracking+Sternberg)	motor, attention	----	n/a	Memory unaffected, single/dual tracking affected, argued as related to workload/fatigue	*(Manzey et al., 1995)*
8	4 astronauts flight, 4 astronauts capsule	None	3 preflight, 4 inflight, 3 postflight	IIB	MWPE: sternberg, unstable tracking	motor	----	n/a	Degraded (slowed) motor performance but NOT cognitive performance	*(Newman and Lathan, 1999)*
8	5 astronauts	None	2 preflight, 2-3 inflight, 2-3 postflight	IIB	Video subjects shaking pairs of masses to identify the heavier one	perception	----	n/a	Discrimination deteriorated during flight; adaptation (and re-adaptation) took several days	*(Ross et al., 1987)*
7	2 astronauts	None	2 preflight, 6 inflight	III	Body orientation perception, mental rotation, writing his name	perception	----	EMG	Altered orientation perception, mental integration of passive orientation changes affected; mental rotation improved	*(Clement et al., 1987)*
6	1 cosmonaut	None	4 preflight, 3 inflight, 2 postflight	III	CogiMIR: simple RT, complexRT, arrows, visual perception, time estimation, spatial WM	no	----	n/a	No significant differences	*(Benke et al., 1993a; Benke et al., 1993b)*
5	4 astronauts	None	2 preflight, 3 inflight, 2 postflight	IIB	Simple RT, choice RT, time estimation	perception, motor	----	SMS	Time estimation altered (too-long for 2sec intervals, too-short for 16 sec intervals); RT associated with SMS	*(Ratino et al., 1988)*

Table 1 shows 9 studies at level III (all case reports), 16 at level IIB, and 6 at level IIA. For a graphical summary of the published cognitive research, see the three curves in Figure 1 (and inset). The black curve represents the total number of spacefarers reaching each flight day (data from **House *(2009)***, supplemented by data from http://www.spacefacts.de), and represents the maximal potential set of cognitive experiment participants through January 2010. The x-axis extends to 900 days, since that is the approximate duration of a two and a half year Mars reference-mission. The red curve represents the actual number of crewmembers tested on a least one cognitive measure on each flight day. This curve is more clearly visible in the figure inset. The blue curve represents the total number of crewmembers on flights with an active cognitive experiment aboard, thus representing the total potential subject pool based on the experiments that were flown. Note that sampling is extremely low in terms of subjects run after flight day 21 (red). Note also that the co-availability of participants and a cognitive experiment (blue) essentially disappears in flights with durations greater than 180 days.

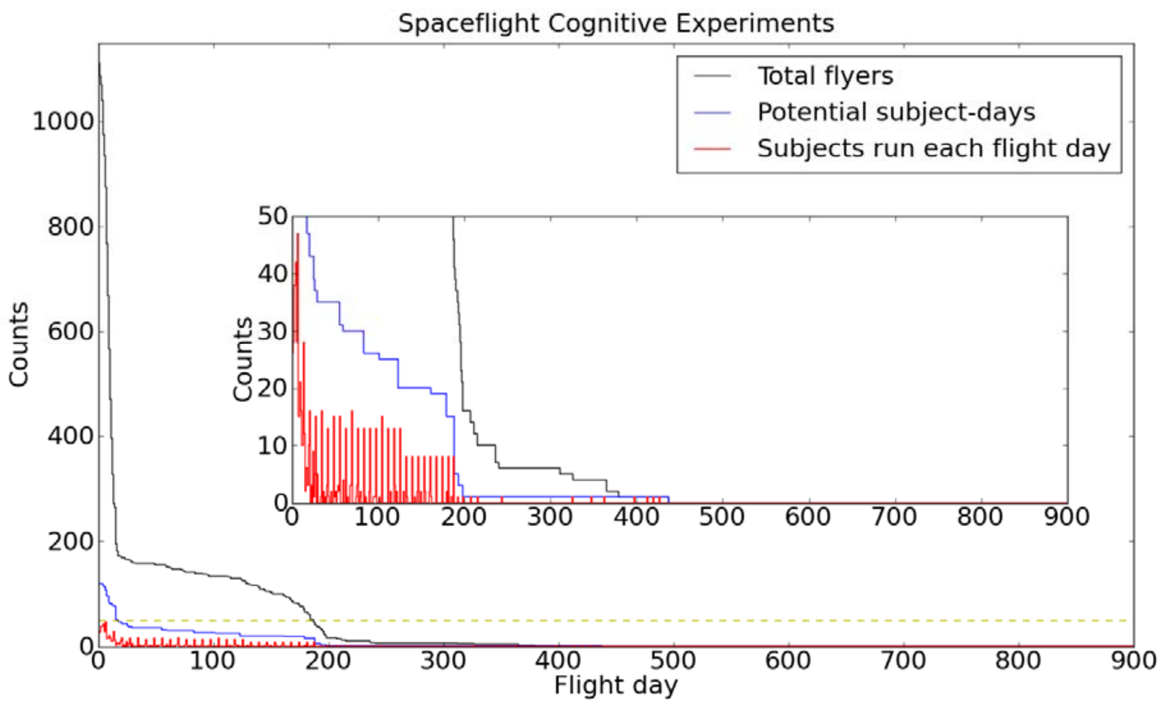

Figure 1: Spaceflight cognitive experiment data collection as compared to total spaceflight experience. The x-axis extends out to 900 days—the approximate duration of a proposed Mars mission—although the last data point available occurs at 438 days. The number of subjects participating in cognitive experiments during spaceflight for each post-launch flight day is shown in red (data from studies in Table 1). The total number of crewmembers aboard flights hosting cognitive experiments is shown in blue (again, data from studies in Table 1). Black indicates the total number of spacefarers as a function of flight duration for flights through January 2010 (data from House *(2009)*, supplemented by information found at http://www.spacefacts.de). The area below the dashed line in the main figure is blown up in the figure inset. Two gaps are represented by the figure. The gap between the black and blue curves represents the gap between all flights and those flights with cognitive experiments on-board—that is, an "**experiment availability gap**". The gap between blue and red curves represents the gap between potential cognitive subjects on that flight-day and the actual number of subjects participating on that day—in essence, a "**recruitment gap**".

Not represented in Figure 1 is the fact that different experiments involved different test types, or tested different cognitive capabilities. Thus, the data collection represented by the red curve in Figure 1 is further fragmented across three broad domains: (1) cognitive tasks (e.g., grammatical reasoning, tracking, mental rotation, working memory, time estimation, operational task performance, and emotional processing), (2) complex perceptuomotor tasks, and (3) surveys with questions about cognitive status. The partitioning of the red curve from Figure 1 into these three domains is shown in Figure 2, where subjects from these test types are "stacked" atop one another. Yellow spikes represent weekly surveys using the Profile of Mood States (**POMS**) in a study by Kanas and colleagues *(2001)*. The small red spikes reaching out past day 400 represent the cognitive assessments of Dr. Polyakov.

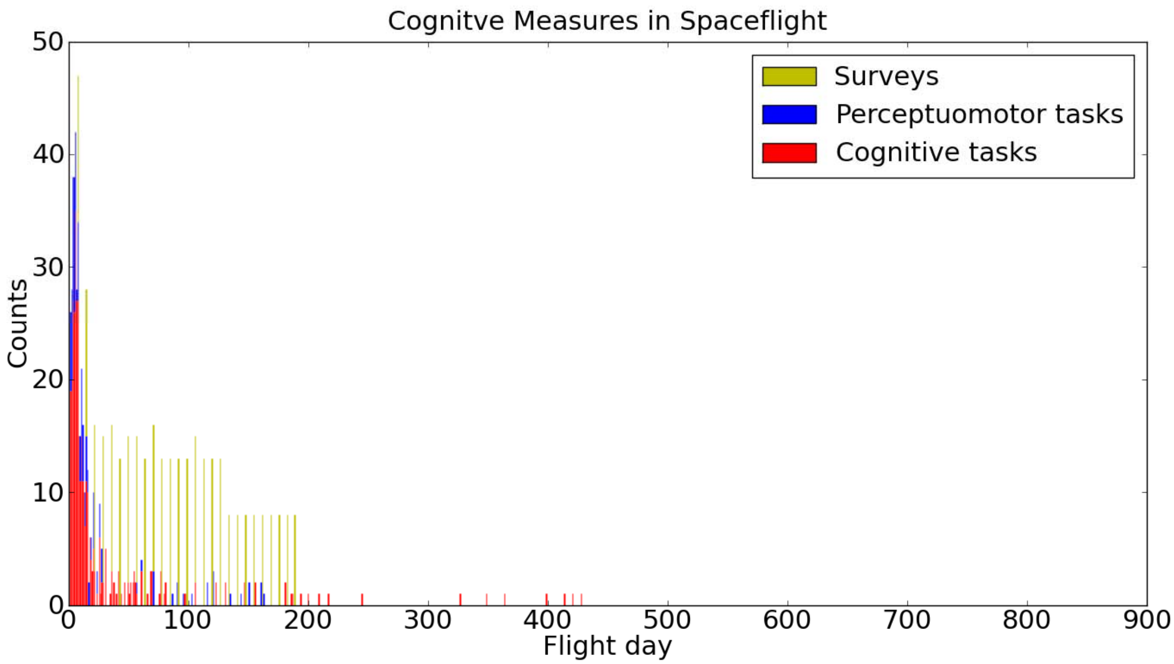

Figure 2: Partitioning of the spaceflight studies from Table 1 into cognitive testing, complex sensorimotor testing, and surveys. The cognitive tasks are further broken down into cognitive domains in Figure 6.

3.2. Very Long Duration Studies (90+ days)

The number of studies and number of research participants in very long-duration (90+ day) spaceflight studies remains quite low. However, there are a few findings to discuss. To begin, the 438-day flight of Dr. Polyakov included a subset of four AGARD-STRES cognitive tasks along with mood and workload questionnaires, all collected at 4 preflight, 29 in-flight, and 6 post-flight time points ***(Manzey et al., 1998)***. Performance on most measures was impaired in the first 14-21 days after launch and again after landing, coinciding with periods of high workload, high stress, and early adaptation. Cognitive performance over the intervening 13+ months of spaceflight, however, was quite stable. Performance during this period was, in fact, equivalent to post-flight performance following re-adaptation. While this represents only a single subject, the study provides an existence proof that, at least for one individual, on this flight, and on those selected tasks, cognitive performance could be maintained over extended periods in microgravity. The argument that compensatory mechanisms or motivation counteracted any

impaired or steadily deteriorating performance over time is undercut by the maintenance of an essentially flat performance curve across 25 separate tests spanning nearly 400 days. As for the selected tasks (grammatical reasoning, Sternberg memory search, unstable tracking, dual-task memory search and tracking), these have previously been shown to be affected by environmental effects such as sleep loss, time of day, and pollution, among others *(Englund et al., 1987; Perez et al., 1987; Poulton et al., 1978)*, thus suggesting reasonable sensitivity. It must be stressed, however, how unwise it is to generalize the cognitive performance of a single individual to spaceflight participants in general.

Five additional papers have described results from spaceflights of greater than 90 day duration. First, Leone et al. *(Leone et al., 1995b)* tested mental rotation in eight cosmonauts on flight durations up to 194 days, using backup crewmembers as controls. They found evidence of a learning effect, such that mental rotation became faster during the mission. This provides evidence for at least partially intact implicit learning in spaceflight. However, the learning effect unfortunately complicated interpretation of mental rotation performance, which potentially could have been deteriorating in the absence of learning. Second, in a study of asthenia, Kanas et al. *(2001)* administered the POMS questionnaire weekly to 5 astronauts (119-133 days in space) and 8 cosmonauts (175-203 days in space), as well as 58 American and Russian mission control personnel. This represents the largest study with even an indirect cognitive measure in LD spaceflight. Flyers rated the two cognitive items “unable to concentrate” and “forgetful” (attention and memory, respectively) close to the “not at all” end of the rating scale. Hence, this study did not support previous anecdotal accounts of memory and attention deficits, although it involved subjective self-report measures. In the third LD spaceflight study, McIntyre et al. *(2001)* had 5 cosmonauts and 15 control subjects perform tests of short term memory for oriented lines. Two of the cosmonauts, both repeat flyers, performed the task seven times over their 6 month stay in orbit. Although the study was targeted at identifying frames of reference, after the first few weeks, both LD flyers demonstrated “similar” response times and variability during the course of their flight, again suggesting relatively intact orientation perception and working memory. Fourth, Berger et al. *(1997)* examined point-to-target arm movements in three cosmonauts during flights of 10, 140 and 172 days duration, respectively. Using the MONIMIR infrared movement recording system, the cosmonauts performed the task pre-flight, in-flight, and post-flight. Accuracy remained high throughout, but movement was significantly slowed in-flight, along with a reduction in peak velocity. This finding was consistent across both short and long duration flights. Finally, using a motor tapping task designed to evaluate internal timing, Semjen et al. *(1998b)* tested two long-duration astronauts and two ground-control personnel during a 180 day flight. Astronauts undershot the target timing intervals and exhibited increased variability in tapping throughout the flight, with no additional in-flight trends.

In addition to these specific studies, Gazenko *(1987)* summarized early results from long duration Russian studies as follows: “Results of medical investigations and observations carried out in short- and long-term space flights have demonstrated that man can efficiently work in orbital flights of up to 8 months in duration. His work capacity remains adequately high at essentially every flight stage. This is confirmed by the successful performance of complex manoeuvres (sic) and docking of transport vehicles and the station at the stage of acute adaptation, performance of extravehicular activity at different flight stages (including flight months 6-7) with moderate physiological changes as well as adequate tolerance to provocative, e.g. exercise, tests.” The level of evidence supporting these statements is

unclear, however, and contemporaneous reports suggest continued cognitive alterations in the Russian program *(Bluth and Helppie, 1986)*.

Altogether, the very long duration studies in Table 1 involved a grand total of 28 long-duration participants, and included studies on four AGARD-STRES tasks (grammatical reasoning, memory search, unstable tracking, and dual-task performance; N=1), mental rotation (n=8), POMS questionnaires (n=13), arm pointing movements (n=2), oriented line memory (n=2) and timed tapping (n=2). The coverage of any particular cognitive function was thus vanishingly small, and as a result no conclusions can be drawn about cognitive performance in spaceflight exceeding 90 days in duration. That said, the slowing of arm pointing movements, time underestimation, and increased motor variability exhibited mildly consistent evidence of continued alteration for the duration of the flight. These were separate from early adaptation, and hence warrant further investigation. Note that a "very long duration" study of 90 days would still represent merely one tenth the duration of a proposed Mars mission, and even the longest running flight experiment ever (438 days) was less than half the proposed duration of a Mars mission.

3.3. Long Duration Studies (22-90 days)

An additional four studies have been conducted which would be characterized as long duration based on previous definitions. In the first, Garriott and Doerre *(1977)* examined crew operational efficiency in performing 120 spaceflight tasks during the 84-day Spacelab 4 mission. Operational efficiency was defined as the number of tasks accomplished divided by total man-hours available to accomplish them. They found relatively steady increases in efficiency during the flight, attributed to the waning of initial motor and physiological adaptation processes. This measure, however, is likely influenced by task-specific learning effects (e.g., learning how to manipulate objects in 0g, how to efficiently use the stowage facilities, where to find the handles, how to operate the fasteners, etc.). In six astronauts, two for each of three Spacelab flights, Kubis and colleagues *(1977)* quantitatively compared some 31,000 feet of preflight video with some 10,000 feet of in-flight video to measure the time required for performing a large number of operational tasks. Again, performance (time on task) improved as the mission progressed, though the first in-flight performance took longer than the last pre-flight performance, suggesting interference by early adaptation effects. While painstakingly quantified, this measure is also likely affected by task-specific learning effects. Third, Semjen and collaborators *(1998b)* performed a motor timing task much like the one for the 180 day flight described above, but during a 27 day mission. They found increased tapping variability throughout the mission, with evidence that the variability was related to the internal timekeeping mechanism rather than pure motor variability. Finally, Matsakis et al. *(1993)* tested mental rotation in 3 astronauts over a 26 day mission and found no change or even slightly facilitated rotation in-flight, mirroring the results of Leone et al. *(1995b)*. However, again lacking controls, it is possible the facilitation is due to practice with mental rotation in flight—given the constant need to compensate for the orientation of oneself, one's environment, and other crewmembers—and that cognitive performance was actually deteriorating.

In this range of flight durations there were 11 distinct participants. They exhibited early performance degradation followed by improved operational efficiency and time on task (n=6), stable or improving mental rotation abilities (n=3), and a sustained increase in motor timing variability (n=2).The former two observations of improvements—while operationally relevant— were confounded with potential learning effects and a lack of suitable controls.

3.4. Short Duration Studies (less than 22 days)

Finally, some 21 short-duration studies were identified (cf. Table 1). Collectively, these studies provide reasonably consistent evidence for reductions in motor speed, at least when complex motor performance is required (e.g., more than just pressing a single button). When speed is forced to be constant, as in a tracking study, reductions in accuracy are observed. And, there are clearly alterations in perception, particularly as relates to the first few days of spaceflight adaptation. There is variable support for alterations of attention *(Manzey et al., 1995; Manzey et al., 2000; Schiflett et al., 1998)* and memory *(de Schonen et al., 1998; Eddy et al., 1998; Kelly et al., 2005)* in flight. Though only data from one study, there is a suggestion that stimuli which are emotionally related to current personal or flight conditions are more difficult to process *(Pattyn et al., 2005)*. This is intriguing, given the common reports of affective changes during spaceflight *(Kanas and Manzey, 2008)*. Unfortunately, several of these short duration studies were confounded by potential effects of sleep deprivation/fatigue *(Eddy et al., 1998; Kelly et al., 2005)*, workload *(Manzey et al., 1995; Pattyn et al., 2005)* or learning effects *(Tafforin and Lambin, 1993)*. Perhaps the most consistent finding from cognitive studies of less than three weeks duration is that there is considerable inter-individual variability in cognitive performance in response to spaceflight. This is a particularly important issue to consider, given that our current knowledge about cognitive performance in LD spaceflight—described above—is based on an exceedingly small number of subjects. Hence, it would appear particularly unwise to extrapolate or generalize the findings from the existing small numbers of studies and subjects on LD missions.

3.5. Summary and Conclusions

To date, no study has conclusively demonstrated a major adverse effect of LD spaceflight on cognitive performance. However, this is a negative finding based on extremely small numbers of subjects. The frequent learning confounds and general lack of control subjects severely limits our ability to make positive conclusions or inferences. Thus, there remains a substantial mismatch between the frequency of anecdotal reports describing generalized cognitive slowing, attention and memory problems *(Schroeder and Tuttle, 1991)*, and the experimental evidence supporting such deficits. Motor slowing and increases in at least motor variability appear to be an ongoing concern for LD spaceflight, though it is unclear whether this is localized to the motor system, or if it is related to perceptual, attentional, or cognitive processes that drive motor outputs. Even less evidence exists for the remaining concerns, in large part due to fewer studies conducted on more purely cognitive functioning.

Based on the available research, it is possible that such effects have not been observed due to the high level of between-subject variability. Even moderately large cognitive effects could have been missed given the extremely low power of published studies, and particularly so if individual variability plays as substantial a role, as the available literature suggests. Enhanced variability could arise from a number of sources, including individual variations in physiological adaptation to spaceflight, individualized stress responses to spaceflight, perceptual sensitivity differences, or variability in plasticity. Alternatively, or in addition, numerous relevant conditions vary across spaceflights—e.g., workload, sleep schedules, medication use, personality conflicts—and these may have contributed substantial spaceflight stress variability and thereby reduced test sensitivity. Currently, however, the available evidence fails to either support or refute the existence of cognitive deficits in LD spaceflight.

4. Analog Environments

Ideally, one would like to supplement the dearth of spaceflight information via ground-based studies. One important approach to look for further insights into cognitive deficits during long duration spaceflight is human performance in environments that are in some way analogous to spaceflight. Numerous analog environments have been utilized to approximate the conditions in spaceflight *(**Harrison et al., 1991**; Sauer et al., 1997; Stuster, 2005)*, each of which will be examined in turn.

4.1. Historical expeditions

Stuster has provided excellent summaries of the psychological and psychosocial effects of expeditions through the centuries *(**Stuster, 2000**)*. Several such expeditions closely resemble long duration spaceflight in that they were of suitably long duration (one or more years) and involved severe isolation and confinement, dangerous external environments, and substantially altered lighting, nutrition, fluid intake, and exercise. There appear to be moderately predictable neuropsychological and psychosocial effects on such voyages and, as with spaceflight, anecdotal reports of cognitive alterations have been reported *(Stuster, 2005; Stuster, 2000)*. From a cognitive point of view, these reports again tend to include inability to concentrate and memory difficulties, the most commonly voiced concerns during spaceflight. Controlled research studies, as might be expected from voyages of exploration, were generally absent from such accounts.

4.2. Antarctica

One of the most commonly cited and utilized analogs for spaceflight are Antarctic stations, and particularly wintering-over. These analogs are perhaps uniquely comparable to spaceflight given the extended periods of altered ambient light, harsh and dangerous environment, remoteness, isolation and confinement. The smaller stations (e.g., Concordia) provide an even better simulation, given the more extreme social isolation and more limited recreation and sensory opportunities. Numerous reviews have been written on the general effects of wintering over, which typically include fatigue, gastrointestinal alterations, headaches, multiple sleep disturbances, intellectual inertia, negative affect, and interpersonal conflict *(Harrison et al., 1989; Lugg, 2005; Olson, 2002; Palinkas, 1992)*. Specific cognitive complaints consistently include memory impairment, difficulty concentrating, and reduced alertness *(Palinkas and Suedfeld, 2008)*. One of the first studies utilized interviews of Antarctic personnel and reported a wandering of attention, reduction in awareness, and memory impairments *(Mullin, 1960)*. Similarly, Palinkas and colleagues *(1992)* reported that some 51% of individuals wintering over at Antarctic stations report memory and/or attention difficulties, which again is consonant with reports from spaceflight participants. From the available literature and supplementary reviews, some 15 Antarctic studies were identified that utilized a cognitive performance measure that might provide evidence to support or refute these self reports; these are listed in Table 2. The number of subjects participating in cognitive experiments in Antarctica as compared to spaceflight appears in Figure 3.

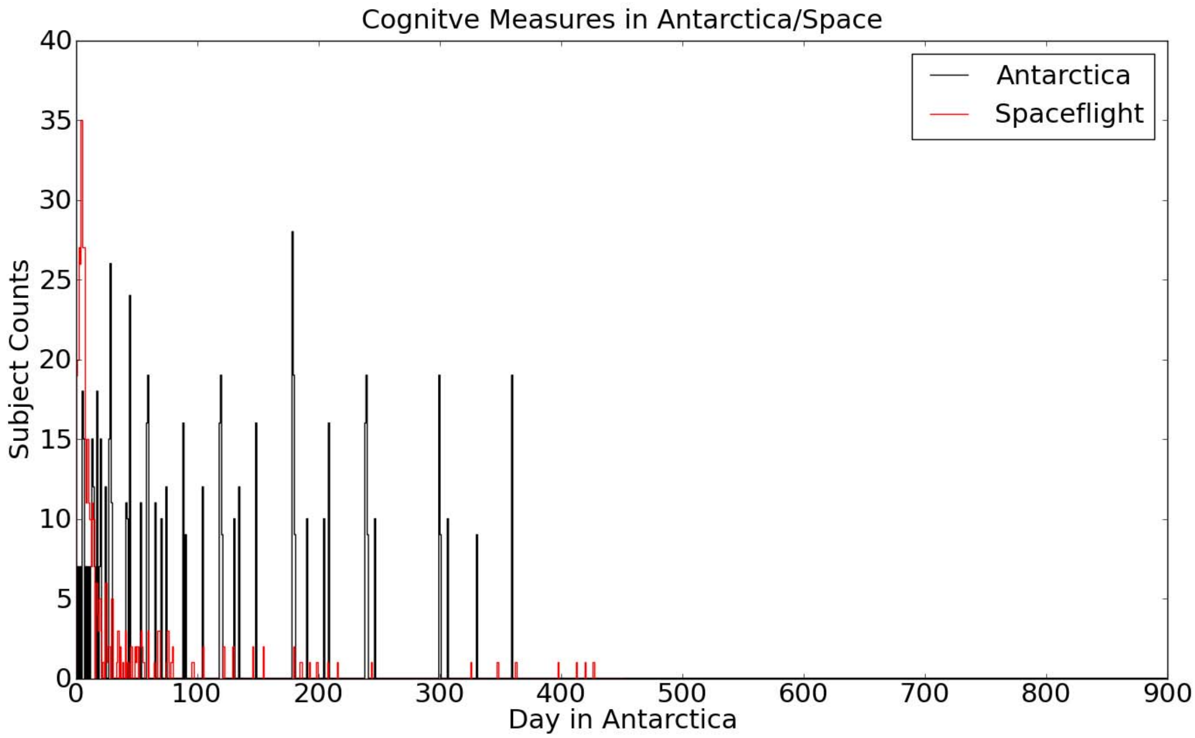

Figure 3: Comparison of the cognitive testing profile for Antarctic studies (black) as compared to spaceflight (red; matching the red curve in Figure 2). Antarctic data is derived from studies in Table 2, excluding those for which data collection schedules were not reported or where data was collected exclusively pre-/post-Antarctic stays, which includes a substantial study by Palinkas et al. *(2007b)*.

Table 2: Antarctic analog studies involving cognitive performance measures

Duration (days)	Subjects	Controls	Repetitions	Level of Evidence	Cognitive measures	Impairments due to environment	Other measures	Findings	Reference
370	19 men	None	1 pretest, 6 during (every 2 months)	IIB	Kraepelin Test (continuous math addition)	?	emotional status	Improved efficiency and (contrary) decreased work capacity; explained by increased capability for "burst" performance at start of 1-hr test; unrelated to emotional status	*(Terelak et al., 1985)*
365	9 subj	None	1 pretest, 1 posttest	IIB	Taste perception	no	letter-string recall, time estimation	No changes in perception; did not report results of working memory or time estimation tasks	*(Gregson, 1978)*
300	16 men	None	6 during (approx. monthly)	IIB	AGARD: complexRT, Sternberg, unstable tracking, dual-task	?	interpersonal issues	Cognitive testing related to interpersonal evaluations; no longitudinal cognition data reported	*(Rosnet et al., 2000)*
185	12 subj	12 at-home controls	1 pretest, 3 during, 1 posttest	IIA	Mental paper folding test, series completion	no	n/a	No significant differences	*(McCormick et al., 1985)*
300	10 scientists	6 technical personnel	5 pretest, 8 during	IIB	AGARD: complexRT, Sternberg, unstable tracking, dual-task	no	n/a	Major difference between techs and scientists, rest is messy	*(Le Scanff et al., 1997)*
250	85 crew (all)	None	? during	III	Interviews	attention, memory	n/a	Wandering of attention, reduction in alertness and awareness (requires further study); memory impairments	*(Mullin, 1960)*
250	100 summer, 85 winter-overs	None	1 pretest, 1 posttest	IIA	ANAM-ICE	no	physiology	No cognition differences (also testing McMurdo vs. South Pole station)	*(Palinkas et al., 2007a)*
250	10 scientists, 6 technicians	None	2 pretest, 8 during, 2 posttest	IIB	CAMS (life support)	yes	n/a	"Hidden" performance deficits (expected learning, but saw none)	*(Sauer et al., 1999b)*

250	12 scientists	12 at-home controls	not reported	IIA	Necker Cube, motified Stroop, time estimation, Vigil digit memory and string-of-digits comparison, simpleRT, mental paper-folding	no	n/a	No cognitive changes in evidence	*(Taylor, 1991)*
250	15 personnel at Scott base	24 police recruits	4 tests (1/week)	IIA	Mental paper folding	yes	n/a	Slower completion times in winter-over personnel than recruits	*(Barabasz et al., 1984; White and Taylor, 1984; White et al., 1983)*
140	12 McMurdo winter-overs	RCT	1 baseline, monthly testing	IB	Match-to-sample	memory	thyroid	T4G=normal, placebo=MtS impaired	*(Reed et al., 2001)*
138	65 summer-/winter-overs	RCT	1 pretest, 1 posttest?	IB	ANAM-ICE	no	mood, hormones, lipids	Complex tasks improved, not simple	*(Palinkas et al., 2007b)*
90	33 at Scott Base	None	1 pretest, 1 posttest	IIA	Vigil97 (digit span, visual discrimination)	perception	n/a	No worsening; more visual differences detected after winter-over; learning confound?	*(Taylor and Duncum, 1987)*
71	11 subj	None	1 pretest, 6 during, 1 posttest	IIB	Working memory, visual discrimination, Stroop, necker cube, time estimation, simpleRT	no	n/a	Steady improvements over time, attributed to a learning effect or "subject motivation"	*(Defayolle et al., 1985)*
21	4 men, 3 women	None	1 pretest, 3 weekly tests during	IIB	POMS (self-report)	no	n/a	Modest improvements over time	*(Palinkas et al., 1995)*

NOTES: The 250-day sessions all represent winter-over experiments where the total duration of the Antarctic stay has been estimated.

Within these studies, two randomized controlled trials were identified (level IB evidence)—the highest level of evidence found during this review. In the first, 12 individuals performed a match to sample working memory task ***(Reed et al., 2001)***. After four months of Antarctic residence, half were randomized to receive L-thyroxine, and half received placebo. Both groups became impaired on the match to sample task (up to 11%) over the first four months. Those receiving placebo continued to show impairment in the memory task, whereas those receiving L-thyroxine returned to baseline. This provided relatively strong support for the self-report of memory alterations in Antarctic analogs, and also suggests both a mechanism (hypothyroidism) and a countermeasure (L-thyroxine replacement). However, a substantially larger follow-up randomized trial ***(Palinkas et al., 2007b)*** involving 65 Antarctic residents and utilizing the ANAM-ICE battery (tasks: code substitution, continuous performance test, logical reasoning, match to sample, simple RT, Sternberg memory search) found no cognitive decrements (and, in fact, some improvements) during the Antarctic winter-over period, with considerable variation across summer/winter periods and across cognitive measures. While a match-to-sample task was part of the testing battery, the match-to-sample results were not reported separately, precluding direct comparison with the previous study. This apparent failure to replicate could be due to a number of factors, including the small size of the initial study, the more heterogeneous sample of the second study (multiple experimental groups), potentially different environmental conditions for the second study, or simply related to how the cognitive measures were reported. As these were the two studies with the highest level of evidence of any encountered in this review, further investigation of this issue appears warranted.

The remaining Antarctic analog studies in Table 2 revealed no cognitive decrements *(Defayolle et al., 1985; McCormick et al., 1985; Palinkas et al., 2007a; Taylor and McCormick, 1985; Taylor, 1991; Taylor and Duncum, 1987)*, mild decrements *(Sauer et al., 1999b)*, and/or considerable inter-individual variability *(Le Scanff et al., 1997)*. It is worth repeating that the findings of mild or no cognitive deficits could in fact be a *result* of high variability across participants. Some studies were further complicated by residual task learning, e.g. *(Defayolle et al., 1985; Taylor and Duncum, 1987)*, while others suffered from inadequate control groups, e.g. *(Mullin, 1960; Sauer et al., 1999b)*.

To summarize, one study provided reasonably strong evidence that memory is impaired in winter-over personnel, and that this may be related to hypothyroidism (n=12). A follow-up study, with more subjects and a broader cognitive measure, failed to replicate these initial findings (n=65), calling into question the results from the first study. The remaining work similarly provided mixed results, with no major findings of impaired cognitive performance, but with caveats in terms of learning effects and inadequate controls. As with spaceflight, this is at odds with the anecdotal and self-report measures indicating considerable attentional and memory difficulties during winter-over in Antarctica. Again, the modest subject numbers do not help clarify the situation—some 16-20 individuals in each experimental group are often necessary to obtain stable estimates of reliable behavioral performance effects *(van Belle, 2002)*, and only a small fraction of studies achieved this number.

4.3. Submarines

Another particularly good analog environment for spaceflight is a submarine mission. Here again, confinement, with a dangerous external environment, high-stress jobs, and at least some social isolation are the key variables. Two reports by Ferguson *(Ferguson and May, 1970; Grumman, 1970)* describe the

results of a 30-day drift dive of the Ben Franklin submersible. Numerous cognitive tests were administered via the Langley device *(Grumman, 1970)*, however total time to completion of all tasks was the sole measure. The majority of the six crewmembers demonstrated increases in time to completion (10% on average), even in the face of potential learning effects. However, the authors did not separate any early adaptation period and later dive periods in the analysis, so the effect of time was obscured in these reports.

The Navy has of course been active in assessing performance in submarine missions lasting more than 60 days. Weybrew has provided a number of summaries of the work performed on long-duration nuclear submarine missions *(Weybrew, 1961; Weybrew, 1971*, *1991)*. Relatively few peer reviewed research studies have been published, however, and fewer have addressed cognitive processing per se, making the domain difficult to assess. From those that do address cognition (ranging from 30-70 days), the summaries mirror those from spaceflight and Antarctic research: one study demonstrated cognitive changes such as impaired declarative memory on a picture memorization task *(Trousselard et al., 2009)*, another found mixed results on tone detection, Sternberg memory search, unstable tracking, dual-task tracking and memory search *(Lorenz et al., 1992)*, and still others have demonstrated mixed results in mental arithmetic, choice response time, symbol substitution *(Schlichting et al., 1989)*, and presence of emotional alterations *(**Weybrew, 1991**)*.

Beyond these papers, there have been a small handful of distinctive findings that appear particularly relevant to LD spaceflight *(Weybrew, 1991)*. First, the close viewing-distances in submarines were found to cause lateral phorias to become esophoric. Similar effects may occur in LD spaceflight given the similarly cramped quarters and close viewing distances. The recommended countermeasure for submarines was to install landscapes and seascapes with deep depth cues to counter this maladaptation. Second, and similar to what is described for space capsules, the absolute level of olfactory stimulation becomes high soon after submergence, thereby reducing olfactory sensitivity. It was thought that changes in food preferences may be related, and that this posed concerns for long-duration patrols. Third, as missions progressed, time tended to be overestimated. Finally, there were numerous stressors expressed by nuclear sub crews which, ranked from highest to lowest, were: concern about radiation, gas or biological contamination of the sub, hull breach, restricted space, family separation, loss of circadian cues and sleep difficulties, noise, work over-or under-load, and boredom. All of these findings have close parallels in the spaceflight environment, but limited follow-up or comparative investigation was identified.

4.4. Bedrest, Isolation and Confinement

Other analog environments involve somewhat lower fidelity representations of spaceflight than Antarctica or submarines. Instead, these analogs seek to mimic one or two particular conditions of spaceflight. Head down tilt (HDT) bedrest couples inactivity with cephalic fluid shifts, whereas isolation and confinement studies provide variable degrees of separation between participants and their normal environment or typical social contacts. A recent review by **Lipnicki and Gunga *(2009)*** identified 17 bed rest studies of durations 7-70 days that included cognitive testing (including many Russian studies). The reader is referred to that article for details, though the relevant articles are referenced here *(Artishuk et al., 1974; Asyamolov et al., 1986; DeRoshia and Greenleaf, 1993; Edwards et al., 1981; Haines, 1973; Ioseliani et al., 1985; Marishchuk et al., 1970; Ryback et al., 1971a; Ryback et al., 1971b; Seaton et al.,*

2007; Shehab et al., 1998; Storm and Giannetta, 1974; Traon et al., 1995; Trimble et al., 1970; Zubek et al., 1962; Zubek and MacNeill, 1966). The overall findings can be summarized much like those for both spaceflight and Antarctic research: (1) the specific tests used, the protocol, and prior exposure to the test material were highly variable across studies; (2) cognitive effects were also variable, significant findings in some studies, no findings in others, and sometimes failures to replicate; (3) several studies were confounded by learning effects and/or lack of control groups, and (4) executive function testing was underrepresented.

To supplement the above, four more recent papers on head-down tilt can be added. In the longest HDT study of cognition described to date, 90 days in duration, **Seaton et al. *(2009)*** had 13 participants perform the NASA WinSCAT battery approximately every two weeks. No significant changes in cognitive performance were found. However, prior to analysis, all raw data was thresholded to “off nominal” or not, where “off nominal” was a more liberal threshold than the standards used for astronaut subjects. This thresholding process substantially reduced the sensitivity of the measures collected and prevented a meaningful assessment of changes in variability. Thus, the lack of significant cognitive changes is difficult to interpret. In conjunction with the same 90 day duration HDT study, and not purely cognitive, Roberts et al. *(2010)* examined brain plasticity in two men and two women, as measured via transcranial magnetic stimulation. Decreased leg (but not hand) corticospinal excitability was observed, presumably caused by leg disuse, but substantial inter-individual variability was in evidence. Finally, Lipnicki and colleagues provided two reports involving 60 days of HDT *(Lipnicki et al., 2009a*, *b)*. In the first *(Lipnicki et al., 2009a)*, three executive function tasks were examined (Iowa Gambling task, 2-back working memory, and a flanker task). Significant impairments were found only in the gambling task, although potential learning confounds likely affected results of the latter two. In the second study *(Lipnicki et al., 2009b)*, researchers examined in detail the Iowa Gambling task performed either before bed rest (n=13) or on the 51^{st} day of a 60-day bed rest period (n=12), designed to avoid learning confounds. Overall performance on the task was equivalent between groups. However, controls exhibited a typical change in strategy across task trials, whereas bed rest participants did not. This provided limited evidence supporting executive function deficits (perseveration) in HDT bed rest.

Beyond bed rest, 19 additional studies were identified that involved physical confinement or social isolation and utilized cognitive measures; see Table 3 and Figure 5. As background, considerable work with animals suggested that early perceptual deprivation can have extreme and long-term consequences on sensory systems *(Mitchell and Sengpiel, 2009)*, and social isolation at infancy can have truly profound effects on a wide range of measures including parental bonding, social standing, learning, and more *(Harlow, 1965; Harlow et al., 1965)*. Perceptual deprivation and isolation of older animals does not generally have either as profound or as lasting effects *(Harlow et al., 1965; Reimers et al., 2007)*, but the animal work still raises questions about the cognitive effects of long term restriction of perceptual or social variation in spaceflight settings.

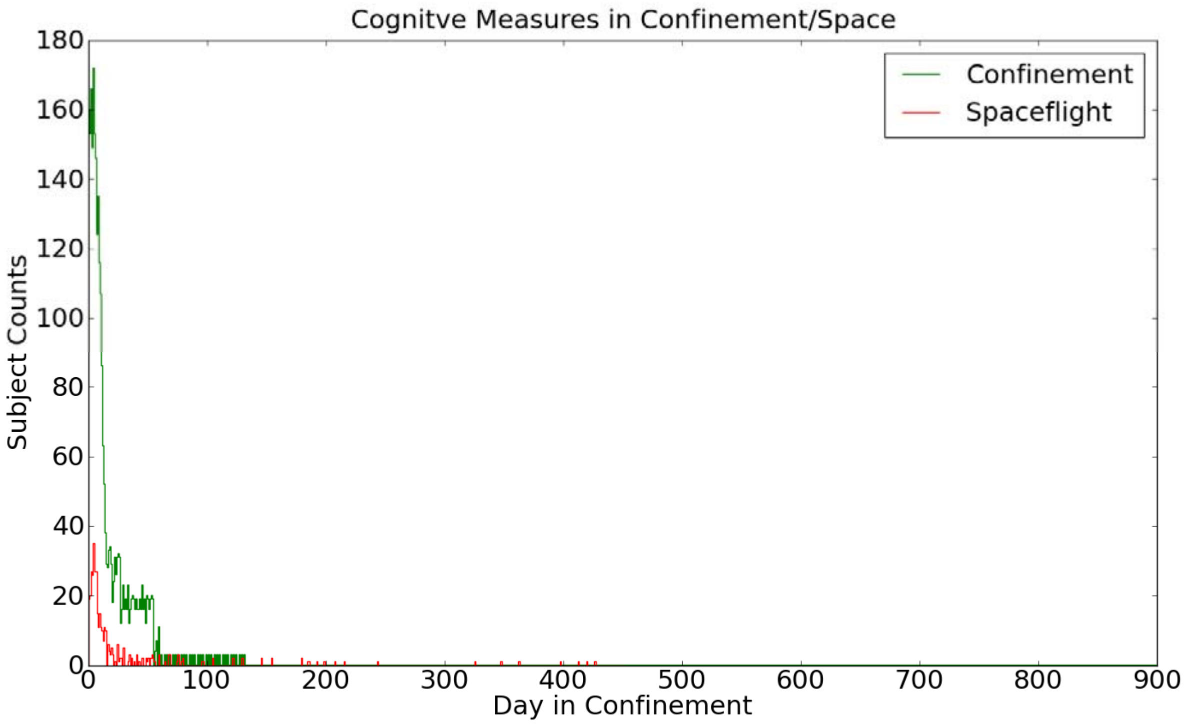

Figure 4: Comparison of cognitive test sampling profile for confinement/isolation studies (green) compared to spaceflight (red; matching the red curve in Figure 2). Confinement data comes from Table 3, excluding those studies where data collections schedules were not reported or where various studies were summarized jointly.

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Table 3: Isolation and confinement studies incorporating cognitive measures.

Duration (days)	Subjects	Controls	Repetitions	Level of Evidence	Cognitive measures	Impairment?	Other measures	Findings	Reference
365	various	not reported	various	III	various	attention, memory, motor, executive fcn	n/a	Multiple findings for both mild and severe isolation: incresed decision time, decreased fidelity, increased latencies, reduced attention, reduced memory	*(Gushin et al., 1993)*
135	3 cosmonauts	None	2 pretest, 57 during (3x/week), 2 posttest	IIB	CAMS (life support)	no	self-report effort, anxiety	Pretty stable performance throughout	*(Sauer et al., 1999a)*
60	3 male, 1 female EMSInauts	None	40 during (1/workday)	IIB	Contaminants Monitoring Task; simplified from 1993 study	executive fcn, motor	ECG, BP, respiration, questionnaires	Slowing of decision time and checking time with isolation; increases in performance variability with isolation	*(Hockey and Sauer, 1996)*
60	3 male, 1 female EMSInauts	5 ground crew (2 males, 3 females; not confined)	2 pretest, 16 during, 2 posttest	IIB	Sternberg, unstable tracking, dual-task (previous two)	no	mood, EEG	Steady improvement in Sternberg; some bumps in tracking and more problems in EMSInauts (esp. in high-load dual-task Sternberg4); learning effect, possible order effect	*(Lorenz et al., 1996)*
60	4 men	5 men	1 pretest, 10 during (1x/week), 1 posttest	IIA	Auditory detection	attention	ERP-P300	Detection RT to rare events (20%) fell part way through isolation; P300 altered too	*(Mecklinger et al., 1994)*
56	4 men	None	118 during (3x/day)	IIB	8 tasks: vigilance, working memory, tracking, math, problem solving	attention, memory, executive fcn?	sleep diaries	Vigilance/attention and working memory were most affected; problem solving demonstrated a systematic decrement over time (but argued to be motivation loss)	*(Rodgin and Hartman, 1966)*
28	6 male EMSInauts	None	20 during (1/workday)	IIB	Contaminants Monitoring Task (complex working memory and executive fcn task)	variable	n/a	High error rates made analysis difficult (only 1 "good" subject); alterations marked by variability more than steady decline; learning effect	*(Hockey and Wiethoff, 1993)*

28	6 male EMSInauts	None	1 pretest, 4 during, 1 posttest	IIB	Distributed attention (dual-task), visual search, orientation of attention	variable	n/a	Disappearance of the typical "meridian effect" (no bias in orienting to stimuli in current attended L/R or U/D field); large increase in individual differences	*(Rizzolatti and Peru, 1993)*
28	6 male EMSInauts	None	not specified	IIB	Operational sustained attention test, working memory, simple RT	variable	ERPs	Simple tasks unaffected (but evidence of a learning effect); critical flicker fusion slowed, sustained attention led to change in strategy (per other stressful settings) but not performance, working memory became more variable	*(Vaernes et al., 1992)*
28	6 male EMSInauts	None	14 during (every other day)	IIB	Math "operational test" (figure out math operators to make a number-sentence), short term memory (forward digit span), visualRT	no	ERP	Concluded that there was no operational test deterioration; similar for memory; even some improvement in simpleRT; no change in N100 or P300 latencies; learning effect	*(Vaernes et al., 1993)*
26	4 students	4 students	3 pretest, 12 during, 1 posttest	IIA	AGARD-STRES (4 tests)	no	mood, workload	0.7% CO2 had no effect (grammatical reasoning improved?), tracking performance problems at 1.2% and lower alertness	*(Manzey and Lorenz, 1998)*
15	16 men (two shifts of 8 each)	None	30 during (2x/day)	IIB	Grammar reasoning, STM, symbol coding, Ravens10	no	core temp	Very small (or no) effects of hypoxia, some improvements over time (learning effect?); circadian variability	*(Linde et al., 1997)*
14	22 subj	None	approx. 20 during (1-2x/day for 11-14 day experiment durations)	IIB	Manikin, Stroop, choiceRT, finger tapping, pursuit, aiming, tracing	no	mood	No behavioral decrements observed (generally, improvements across the board, but no control for learning confounds)	*(Gustafsson et al., 1997)*

14	various	various	various	IIA-III	Various intellectual tests	no	various	No intellectual impairment noted even up to 60 days; sensorimotor performance generally unimpaired as well; controls unclear, learning confounds common	*(Smith, 1969)*
10	18 sailors	18 sailors	10 (1x/day)	IIA	8-light vigilance task, dyad syllogistic reasoning, CIC task	no	group composition, indiv. characteristics	No decrement in monitoring with isolation; actually, facilitation on all tasks with isolation; isolates reported more stress (eustress explanation)	*(Altman and Haythorn, 1967)*
9	2 men	None	6 pretest, 14 during, 4 posttest	IIB	Psychomotor (aiming, coordination, steadiness), flicker fusion	no	physiology	No behavioral changes, tendency to improve performance (learning confound?)	*(Schaefer et al., 1967)*
8	3 men	None	variable	IIB	Flight control tasks, emergency readiness, star readings, systems monitoring	no	stress, BP	No task degradation was noted	*(Hatch Jr. et al., 1964)*
7	6 men	None	14 during (2x/day)	IIB	Tracking, simpleRT, listening comprehension, math reasoning, learned associations, verbal processing, weight discrimination, time estimation, reasoning (pre/post confine)	perception, motor	diary	Decrement in time estimation; considerable performance variability noted on other tasks; practice effects observed for the more complex tasks	*(Hanna and Gaito, 1960)*
7	4 astronauts	None	2 pretest, 6 during, 1 postflight (all 1x/day)	IIB	CAMS (life support)	no	anxiety, fatigue	Subjects adjusted; no serious performance problems in primary task (errors seen in 2ndary task); no evidence of an "adaptation period"; learning confound likely; ground crew controls excluded (only 14% compliance)	*(Sauer et al., 1999c)*

In humans, Russian isolation and confinement studies have lasted up to 365 days ***(Gushin et al., 1993)***, but the vast majority of studies last less than 90 days *(Harrison et al., 1991)*. Smith and Lewty *(1959)* summarized the early literature as supporting no intellectual impairment even up to 60 days, as well as maintenance of what they termed "adequate" sensorimotor performance. More recent work has showed relatively stable cognition with isolation and confinement *(Sauer et al., 1999a)*. However, there are studies that demonstrate slowing of critical flicker fusion frequency *(Vaernes et al., 1993)*, decreased response time to rare events *(Mecklinger et al., 1994)* and, as with other environments, multiple reports of increased variability *(Hockey and Sauer, 1996; Hockey and Wiethoff, 1993; Rizzolatti and Peru, 1993; Vaernes et al., 1993)*. No studies were identified that investigated the cognitive processing of social stimuli, or the effect of social isolation specifically on cognition. Thus, in yet another spaceflight analog environment, there is modest evidence for alterations in certain aspects of cognition, substantial evidence of increased variability in cognitive performance, and considerable difficulty interpreting many studies due to learning or other confounding variables (e.g., sleep loss, circadian effects).

4.5. Sensory deprivation/restriction

Spaceflight imposes substantial sensory restriction on astronauts, in the form of a reduction in the variety of visual, auditory, somatosensory, olfactory and gustatory inputs. As indirect support of sensory deprivation's effect on cognition, it should be noted that sensory deprivation is a recognized form of torture *(Seguin, 2005)*. For a period from the mid 1950s through the 1960s, a series sensory deprivation and sensory restriction studies were conducted in healthy humans, several of which sought to identify cognitive effects of reduced sensory input (for a good review, see **Zubek *(1964)***). Initial studies noted a decrement in verbal cognition as well as hallucinations under conditions of extreme sensory impoverishment *(Bexton et al., 1954)*. Many follow-on studies examined the hallucination or suggestibility aspects of sensory deprivation or sensory restriction, finding equivocal or variable evidence. Those studies investigating cognitive function—which never lasted longer than 14 days—found reduced abilities to detect events *(Zubek, 1969b; Zubek et al., 1962)*, some improvements in memory *(Grissom et al., 1962)* possibly due to reduced retrograde interference, and various changes in EEG patterns *(Zubek, 1969a)*. In addition, two particularly interesting studies were noted. In one serendipitous case, two participants were accidentally exposed to heat stress in the isolation chamber. The effect of heat stress overwhelmed the expected effects of confinement, suggesting that heat may be a substantially more potent modifier of cognitive performance than sensory deprivation. A second, well-controlled study looked at the effect of immobilization on cognitive performance, to compare with previous sensory restriction studies ***(Zubek and Wilgosh, 1963)***. Results in 22 males suggested that immobilization (for approximately 14 waking hours per day over 7 days) generated cognitive decrements in verbal fluency, attentive cancellation, color perception, reversible figure perception. These decrements were quite similar to, though not of the same degree or as wide ranging, as immobilization combined with sensory restriction. Thus, it would appear that restrictions in both sensory input and motor output can induce deficits in attention and cognitive performance, perhaps in a graded fashion. This is consistent with previous reviews of the sensory restriction and deprivation literature, where more severe deprivation leads to more severe deficits *(Zubek, 1969a, b)*, as well as the exercise literature showing cognitive deficits associated with inactivity and cognitive improvements associated with exercise *(Lipnicki and Gunga, 2009)*.

4.6. Environmental concerns: noise, vibration, toxins, hypoxia, dehydration

A number of other relatively unique environmental conditions are also found in spaceflight, including temperature extremes, constant noise and vibration *(Bogatova et al., 2009)*, variable levels of atmospheric toxins *(Mukhamedieva et al., 2009)*, hypoxia/hypercarbia, and ambient pressure changes. Being relatively unique conditions, even less research has been conducted on the cognitive effects of such exposures. However, studies have demonstrated that cold can induce deficits in working memory *(Giesbrecht et al., 1993; Makinen et al., 2006; Palinkas et al., 2005)*, reduce vigilance *(Lieberman et al., 2005a; Lieberman et al., 2005b; Makinen et al., 2006)*, and may adversely affect reading and comprehension *(Slaven and Windle, 1999)*. Interpretation is complicated, however, in that the cold studies usually involved or induced at least some sleep deprivation, which is well known to adversely affect cognitive performance *(Durmer and Dinges, 2005; Lim and Dinges, 2008)*, or exhibited uncontrolled learning effects. Vibration has been shown to adversely affect short term memory *(Sherwood and Griffin, 1990)*. Despite the well known toxic effects of carbon monoxide, particularly on the hippocampus and brain structures involved in memory *(Hood et al., 1999)*, two studies on exposures to carbon monoxide involving up to a 10% bolus (i.e., over periods considerably less than one day) demonstrated few cognitive effects *(Bunnell and Horvath, 1988*, *1989)*. Finally, a recent experiment demonstrated that changes in ambient pressure equivalent to a commercial airline cabin can alter taste perceptions (Kaiser, 2010). While important from a nutrition standpoint, such perceptual changes are less likely to directly impact cognitive performance.

In contrast to the studies above, dehydration studies appear to demonstrate clear and consistent cognitive performance deficits *(**Grandjean and Grandjean, 2007**; Maughan, 2003; Wilson and Morley, 2003)*. Deficits in attention *(Baker et al., 2007)*, perceptuomotor skill and memory *(Baker et al., 2007; Cian et al., 2000)*, and cognitive performance on arithmetic tasks *(Grandjean and Grandjean, 2007)* have all been demonstrated with 1-3% dehydration states. Interestingly, most dehydration manipulations are achieved through exercise. Hence, one cannot cite inactivity as a potential cause of cognitive deficits, as has been done in critiques of bedrest, isolation and confinement studies.

One study of carbon dioxide exposure is of particular interest for spaceflight, given the potential for CO_2 "pockets" in the cabin due to the lack of gravity-based air mixing. **Fothergill *(1991)*** studied CO_2 in 3 separate ranges, up to 6 atmospheres pressure. He found it to be up to 175 times more narcotic than N_2 and exhibited no minimum threshold value for exerting its detrimental effects. Specifically, CO_2 resulted in a slowing of motor performance (not an increase in errors), and more difficulty concentrating. While these are two of the most common symptoms voiced by spacefarers, and headaches (another consequence of CO_2) are a third commonly reported spaceflight symptom, it has yet to be conclusively demonstrated that CO_2 negatively impacts cognitive performance in spaceflight settings.

With regard to LD spaceflight, none of the above studies have involved extended exposure to the stressor—most studies were performed in one laboratory session on a single day. Thus, the cognitive effects of *long-term* exposure to any of these stressors—dehydration, CO/CO_2, or long-term noise or vibration exposure equivalent to the levels one might experience in spaceflight—remains unknown. Dehydration and CO_2 are of particular concern in this light. Dehydration is induced during spaceflight via physiological responses to cephalid fluid shifts in weightlessness *(Huntoon and Cintron, 1996)*, whereas CO_2 can pool up in most any location of the spacecraft and there are relatively few on-board sensors for

measuring local concentrations. Importantly, both of these conditions (1) have potent effects on cognitive performance, (2) may wax and wane over the course of hours (rather than minutes) making them hard to localize in time or space, (3) are difficult to avoid in spaceflight, and (4) are likely result in variable exposures across individuals. These concerns will be reconsidered when discussing gaps and recommendations.

5. Radiation

Radiation is perhaps the most serious environmental hazard that will be faced by crews during interplanetary missions *(**Cucinotta, 2009**)*. The Earth's magnetic field acts as a shield against many forms of extraterrestrial radiation. Outside the protection of the Earth's magnetosphere, radiation from two principal sources will pose significant biological risks, solar particle events (**SPE**) and galactic cosmic rays (**GCR**). Solar particle radiation is almost entirely composed of protons (>95%), usually at lower energies (<100 MeV). Their direct effects are bounded by their limited ability to penetrate deeply into biological tissue. Thus, while of concern for skin and eye exposures, SPE are of minimal concern for central nervous system (**CNS**) effects.

GCR, in contrast, are believed to originate from supernova explosions. Composed of approximately 85% protons, alphas particles, plus approximately 1.5% of heavy ion particles, including oxygen, carbon and iron, GCR are of greatest neurological concern during interplanetary missions. The acute and long-term effects of these high charge and energy (**HZE**) particles on the CNS, and underlying mechanisms, are only beginning to be investigated. However, ground-based studies have shown that, in addition to increasing cancer risk, HZE radiation can cause both sensorimotor performance impairments in rodents *(Rabin et al., 1989; Torosian et al., 1989)* and damage to the nigrostriatal dopamine system *(Koike et al., 2005)*. These findings are of particular concern because there is growing evidence that Parkinson's disease has a long preclinical course, with accumulating damage to the nigrostriatal dopamine system finally culminating in obvious behavioral manifestations including slowness in action and cognition. Although there is no direct evidence from animal studies that long-term exposure to GCR in the doses expected during LD missions will result in striatal neurodegenerative changes, the animal findings warn of the potential dangers faced by flight crews exposed to HZE radiation for extended durations.

In addition to the complex nature of space radiation with respect to its energy and fluency characteristics, there is a significant knowledge gap concerning the effects of low-dose or long-term exposure of the CNS. Epidemiological approaches have been somewhat ineffective in assessing the effects of low-dose exposures. In such studies, linear no-threshold models are utilized to estimate the CNS effects of low-dose exposures by extrapolation from high-dose epidemiological data *(National Research Council, 2005)*. Many of these models incorporate two questionable assumptions. The first assumption is that low-dose radiation exposure elicits the same classes of cellular response mechanisms as high-dose radiation exposure. The second assumption is that the complex molecular and cellular responses to radiation exposure extrapolate linearly from the high to low doses. Recent studies of cellular responses to low-dose radiation have largely failed to provide strong support for the linear no-threshold models *(Morgan and Schwartz, 2007)*, suggesting that low dose CNS effects may need to be directly examined, rather than extrapolated from much higher exposure levels.

The known CNS effects of space radiation can be summarized at four levels of analysis, the cellular and molecular effects of ionizing radiation, electrophysiological effects, structural brain changes, and finally the resulting behavioral changes.

The CNS cellular effects of radiation have been most thoroughly examined in the hippocampus, part of a brain system responsible for formation of new memories and the efficient acquisition of new cognitive and sensorimotor skills. Rodents exposed at one-month of age to ^{56}Fe-particle irradiation over a range of 0-4 Gray (Gy) were examined using ^{1}H-magnetic resonance spectroscopy, which showed a significant increase in the N-acetylaspartate/choline ratio and a lactate peak at the 4 Gy exposure level. Although histology failed to demonstrate clear pathological changes in neurons and astrocytes, changes in the microglia were detected *(Obenaus et al., 2008)*. These findings support the notion that alterations in local brain metabolism may occur in the absence of detectible microstructural brain damage. In another study mice were irradiated with 1-3 Gy of ^{12}C or ^{56}Fe ions. Nine months later proliferating cells and immature neurons in the dentate subgranular zone were measured and reductions in cell numbers were observed which were dependent on both the dose and linear energy transfer. These changes were persistent, worsened with time, and were associated with a robust inflammatory response *(Rola et al., 2005)*. Observation of a persistent inflammatory response in the hippocampus may suggest mitigation strategies employing anti-inflammatory drugs. In addition, related studies found that ^{56}Fe-particle radiation has further effects on hippocampal function, reducing neuronal output and attenuating lipopolysaccharide-induced inhibition of long-term potentiation *(Vlkolinsky et al., 2008)* and impairing synaptic plasticity *(Vlkolinsky et al., 2007)*. All of these disrupted processes are thought to be involved in supporting memory formation by this structure.

Electrophysiological changes in the hippocampus have also been observed following HZE-particle radiation exposure that causes accelerated age-related neuronal dysfunction in transgenic mice, as evidenced by over-expression of human amyloid precursor protein. In this study radiation accelerated the onset of both age-related field excitatory postsynaptic potential decrements and post-synaptic amplitudes. While radiation did not significantly affect survival of the transgenic mice, the authors concluded that that CNS irradiation with HZE particles accelerates Alzheimer's disease-related neurodegenerative changes *(Vlkolinsky et al., 2010)*. This suggestion is of particular relevance, since Alzheimer’s Disease, like Parkinsonism, is thought to have a long preclinical course in which the cognitive manifestations of memory decline and impairment in spatial orientation may be preceded by many years of progressive damage to CNS memory systems.

Most studies of the CNS structural effects of HZE radiation have utilized short exposures to high doses, and therefore may be of limited relevance to long duration spaceflight. However, some low-dose work also suggests effects at the cellular level. One study identified 40% reductions in hippocampal mitochondrial volume in rats exposed to 50 cGy of 600 MeV/n iron ions *(Philpott and Miquel, 1986)*. These morphological changes were associated with impairments on a maze running task (spatial memory). In another study, exposure to ^{56}Fe-particle irradiation over a 0-4 Gy range were examined using T2-weighted and diffusion-weighted MRI imaging. Quantitative analysis demonstrated microstructural white matter changes evidenced by changes in the apparent diffusion coefficient, with increases at 1 Gy and decreases at 4 Gy *(Obenaus et al., 2008)*. Taken together, the microstructural

effects seen in the hippocampus and its anatomical connecting fibers, suggests widespread cellular effects following low-dose space radiation.

While it is well know that high-dose radiation can cause clear cognitive impairments, including learning disabilities *(Abayomi et al., 1990)* and memory impairments *(Abayomi, 1996*, *2002)*, the behavioral effects of low-dose HZE radiation are less well known. In rodents, exposure to high-energy Fe-particles in the 5-500 cGy range can produce dose-dependent taste aversion with a maximal effect achieved at a dose of 30 cGy *(Rabin et al., 1989)*. These effects were not seen following exposure to an equivalent dose of gamma rays or fission spectrum neutrons, suggesting that the effects of exposure to heavy particles cannot be extrapolated from studies using dose-equivalent gamma rays *(Rabin et al., 1998)*. In addition, spatial learning and memory deficits can be induced by exposure to ^{56}Fe-particle radiation *(Shukitt-Hale et al., 2000)*.

Of additional concern is the notion that extended exposure to low-dose iron HZE radiation may damage basal ganglia structures. A series of animal studies have provided increasing support for the notion that HZE radiation may selectively damage the nigrostriatal dopamine system *(Joseph et al., 1998; Joseph et al., 1992; Joseph et al., 2000; Rabin et al., 1989; Rabin et al., 1998; Rabin et al., 2000)*. Although these studies raise a number of concerns relative to the possibility that long-term HZE radiation may result in the development of clinical Parkinsonism through the mechanism of accelerated striatal “aging” *(Joseph et al., 1992; Joseph et al., 2000)*, they also suggest potentially effective countermeasures, including prevention by nutritional supplements, precursor treatment or dopamine agonists.

6. Stress

Multiple researchers have suggested that the cognitive decrements observed in flight may be driven by a mechanism considerably more general than microgravity or spaceflight: namely, the stress response *(Hockey, 1997; Manzey, 2000; Steel, 2005)*. It has been known for quite some time that stress affects cognition *(Broadbent, 1971)*, with both too much and too little stress leading to impaired behavioral performance *(**Lupien and McEwen, 1997**)*. Although reviewing the entire domain of performance under stress is well beyond the scope of this work, there are a few important aspects of the stress literature that bear particular relation to long duration spaceflight.

There is little question that spaceflight is a stressful endeavor, with time pressures, exceptionally high expectations, and the presence of multiple interacting physiological, psychological and social stressors. It is perhaps not surprising, then, to note the similarity of symptoms associated with stress and symptoms reported by spaceflight participants. A comparison is shown in Table 4, with symptom lists drawn from the papers in the bibliography, especially *Christensen and Talbot, 1986; Levine, 1991*. While many of these symptoms are relatively general in nature, the remarkable alignment of symptoms across these three types of exposures is sufficient to provide initial justification for investigating this issue further.

Table 4: Comparison of reported cognitive symptoms of spaceflight, Antarctic residence, and stress

Domain & Symptom	Spaceflight	Antarctic	Stress
Cognitive			
Anxiety	✓	✓	✓
Boredom	✓	✓	✗
Concentration	✓	✓	✓
Judgment	✓	?	✓
Memory	✓	✓	✓
Worry (esp. health)	✓	✓	✓
Emotional			
Agitation	✓	✓	✓
Depression	(✓)	mild	✓
Irritability	✓	✓	✓
Loneliness	✓	?	✓
Moodiness	?	?	✓
Overwhelmed	?	?	✓
Behavioral			
Eating changes	✓	✓	✓
Escape via alcohol etc	✗	✓	✓
Headache	✓	✓	✓
Isolation from others	✓	✓	✓
Nervous habits	?	?	✓
Reduced motivation	✗	✓	✓
Sleep alterations	✓	✓	✓

Stress can be induced in many ways, and different stressors induce different physiological reactions, particularly by altering the mix and concentrations of multiple highly potent endogenous stress hormones *(**Joels and Baram, 2009**)*. Interestingly, extreme environments don't necessarily induce stress at all, or at least not the same levels of stress across individuals *(Mocellin et al., 1991)*. As a result, one would anticipate different effects on cognitive performance in different individuals, in different environments and under different working conditions. Starting from the operational perspective, environments involving multiple stressors (e.g., simultaneous exposure to dehydration, under-nutrition, sleep deprivation, heat) have been shown to seriously and negatively affect a wide range of cognitive performance measures *(Lieberman et al., 2005a; Lieberman et al., 2005b)*. Submarine and Antarctic environments, discussed above, can also provide operationally relevant insight into cognitive alterations in the presence of multiple stressors. Social relationships are quite strongly linked to health *(House et*

al., 1988) and, at least in animal models, perceived or experienced stress depends heavily not just on the rate of stressors, but on the availability of social support, and the presence of kin *(Sapolsky, 2005)*. Thus, mere alterations in social settings—which are a core feature of spaceflight—have the potential to generate considerable stress in individuals, particularly when exposed to multiple other stressors. Given the variability in social networks for different astronauts, social stress would also be expected to vary across spacefarers.

One key component of stress which defines an individual's response is the controllability of the stressor. Stress that is perceived as uncontrollable interferes with hippocampal based memory function as well as long term potentiation *(Kim and Haller, 2007)*. This is argued to be mediated through concentrations of glucocorticoid (**GC**) stress hormones, which are also linked to aggressiveness. Extensive work on both animals and humans has shown that controllable stress is far less disruptive and damaging than uncontrollable stress *(Breier, 1989; Breier et al., 1987; Kant et al., 1992; Kavushansky et al., 2006; Maier and Watkins, 2005)*, perhaps mediated by prelimbic control of the dorsal raphe nucleus which in turn modulates the GC response *(Baratta et al., 2009)*. Issues such as when do individuals perceive a difficult situation as controllable, how can perceptions be shifted toward a perception of controllability, and even exactly how GCs influence the associated stress response ***(Lupien et al., 2009**; Sapolsky et al., 2000)* remain to be fully understood.

In addition to variable induction methods, levels, and controllability, another key component of stress is its duration: acute or chronic. Going back to the 1940s, studies on cognitive tasks, particularly those requiring complex, flexible thinking, revealed that even acute stress can impair performance, presumably mediated by catacholamines in the prefrontal cortex *(Broadbent, 1971)*. Interestingly, while acute stress specifically during perception and encoding can *improve* performance on memory tasks, acute stress during retrieval appears to *interfere* with memory *(van Stegeren, 2009)*. As might be expected, chronic stress interferes more extensively with prefrontal cortical function. Chronically elevated cortisol concentrations have been shown to impair both explicit memory and selective attention *(Lupien et al., 2005)*, and chronic stress has been further shown to induce a number of structural changes in the brain *(**Arnsten, 2009**)*.

These and related findings have led to the neurotoxicity hypothesis as the underlying mechanism by which stress affects the brain and cognition *(Lupien et al., 2009)*. This hypothesis suggests that chronic stress, and the associated elevation of GC stress hormones, leads to a diminished ability of neurons to resist insults, thereby increasing the rate at which they are damaged. The hippocampus and medial cortical structures appear particularly at risk *(Dedovic et al., 2009a; Dedovic et al., 2009b; Lupien et al., 2005; Roozendaal et al., 2009)*, and these structures are central to learning and memory functions. The lateral prefrontal cortex is similarly affected, which is essential for cognitive capabilities such as attention, working memory, and executive functioning *(Lupien et al., 2009)*. Thus, while acute stress in shorter duration spaceflights may be expected to generate mixed effects on memory and generally modest effects on complex cognitive performance, chronic stress over a long-duration spaceflight has the potential generate serious and progressive structural and functional changes in the neural circuitry for memory and decision making. The severity of such changes are likely related to the duration and intensity of stress, which in turn is likely related to the perceived controllability of the stress as well as other, less adequately understood environmental and individual characteristics.

7. Other issues

7.1. Drug effects

Over 200 drugs are currently available on-orbit between US and Russian medical kits, and sleep medications are particularly commonly utilized. Of the US medications, 27 have substantial sedative effects—some as a primary effect (e.g., sleep aids), and others as a side effect. Such drugs by definition affect cognitive performance, and concerns have been raised regarding response to emergency alarms following the atypically heavy sleep medication regimens that are known to be utilized in flight. Numerous other drugs are either directly psychoactive or have potential interactive effects that can adversely affect cognitive readiness or performance. While these effects are reasonably well understood on Earth and there is some knowledge about the effects of scopolamine and promethazine in microgravity *(Boyd et al., 2007)*, remarkably little is known about how drug pharmacokinetics and pharmacodynamics change in-flight *(Cintron and Putcha, 1996; Graebe et al., 2004)*. This substantial lack of knowledge brings into question even the known effects of common drugs when used in flight and, in turn, seriously limits our understanding of the cognitive consequences of medications—either individually or in combination—during spaceflight.

7.2. Synergistic effects

One research topic that has received almost no attention with regard to cognitive performance in spaceflight is the synergistic effects of spaceflight stressors: interactions between stressors that exacerbate cognitive performance difficulties. For example, even if we had a clear understanding of the cognitive effects of sleep medications in spaceflight, how do the sleep medications that are used by astronauts affect cognitive performance in the face of extreme ambient lighting changes and chronic sleep debt? Is the decrement additive, sub-additive, or super-additive? During short flights, such issues may be surmountable. However, in longer duration flights, such effects may be cumulative and eventually reach a tipping point. To date, all spaceflight studies—and most analog studies—involve multiple stressors, but such stressors are typically highly correlated with one another and hence confounded, making it difficult to identify individual from interactive effects. Laboratory studies, in contrast, typically only examine the effects of a single stressor. While a clear understanding of which spaceflight conditions adversely interact with which others to impair cognitive performance, much larger subject numbers are required to identify and characterize interaction effects *(Brookes et al., 2001)*—subject numbers which are usually well beyond the reach of spaceflight studies, and even beyond the reach of many analog studies.

As a starting point, however, Ushakov and colleagues summarized a wealth of interactive effects on human physiology, focusing on pairwise comparison of spaceflight relevant conditions such as radiation plus acceleration, radiation plus hypoxia, heat plus hypoxia, and so on ***(Ushakov et al., 1996)***. In a table of some 36 distinct physiological interactions developed by Ushakov and collaborators (reproduced here as Figure 5), a total of 15 of these 36 interactions were additive or synergistic as opposed to null or antagonistic. This provides an excellent guide for future research on interactions that may affect cognitive performance. Thus far, however, almost no research has been conducted regarding cognitive effects associated with such spaceflight stressor interactions. In the recommendations section it will be discussed how this table might be used to generate hypotheses about particularly important interactions to test for cognitive impairment.

Table 6 Interactions among selected spaceflight factors (Ref. 16)

	Weightlessness	Acceleration	Vibration	Radiation	SHF EMR	Hypoxia	Hyperoxia	Heat	Cold
Weightlessness			↑	↑					↑
Acceleration	↑		↑	↑		↑	↓	↑	↑
Vibration	↑?	↑		↑		↑		↑	↓
Radiation	↑?	↓			↑	↓	↑	↑	↑
SHF EMR				↑		↓		↑	↓
Hypoxia	↓	↑	↑	↓	↓		↓	↑	↑
Hyperoxia		↓		↑		↓		↓	↓
Heat	↑	↑	↑	↑	↑	↑	↓		↓
Cold	↑?	↓	↓	↓	↓	↓	↑	↓	

↑, additive or synergistic effects; ↓, antagonistic effects. SHF EMR, super-high-frequency electromagnetic radiation.

Figure 5: Reproduction of Table 6 from Ushakov et al. *(1996)* describing the interactions observed in physiological measures among select spaceflight stressors.

8. Summary of Findings by Cognitive Domain

Having separately reviewed spaceflight and analog environment studies, as well as radiation, stress, drugs and synergistic interactions, the findings will now be summarized according to the typical elemental cognitive disciplines of sensory and motor systems, attention, memory, learning, higher cognitive functions, language, and emotion, plus two spaceflight-specific domains of interest, namely spatial transformations and operational tasks. Figure 6 graphically depicts the distribution of data collection for each type of cognitive measure as a function of flight day (i.e., partitioning the red curve from Figure 2—reproduced in the center panel of Figure 6—into the elemental cognitive capabilities). Note that the “All Cognitive” histogram is not simply the sum of the histograms from the other categories. Nor, in fact, are the subject counts in the various cognitive categories completely non-overlapping. Why? In many spaceflight experiments, a single individual may have participated in anywhere from one to six different cognitive experiments. For Figure 6, participants were included in more than one histogram if they participated in more than one type of cognitive study (potentially on the same flight), as would happen if performing a full battery of cognitive tests. For example, if an astronaut performed a memory task on flight days 3, 10 and 20, and performed an attention task and a sensorimotor task on flight days 3 and 9, they would be included on days 3, 10 and 20 for the memory histogram, and on days 3 and 9 for the attention and sensorimotor histograms, and included (only once) on each day (3, 9, 10 and 20) for the All Cognitive histogram. Thus, the “All Cognitive” category counts all unique participant-days from the other categories. It can thus be discerned that a substantial number of participants in the various types of cognitive task did so as part of cognitive task batteries. The findings in each cognitive category will now be separately summarized.

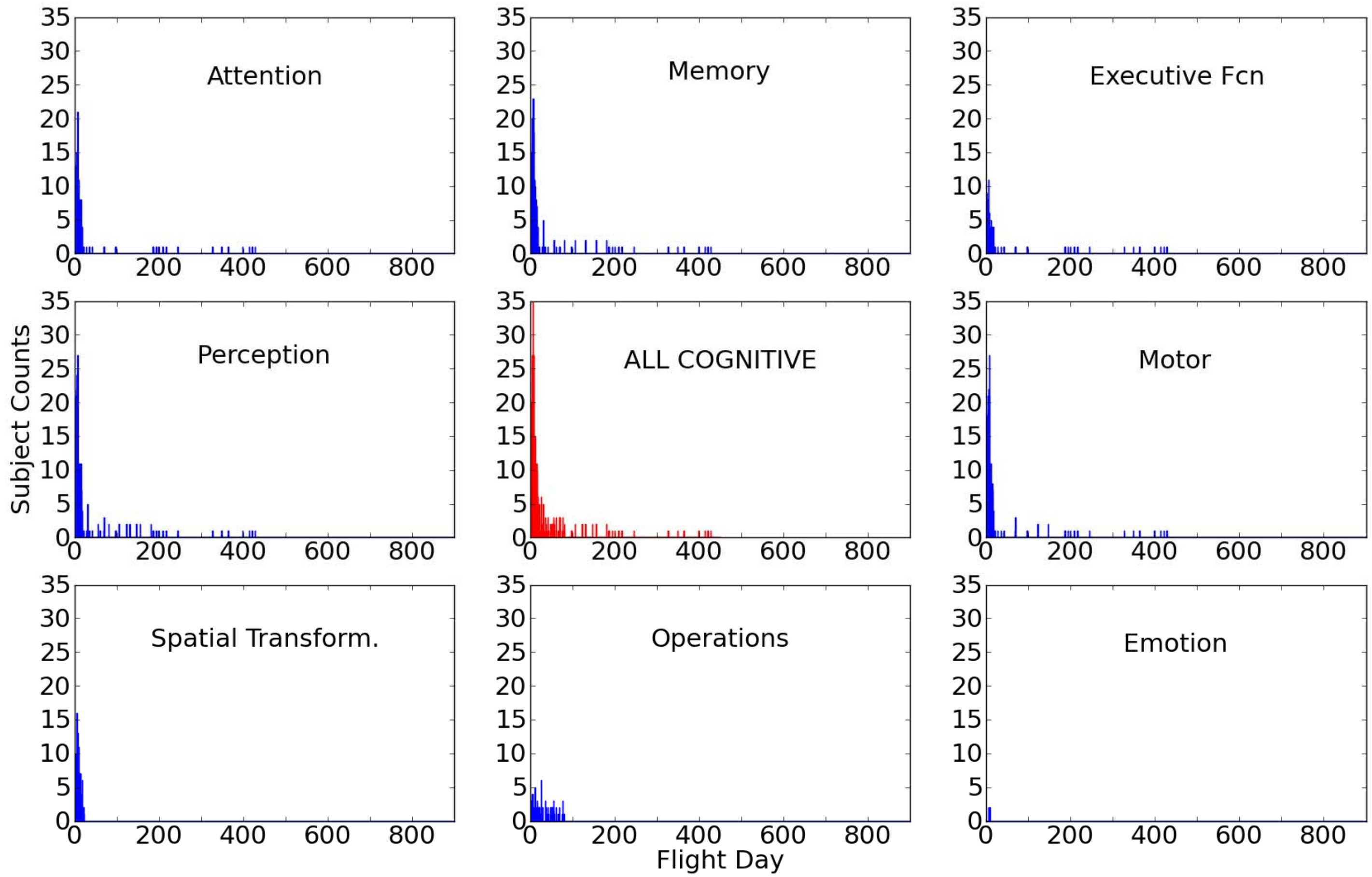

Figure 6: Distribution of all cognitive measurements (center, red) across typical categories of cognitive functioning. Social and language processing do not appear because no direct studies on these topics have been performed in spaceflight. Spatial transformation studies include mental rotation tasks. The "Operations" panel refers to complex/operational tasks that incorporate many of the other capabilities in variable and unknown proportions.

8.1. Perceptual and Motor Systems

A few of the papers in this review, plus a substantial number of additional papers described in sensorimotor reviews, describe studies focusing more or less exclusively on sensory systems or motor control. This review, however, was intended to focus more on more complex capabilities and cognitive processing. Reschke and colleagues *(Reschke et al., 1998; Reschke et al., 1996)* have written excellent reviews on the effects of spaceflight on sensory and motor systems and the reader is referred there for details with regard to the performance disruptions associated specifically with simpler sensorimotor function. This includes studies on the vestibular system, oculomotor control, postural control, and space motion sickness. The important issues to keep in mind from this literature is that both sensory and motor systems appear to largely but perhaps not completely adapt to the spaceflight environment over time, and that adaptation may be more rapid with previous microgravity experience. The associated adaptation time constants are variable across subjects. Importantly, not all functions adapt in all individuals, nor is adaptation necessarily complete within any particular time period (like 21 days, or 30 days, or even 90 days). Certain effects, such as lengthening of time perception, sensitivity to sudden head motions, motor slowing, and increased motor variability were all in evidence beyond 30 days, and hence may represent capabilities that do not completely adapt (or are maladaptive) in spaceflight. Understanding the mechanisms underlying such deficits, particularly on the performance of unstable tracking (tested in multiple studies and found to be impaired; Table 1), will be important to determine whether the observed cognitive-related deficits are due directly to the motor system, perceptual system, or other more central cognitive capacity.

8.2. Attention

Difficulty concentrating or focusing attention is a recurring anecdotal complaint from astronauts *(Schroeder and Tuttle, 1991)*, from individuals wintering over in the Antarctic *(Palinkas, 1992)*, and from those in confined or restricted sensory environments *(Gushin et al., 1993)*. The anecdotal findings are at least partially supported by self report experimental data in Antarctic analogs *(Mullin, 1960; Palinkas, 1992)* and experimental data in confinement and deprivation studies *(Gushin et al., 1993; Zubek, 1969b)*. The evidence in spaceflight studies is somewhat more equivocal in that certain attention demanding tasks such as simple and choice reaction time appear unaffected, whereas a dual-task paradigm (unstable tracking and Sternberg memory scanning) have more consistently led to behavioral deficits in spaceflight *(Heuer et al., 2003; Manzey et al., 1995; Manzey et al., 2000)*. However, given that attention is a multi-faceted cognitive capability *(Treisman and Gelade, 1980)*, and the tests to date have been quite limited, it may be that certain aspects or types of attention are altered while others are not; or that individual variability in response to the stresses of spaceflight is a key modulating factor.

8.3. Memory

A major cognitive capability of concern during spaceflight is memory function. Intact memory function, particularly for remembering pre-flight training and procedures, is crucial for mission success, and multiple anecdotal reports include memory dysfunction as an explicit concern in-flight *(Schroeder and Tuttle, 1991)*. Currently, there is little direct evidence to support these anecdotal reports, either in spaceflight or analog studies. In part, this is because of various confounds in many studies on the topic. In addition, different processes and mechanisms exist for working versus long term memory, implicit versus declarative or explicit memory, and storage versus retrieval, whereas nearly all experiments to

date have focused on working memory. Largely unintended (and uncontrolled) tests of longer term memory have also effectively been performed, via the observation of learning confounds on various in-flight tasks. In LD spaceflight studies, memory tasks have included Sternberg memory search, and working memory for oriented lines. Only in short duration spaceflight studies have long-term memory studies been conducted, and then only for faces *(de Schonen et al., 1998)*. Thus, memory function—and particularly long term memory—remains to be tested more directly and in detail.

Despite the current equivocal evidence for memory deficits in flight, two particular concerns remain regarding memory specifically during LD spaceflight: the potential effects of radiation and chronic stress. The hippocampus is a key structure in memory formation and retrieval, and this structure has proved highly sensitive to radiation *(Obenaus et al., 2008)*. The hippocampus and medial temporal lobe have also been shown to be adversely affected by chronic stress *(Kavushansky et al., 2006; Lupien et al., 2005; Pruessner et al., 2005)*. Given the likelihood of continuous and simultaneous exposure to chronic stress and radiation during LD spaceflight, the hippocampus would appear to be uniquely at risk for additive or even synergistic damage, progressive degeneration of function, and the real potential for serious and permanent memory dysfunction. That is, the hippocampus, and the memory functions it subserves, may be uniquely at risk during long duration missions. The basal ganglia also appear at risk for chronic degeneration in the face of chronic radiation and chronic exposures. This issue warrants considerable further attention.

8.4. Learning /Plasticity

As discussed, various adaptation-based learning mechanisms appear to function during spaceflight, as these are likely responsible for various changes observed in the sensory and motor systems during the first hours, days and weeks of flight *(Pozzo et al., 1998; Reschke et al., 1996)*. In addition, numerous studies have posited learning confounds to explain improvements in performance during longitudinal in-flight studies *(Leone et al., 1995a)*. If this interpretation is accurate, it would lend further support to the hypothesis that learning and plasticity remain functional in spaceflight. However, the vast majority of spaceflight studies lack matched control groups who perform the tasks on the same time schedule (cf. Table 1). Moreover, even those studies that included ground-based controls rarely performed direct statistical comparisons of the performance changes in-flight with those observed on the ground. This leaves open the possibility that learning during spaceflight, while still possible, is diminished relative to non-spaceflight conditions. Similar gaps, for similar reasons, exist in the spaceflight analog literature (cf. Table 2 and Table 3). And, as discussed above, the hippocampus and basal ganglia—key brain structures for learning—may be uniquely at risk during LD spaceflight. Thus, learning needs to be investigated more directly, and in concert with memory function.

8.5. Executive and Higher Cognitive Functions

Isolating impairments in executive and higher order cognitive function during spaceflight is difficult. Intact higher order functioning requires intact perceptual and motor processing, attention processing and memory function, all of which have demonstrated at least some alteration in spaceflight. Thus, it can be difficult to tease apart differences specifically in executive functioning relative to compound deficits in other perceptual or cognitive domains. Only 2 spaceflight studies utilized classic executive function tasks, namely Stroop tasks, one finding no performance differences in flight *(Benke et al., 1993b)* and one finding deficits only with personally relevant stimuli *(Pattyn et al., 2005)*. All other

aspects of executive function—e.g., inhibitory control, set alternation, error monitoring—remain unevaluated. Moreover, and as with learning and memory, a looming concern for LD spaceflight is in relation to the effects of radiation and chronic stress. Both conditions appear to affect not only memory structures but also prefrontal cortical structures critical for higher cognitive functioning *(Arnsten, 2009)*. Exploration class missions expected to last twice as long as the current 438 day record flight, plus the potential exposure to much more severe radiation and social isolation stress warrants careful attention to be paid to even mild executive function deficits in low earth orbit (**LEO**). This would seem particularly important given the common justification for continuing manned spaceflight: namely, humans provide unique flexibility in performance and problem solving skills that far surpass the capabilities of robots. While this is true under normal conditions, the stability of executive functioning during spaceflight—particularly given its potential vulnerability—should be thoroughly tested experimentally and, if executive function is found to deteriorate, countermeasures to remedy such deterioration should be developed.

8.6. Language

In terms of specific language processing tasks, topics such as syntax and semantics have not been directly tested in spaceflight or analogs. Lieberman and colleagues have shown impairments in sentence comprehension as well as language production associated with hypoxia during a climb of Mt. Everest *(2005c; Lieberman et al., 1995)*. Baddeley's grammatical reasoning test *(Baddeley, 1968)* is the only test of language function during spaceflight, which involves sentence comprehension for spatial relations. For example, a sentence describing the order of two symbols is presented (e.g., "# is preceded by $" followed by a symbol pair $#, and the subject must indicate whether the statement is true or false. Results for the grammatical reasoning test in spaceflight of either short or long duration have generally suggested no impairment (see Table 1), though again learning confounds were generally not accounted for. While language processing is technically required for other tests utilized in spaceflight, such tests tend to be well practiced prior to flight and hence provide only an extremely crude and indirect test of language performance in flight. It is also unclear whether anecdotal reports of difficulty concentrating during spaceflight specifically relate to difficulties associated with language processing, or a separate or even more general phenomenon.

8.7. Emotion

Extensive evaluations of emotion in terms of psychological and psychiatric maladaptation have been conducted both in spaceflight *(Kanas and Manzey, 2008)* as well as in analog settings *(Palinkas, 2003; Palinkas and Suedfeld, 2008)*. However, only two research studies were identified that examine cognitive processing of emotional stimuli. These included an emotional Stroop task and recognition of emotional facial expressions *(Pattyn et al., 2005; Pattyn et al., 2009)*. This small number of studies is somewhat surprising given the large number of reports—extending from far back in the age of exploration to the present day—indicating that mood disturbance, depression, anxiety, and hostility are all substantial concerns for spaceflight *(Shepanek, 2005; Stuster, 2000)*, and the knowledge that emotional alterations can interfere with cognitive performance *(Pessoa, 2008; Salzman and Fusi, 2010; Storbeck and Clore, 2007)*. In the two experiments conducted to date, spaceflight participants exhibited impaired decision making when the presented words were generically related to personal concerns ("death"), and larger impairments were seen when the emotional words were mission-related

("depressurization"). That is, processing of the spaceflight relevant emotional words was more impaired than processing more generic words. Based on these initial findings—and the known interactions between emotion, social functioning and cognitive functioning— it would appear particularly important to examine in more detail how emotional stimuli adversely affect cognitive processing, and to what extent, in the context of spaceflight or ICE environments.

8.8. Social Functioning

Similar to the emotional material, there are numerous reports of degradations in social functioning in ICE environments, even given the substantial level of screening during the selection process *(Kanas, 1985; Kraft et al., 2002; Palinkas et al., 2000)*. Such disturbances have ranged from altered interpersonal relationships and conflict, to clique formation, to self- or group-imposed isolation such as the Spacelab 4 "mutiny" *(Burrough, 1998; Oberg, 1981)*. As a consequence, social integration is one of the major risks concerns highlighted by NASA for LD spaceflight *(Space Studies Board, 2000)*. While studies have been conducted to examine variables such as team cohesion and team performance, not even one report could be identified that examined changes related to cognitive processing of social stimuli during spaceflight or analog exposure. Examples of such work include, for example, the processing of social cues *(LoPresti et al., 2008)* and social decision making *(Frith and Singer, 2008; Sanfey, 2007)*. The absence of such work may be partly (or largely) historical: such tasks were not generally considered nor were they incorporated into early standardized task batteries *(Bittner Jr. et al., 1986)* from which the more recent ANAM *(Reeves et al., 2007)*, AGARD-STRES *(AGARD, 1989)*, WinSCAT *(Kane et al., 2005)* and other batteries have selected their tests. However, inclusion of such social processing tasks in future studies would appear worthy of serious consideration, given the high priority placed on the psychosocial aspects of spaceflight.

9. Limitations

As with any review, the limitations should be discussed. First, the review does not include spaceflight studies that were published in languages other than English. The figures and tables therefore are assumed to miss many (e.g., Russian-language) studies of relevance, particularly given the Russian's substantial experience with LD spaceflight as well as LD isolation studies. Second, the review of non-spaceflight topics was not absolutely comprehensive. Although attempts were made to be reasonably thorough, the extreme breadth of sources in which relevant articles can be found, and the variability in terminology and keywords used in describing such studies, means that the summaries of radiation, stress, submarine research, sensory deprivation and environmental concerns are unlikely to be fully comprehensive. Those domains were nevertheless included here specifically to bring attention to their relevance, highlight key findings, compare such findings to the spaceflight results, and to help identify topics which may merit more focused attention—e.g., additional research or literature review efforts—when considering cognitive performance in LD spaceflight.

10. Research Gaps and Research Recommendations

In conducting this review, a number of substantial gaps were identified in our current understanding of cognitive performance during long duration spaceflight. These gaps are summarized next, followed by recommended tasks to help fill these gaps.

10.1. Research Gaps

Long duration studies: Figure 1, Figure 2 and Figure 6 clearly illustrate the fundamental problem: there is a particularly serious lack of long-duration studies on cognitive processes under spaceflight-relevant conditions. Moreover, the vast majority of studies that have been conducted were unable to run adequate numbers of subjects and/or lacked appropriate controls. In fact, these problems tended to affect not just spaceflight studies, but analog studies as well. This gap arises not least because long duration spaceflight is still relatively uncommon, particularly for US astronauts. However, with the completion of the ISS, and its renewed utilization plan until at least 2020, the United States is about to embark on a new and potentially rich phase for LD spaceflight research. This phase could certainly be exploited to help identify likely effects that longer duration spaceflight may have on cognitive functioning.

Study Power and Sensitivity: Essentially all prior reviews of spaceflight biomedical research have pointed out the pragmatic challenges of doing research in space. The consequence is that most spaceflight studies enroll very low numbers of subjects and therefore have very low power to detect anything but the grossest deficits. Long duration studies are particularly prone to this difficulty (again, cf. Figure 1). This gap arose in cognitive research because—at least until the deployment of WinSCAT—cognitive testing had not been integrated into standard flight operations. As a result, studies that span multiple flights are extremely rare and subject counts have consequently suffered. This could change, and may be changing already. In addition, new statistical methods for handing small samples have been developed over the last decade or two, but many have yet to see application in spaceflight studies.

Methodology—standardization: Despite the existence of standardized testing batteries for over 25 years, there has been remarkably little consistency across studies in terms of the cognitive tasks employed. Sometimes performance is evaluated on purely operational tasks. In other experiments, simulations of operational tasks are used. In most cases, however, elemental cognitive tasks have been employed. Within this lattermost approach, different elemental tasks were often used to tap the same putative cognitive function. This has served to further fragment the already small subject counts and compounds the difficulty of making meaningful generalizations about cognitive performance. The military recognized this general problem back in the early 1980s and made efforts to standardize tasks. However, these same concerns have been voiced in the spaceflight community by various sources *(Casler and Cook, 1999; Space Studies Board, 2000)*. While the WinSCAT tests are not necessarily the most sensitive to each cognitive capacity of interest, these tests (or similar ones) have demonstrated sensitivity to other environmental effects such as fatigue *(Batejat and Lagarde, 1999)*, cold *(Slaven and Windle, 1999)* and dehydration *(Cian et al., 2000)*, among others, making them a good step in the right direction. However, WinSCAT does not cover the full range of cognitive functions at risk, particularly excluding (1) emotional processing, (2) social processing (3) tests of fine motor control, and (4) only limited testing of executive functioning, all of which this review found to be quite relevant to long

duration spaceflight. Social and emotional processing measures perhaps represent the largest gap: almost nothing is known about their involvement in cognitive processing in spaceflight, yet emotional state and social performance can seriously and deleteriously impact operational performance.

Methodology—elemental vs. operational: There remains a divide between studies involving complex, operationally relevant tests (e.g., simulated environmental monitoring, docking, or robotic arm manipulation) on the one hand, and studies utilizing tests of elemental cognitive processes on the other. Operational simulator tests are assumed to provide the best predictors of performance on "real" mission operations, but they provide little insight into underlying mechanisms (and hence potential countermeasure approaches). Elemental cognitive tests provide the opposite: presumably inferior prediction of operational performance, but better insight into cognitive mechanisms and therefore more opportunities for countermeasure development. A central NASA decision could be made about which type of test to use in spaceflight research. An alternative is to run experiments to identify spaceflight suitable elemental tasks that are closely associated with operational performance. One such example is the perceptual vigilance test (PVT), or Reaction Self-Test. Developing links between elemental and operational behavior typically requires substantial numbers of subjects. However, ground studies in the lab (or analogs) are likely sufficient to identify and test such links.

Experimental Controls: Because repeated testing on a few subjects is easier to achieve in spaceflight than a small number of tests on many subjects, the majority of spaceflight (and ICE) studies have adopted a longitudinal design. This improves power to detect cognitive effects, but far too often longitudinal designs have been employed with limited control conditions and/or no control participants (see tables). The dearth of controls has seriously limited the interpretability of these studies, as one must assume a detailed understanding of how individuals would have performed in the absence of the experimental manipulations or environmental changes. Such a complete understanding is rarely available, particularly in human cognitive research. For example, many of the studies reviewed above indicated that learning effects may have confounded their findings. This occurred even in cases where the employed tests had well-studied learning curves, known requirements for pre-training, and where subjects were indeed "appropriately" pre-trained prior to flight. If suitably matched control groups had been included, assessment of the learning effect and interpretation of the flight results would still have been possible.

Executive/Attentional/Emotional/Social Processing: As discussed above, there has been almost no attention put towards characterizing or monitoring changes in the perception and cognitive processing of social or emotional stimuli by spaceflight or analog environment participants. Given the numerous reports of social and emotional alterations in such environments, this represents a major knowledge gap. There has likewise been limited investigation of executive function. This also appears to be a prominent gap, given the importance of executive functioning when justifying manned spaceflight, and the unique vulnerability of executive processing brain regions in LD spaceflight. Similarly, only limited aspects of attentional processing have been examined thus far. The addition of the PVT to flight operations will be a major step for assessing sustained attention. However, a gap will remain in terms of evaluating other types of attention (e.g., selective attention, divided attention), as well as executive function, emotional and social processing.

Altered Ambient Environments: NASA has considered using altered ambient environments in future spacecraft, planetary habitats, and EVA suits (e.g., reduced barometric pressures, elevated or reduced O_2, etc). However, the cognitive effects of long-duration exposure to such environments have not been assessed, with design decisions generally based instead on human *tolerance* limits found in the Bioastronautics Data Book ***(Parker Jr. and West, 1973)***. If such environments are indeed going to be considered, a detailed understanding of the cognitive effects of long duration exposure to such atmospheres will be important. Related, and perhaps more immediately important, is the need to evaluate in detail the cognitive effects of chronic dehydration and CO_2 exposure. These have proved to be potent modulators of cognitive performance, and may be both unavoidable and chronic concerns during LD spaceflight.

Radiation: Radiation is a major concern for spaceflight in general, and for deep space exploration missions in particular. Although limited, the existing literature on the effect of radiation on the brain and cognitive processes strongly suggests that long duration radiation exposure, even at relatively low levels, could lead to progressive degeneration of sensitive brain structures. Such adverse effects appear especially likely in brain areas associated with memory, decision making and motor control. However, extremely little is known about the neural consequences of exposure to radiation with a profile similar to that in deep space. This gap should be of major concern. Unfortunately, the gap is also relatively unique to long duration spaceflight, since such radiation profiles are (1) less studied, (2) effects may be slow to appear, yet (3) deficits are likely to be progressive and potentially permanent.

Stress: Spaceflight stressors span a huge range: boredom, heavy workload, difficulties in interpersonal relationships, chronic concern about the danger posed by the ambient environment, background annoyances (vibration, noise, low lighting conditions), and acute concerns following emergencies either onboard spacecraft or back on Earth. There is very strong evidence for both cognitive impairment and structural brain changes due to chronic stress. Moreover, there is considerable circumstantial evidence that the effects of other spaceflight environmental conditions on cognition may be mediated through a stress response. Finally, there is ample literature demonstrating high inter-individual variability in physiological responses to stress. Stress may be of particular concern when combined with radiation, as both conditions appear to negatively affect critical memory and learning regions like the hippocampus and basal ganglia. Thus, there is considerable potential for a "double hit" to these structures, but there is insufficient knowledge regarding how severe such conditions might become. Taken together, the induction rates for stress-related cognitive decline, the magnitude of such declines for long duration spaceflight, and ways to prevent such declines need to be better elucidated.

Drugs and Synergetic Interactions: Knowledge about drug pharmacokinetics and pharmacodynamics in spaceflight is exceptionally limited, and knowledge about drug-drug interactions in spaceflight is essentially non-existent. Knowledge about other synergistic interactions on cognitive function, for example between radiation and heat stress, or between hypoxia and dehydration, is also nearly non-existent. Knowledge of multiple synergistic interactions on human physiology based on ground studies, however, strongly suggest the importance of identifying and investigating those interactions most likely to generate serious cognitive degeneration—particularly those factors with potential for synergistically inducing cognitive performance deficits.

Comparative Evaluations: The multitude of potential causes of cognitive decline in spaceflight begs an important question: which conditions are of most concern? Even for those cognitive domains for which some knowledge exists, there is currently no information regarding the *relative* size of cognitive decrements expected from various spaceflight environmental conditions. For example, will 1% dehydration lead to a bigger or smaller decrement than an increase in core body temperature of 3°C? Or, will a consistent sleep restriction to 5 hours per night lead to decrements larger or smaller than a major solar flare event? Almost no comparative evaluations have been performed. It is therefore not known what the relative cognitive effect sizes are for radiation, stress, sleep deprivation, confinement, inactivity, social isolation, and so on. The one exception is the comparison of sleep deprivation to legal intoxication. While such a comparison captures the attention of the popular press, it can also help provide guidance for future scientific research by identifying those stressors or conditions most likely to be serious enough to affect operational performance in a meaningful way. Such information—which can be collected on the ground—would be particularly useful for operational planning and monitoring, as well as for development of the ongoing research program in this area.

Protective Effects: Not included in this review—because there are no studies in spaceflight or analog environments on the topic—was the issue of identifying countermeasures or, better yet, preventative measures for cognitive decline. A number of studies, particularly in animals, suggest that appropriate exposure to certain stressors—for example, heat-stress—can induce a cascade of physiological responses intended to protect the individual from further or future cellular damage *(Morimoto and Santoro, 1998)*. Up-regulation of this protective cascade appears to have a broad effect: an initial exposure to heat or other suitable environment can protect the individual from cellular damage not only due to heat, but also due to hypoxia, toxins, radiation, and a variety of other insults *(Anekonda and Reddy, 2006; Feige et al., 2008; Hamilton et al., 2003; Kim et al., 2007; Lee et al., 2006; Morimoto and Santoro, 1998; Powers et al., 2001; Rokutan, 2000)*. Brain tissue, and hence cognitive performance, may be one area that is protected by this cascade *(Anekonda and Reddy, 2006; Pallas et al., 2008; Tang and Chua, 2008)*. Moreover, these cascades appear to have a built-in hysteresis such that, once triggered, they can remain effective for extended periods (e.g., days or weeks). However, an objective evaluation of the potential cognitive protective effect in the context of human spaceflight or ICE environments remains to be performed.

10.2. Research recommendations

Since the review by Christensen and Talbot nearly 25 years ago *(Christensen and Talbot, 1986)*, several of their near-term recommendations for cognitive evaluation have been or are being achieved, including: instituting a broadly standardized cognitive battery (WinSCAT), onboard video/audio for behavioral observation, longer duration studies in ground based mock-ups (e.g., MARS 500), expert behavioral observation in-flight, investigation of interactions between personality and group performance, and acquiring in-flight data on perceptual phenomena with operations relevance. However, as of 10 years ago, Casler and Cook's *(1999)* review identified the following open questions based on the then-existing research: is there a cognitive adaptation process or period? If so, how long is it and what is the nature of the process? What is the cumulative effect of exposure to microgravity? Does previous microgravity exposure shorten or eliminate the effect? And, what is the underlying mechanism? Unfortunately, these questions remain open today. Based on the review and gap summary

above, the following specific recommendations have been distilled to help address these and other key questions regarding cognition in LD spaceflight.

Compile and Analyze Existing Data: The present review covers published papers as of January 2010, which likely only includes experiments for which data collection ended some time before approximately 2008. Over the past five years or so, a number of additional studies have been conducted or are underway. In addition, WinSCAT has been in use operationally for much of that period. Outside of NASA, it is currently unclear exactly how much new cognitive data has been collected in flight, how frequently, and how uniformly. The data is of course highly sensitive but—at least in the case of WinSCAT—the data has been collected as part of flight operations over several years, providing substantial anonymity. In addition, although thorough evaluation would require raw data (or at least means and standard deviations for each task during each session), there are only three data identifiers that would be absolutely crucial: (1) the day relative to launch or landing (e.g., launch minus 30 days, launch plus 7 days, or landing plus 1 day, etc), (2) the time of day; and (3) a coded subject number to identify test sessions repeated by the same individual. That should quite thoroughly anonymize datasets, even for most long-duration flyers, yet retain adequate information for analysis of cognitive effects over time. If available and possible, inclusion of any concomitant actigraphy and/or Reaction Self-Test data would be important to titrate out cognitive decrements associated with sleep deprivation. In light of the relatively low volume of evidence published to date, the WinSCAT dataset has the potential to be a tremendous resource. Because of its value, the most sophisticated and modern statistical tools for handling small datasets should be applied to this data. Similar approaches should be considered for any ICE analogs in which WinSCAT has been used, such as Mars 500, NEEMO, or Antarctica.

Long-Duration Spaceflight Experiment: Depending on the amount and kind of data currently available from WinSCAT and other recent studies, seriously and directly addressing cognitive alterations during long-duration missions will likely require an ongoing, standardized, occupational monitoring program specifically to assess cognitive performance during long-duration flights. An appropriately designed program would go a long way toward resolving the discrepancy between frequent astronaut anecdotes—forgetfulness, performance slowing, difficulty thinking clearly, unfocused attention—and the limited data demonstrating cognitive alterations in-flight. Regular, periodic assessments on a carefully chosen set of sensitive cognitive tasks in a substantial number of long-duration flyers (i.e., more than 20) would substantially enhance our knowledge in this area. Ideally, at least some of these flyers should remain on ISS for two (or more) contiguous increments—that is, for 12 or 18 months in-orbit rather than the typical 6 months. This would provide better insight into the potential cognitive (not to mention bone, muscle, and cardiovascular) effects of proposed Mars or asteroid missions. The precise cognitive tasks to utilize in such a study would require careful planning—based in part on the findings from this review, plus input on the amount of time astronauts would be both allowed and willing to devote to the effort. WinSCAT could be tremendously helpful in this endeavor, particularly if the WinSCAT tasks were supplemented with ones involving social and/or emotional processing, enhanced executive function assessment, and fine motor control. Inclusion of quantitative operational evaluations or operationally relevant tests would also be helpful, to allow researchers to identify links between operational performance and performance on elemental cognitive tasks. Once such links are made,

cognitive task batteries could be abridged and individual tasks shortened while maintaining sensitivity to operational concerns.

To address the main criticisms of prior work, such a study also needs to: (1) assess key confounding variables such as sleep status (e.g., via actigraphy and/or EEG), physiological markers of stress (e.g., via cortisol), and affective state (e.g., via POMS), and (2) incorporate sizeable number of ground-based control subjects who are tested on the exact same measures and on the exact same schedule. Mission control crews and backup flight crews are ideal candidates for this, as they are much more closely matched to the astronaut corps than typical convenience samples of control subjects. Statistical accommodation can be made for modifications in the testing schedule due to operational constraints. However, if high compliance and regular testing *can* be achieved, then the effort will require substantially fewer subjects, less time, and less money overall. To maximize the utility of this study, long term follow-up post flight (and follow-up during repeat flights) would also be important, to quantify any re-adaptation benefits from prior microgravity exposure and to assess the cumulative effects of exposure to microgravity. A single, comprehensive study of this sort would go a long way towards addressing ongoing criticisms and the standing recommendations of the 2000 National Academies review of NASA's biomedical research program *(Space Studies Board, 2000)*.

As a corollary, it is strongly recommended that any future studies be rigorously evaluated for their relationship to previous work, for appropriate control conditions, *and* required to include suitable control participants. Of course, incorporating such controls means that research studies will be more costly. However, these should not be considered added costs. Rather, such controls are simply necessary for doing good science, obtaining interpretable results, and for maximizing the information gained from each study.

Long-Duration Antarctic Experiment: Obtaining adequate numbers of participants for a long-duration spaceflight experiment is a multi-year affair at minimum. It is feasible, however, to obtain an even more sizeable population in considerably less time in Antarctica, potentially over 1-2 Antarctic winters. A study similar to the above should thus be conducted, with regular testing via a standardized cognitive battery, measurement of major confounding variables (e.g., stress levels, sleep deprivation, affective state), and incorporating appropriate control groups. While technically the results would generalize only to Antarctic missions, the work would still provide important guidance on what one might expect in terms of cognitive performance changes in LD spaceflight. Because such a study may also provide an opportunity to fine-tune data collection processes and tasks, it would be important to strongly consider conducting such a study prior to embarking on the full LD spaceflight study recommended above.

Altered Ambient Environment Experiments: There are various other environments that are sufficiently likely in spaceflight as to warrant more detailed study. Given that dehydration is a difficult to avoid consequence of spaceflight, and is also a known contributor to cognitive decline, a thorough literature search specifically in this domain, likely followed up by relevant human studies is warranted. A similar argument can be made for CO_2, particularly given the cognitive decrements associated with CO_2 and the existence of a medical operations diagnosis named "CO_2 headache". Positive findings in the existing literature on either topic would suggest follow up using ground-based experiments to

investigate the cognitive effects of dehydration and/or CO_2 specifically at spaceflight-relevant exposure levels.

Methodology – tests: As echoed by Christensen and Talbot *(1986)* and Fowler and Manzey *(2000)*, task batteries can always be improved. Based on the results from this review, sensitive tests should be identified to specifically target: (1) the various aspects of attention, since this is a common anecdotal complaint and existing studies have identified dual-task performance as affected during spaceflight, (2) working and (particularly) long-term memory, another area of anecdotal complaint and limited spaceflight evidence, (3) various aspects of executive function, given the paucity of data and the importance of executive function to the justification of manned space missions, (4) the cognitive processing of social and emotional stimuli, given the high risk of psychosocial alterations in LD spaceflight and the near total lack of information about such processing, (5) fine motor control, given the replicated finding of motor slowing, increased motor variability, and impaired unstable tracking, and (6) selection or development of 1-2 tasks of high complexity and high operational relevance (e.g., docking, or robotic arm manipulation), to help identify links between operational performance and elemental cognitive tasks. This will of course require supplementing or replacing tasks in WinSCAT, but with the benefit of targeting the tasks that are anecdotally claimed to be impaired, that were previously found at risk, or about which our current knowledge is inadequate. This will fill key gaps and provide a comprehensive cognitive assessment.

As part of the task identification process, it would be worth considering a re-evaluation of the existing WinSCAT tasks and data in light of modern statistical tools. The ANAM tasks, upon which most current task batteries are based, including WinSCAT, were originally ranked and selected based on how well they met assumptions for traditional ANOVA analysis. However, multi-level regression *(Pinheiro and Bates, 2000)* and growth curve analysis *(Singer and Willet, 2003)* are more appropriate tools for the types of research typically performed in ICE environments—techniques which essentially did not exist at the time the test batteries were initially developed. These newer analysis techniques have somewhat different statistical requirements than ANOVA. A combined literature search and statistical re-analysis of existing data and norms in terms of reliability, validity and responsiveness of each measure would improve our ability to optimally select component tests for inclusion in any ICE battery for use with modern statistical analyses. Tasks may also be able to be shortened in duration, if modern tools provide greater power to detect changes in performance; this remains to be evaluated.

Finally, an important but potentially challenging additional enhancement—also recommended by Christensen and Talbot *(1986)*—would be to develop and deploy *embedded* tasks *(Gawron, 2008)*, and associated data analysis strategies, that enable unobtrusive cognitive monitoring of space- and/or ground-crews on multiple cognitive factors. This would effectively reduce the cognitive testing time to (near) zero and raise the compliance to 100%, making it an exceptionally worthwhile, if challenging, goal to achieve.

Effect Size Studies/Comparisons: One criticism that has regularly recurred is the claim that the cognitive tasks used in any given study lack adequate sensitivity. While this criticism is difficult to refute directly, it is quite possible to work around the criticism by putting the cognitive effects of spaceflight in a useful context. Doing so requires two steps. First, cognitive measures collected during spaceflight need to be parameterized, which is normally achieved via regression analysis (as opposed to ANOVA analysis)

on the raw data. This step thus provides various quantitative assessments of effect sizes. This can be done with most any raw data, including raw WinSCAT data. Second, one needs to conduct (or compile data from) studies that in suitable comparison environments, using the exact same tasks, ideally (but not necessarily) collected on the same time scales. Example manipulations might include chronic sleep restriction, alcohol intake, dehydration, CO_2 exposure, or workload. Regression analysis of cognitive performance in these conditions can then provide a second set of quantitative parameters. These parameters can, in turn, be directly compared to the parameters from spaceflight. In this way, one might show that spaceflight produces cognitive deficits equivalent to (e.g.) 1 oz. of ethanol, or 3 days of 5-hr sleep restriction, or 1% dehydration. While this approach does not refute the sensitivity concern, it can put such concerns in perspective and simultaneously help rank the severity of various environmental conditions relevant to spaceflight. This has been used quite effectively in the sleep literature, where they have compared a single night sleep deprivation to the effect of being legally intoxicated *(Elmenhorst et al., 2009)*. A similar series of studies should be implemented to rank individual spaceflight stressors in terms of cognitive effect: dehydration, CO_2 exposure, sleep deprivation, heat stress, cold stress, confinement, social isolation, and so on. Most importantly, nearly all such comparison studies could be conducted entirely on the ground.

Radiation: Developing a human research program to investigate the effects of space radiation on central nervous system function presents numerous unique challenges. First, human investigation in this area is necessarily limited to observational studies of flight crews. For the foreseeable future, missions will be confined to LEO, where radiation exposure will not match that expected during longer duration missions to the Moon or Mars. Thus, it may be difficult to gather sufficient clinical data to allow accurate extrapolation with respect to CNS effects of longer missions outside the protection of the magneto-sphere. Second, most of the knowledge concerning the effects of ionizing radiation on the human CNS derives from studies of the consequences of medical radiation or atomic bomb blasts. As neither of these situations mimic the quality or fluency of radiation expected to be encountered by crews during LD missions, extrapolation from the current clinical knowledge base is likely to be of limited value. Third, while it is possible to use translational research approaches to study the neural effects of space radiation in animal models, establishing causal links between alterations in human higher cognitive processes and space radiation exposure will be difficult without the use of non-human primates.

That said, it is particularly important to try and characterize, or begin to place bounds on, the cognitive and cerebral effects of spaceflight radiation. In particular, the likelihood of brain structure changes associated with spaceflight needs to be assessed, with particular attention paid to hippocampal and striatal atrophy, alterations in prefrontal cortex function, and damage to cerebral white matter. Occupational monitoring of flight crews in LEO (e.g., detailed neuroimaging pre- and post-flight, combined with individualized radiation dosimetry measures) should be instituted to provide a lower bound on these effects. This approach could be reasonably sensitive if achieved on a large fraction of ISS flight crews. If changes are observed after 6 month LEO missions, one would expect substantially larger effects from long flights into deep space. Animal studies can be utilized to more thoroughly test the effects of deep-space radiation profiles, though care will be needed to properly select dose-equivalents for brain tissue. Finally, another useful guide should be considered: translational studies exploring the molecular, structural and cognitive changes associated with *in utero* radiation exposure *(Verheyde and*

Benotmane, 2007). The developing nervous system is highly sensitive to the effects of ionizing radiation because of its high proportion of rapidly dividing neural precursor cells. Irradiation triggers disturbances in cell proliferation, migration, and differentiation. At sufficient doses, these process cause structural abnormalities. Later, cognitive and sensorimotor impairments can be observed that result from the radiation-induced atypical neural development. Although CNS effects of ionizing radiation are milder in adults, the developing nervous system may represent a useful limiting case in examining the more subtle effects of space radiation.

Chronic Stress: Cognitive deficits in flight may be related more to the individual's perception of the environment as stressful, or to vulnerability factors, than to the spaceflight environment in general. Thus, research to help identify behavioral or biological markers of stress-vulnerable or stress-resistant individuals, and to enhance the stress resistance and/or the stress management capabilities of astronauts is strongly encouraged. Potential countermeasures to consider, beyond the computer-based therapy programs currently under development, might include relaxation, meditation or imagery techniques (all of which require no upmass and modest training), biofeedback, pharmacological approaches, or the use of autonomy as opposed to external control of required activities *(Levine, 1991)*. Cognitive evaluation should be conducted during associated studies to quantify the role that individual variability in the stress response plays in modulating cognitive functioning, both acutely and chronically.

Interactive Effects: Almost nothing is known about the interactive effects of the spaceflight environment on cognition, ranging from drug-drug interactions, to the residual effects of sleep medications plus microgravity, to radiation plus social/emotional stress. The effects of interactions, however, are of considerable concern operationally (Jonathan Clark, personal communication). The substantial number of potentially interacting stressors unfortunately leads to a large search space. Hence, it would seem most prudent to begin with the table generated by Ushakov *(1996)* (see also in Figure 5 herein) to help predict likely cases of synergistic effects and begin testing there. For example, microgravity, heat, radiation and vibration all appear to have mutually additive or super-additive effects biologically, and hence potentially super-additive cognitive effects, making these prime stressors to investigate jointly in ground-based studies. This approach should ideally be combined with the comparative effect size analysis approach discussed above, to allow ranking not only of individual stressors, but of interacting stressors as well.

Extreme Isolation: With the exception of a single research subject, there has been no experimental investigation of long-term (>1 year) extreme isolation and confinement on individual cognitive behavior. Achieving such isolation is complicated by practical and ethical issues. Realistic simulations should include an expectation of a long-duration commitment (even if that commitment is ultimately shorter than anticipated), time-lagged communication with ground crews, a delayed ability to "escape" the chamber, quite severe isolation and sensory restriction including external views of only the stars and limited views of earth, altered lighting, extended periods of low activity (e.g., boredom), and so forth, all of which are expensive conditions to engineer. However, it is the combined force of this mix of stressors that is an overriding concern for LD spaceflight from neurobehavioral and psychosocial perspectives. The Mars 500 is an excellent opportunity in this domain. It is important to emphasize that the ISS also presents an excellent opportunity, particularly if some astronauts can remain for longer durations than the typical 6-month ISS increment. It will be critical to maximize the utility of such projects, and closely

related ones, to help assess the cognitive effects of the truly long-duration isolation and confinement of exploration missions.

Protective Effects: The concept of using pre-flight exposure to heat-stress (or other type of environment) to inoculate individuals against the cognitive decrements of spaceflight has a fairly low countermeasure readiness level (CRL 2-3). However, the notion that such inoculation might be possible is exceptionally appealing—not only for cognition, but in other domains as well—and at initial review the evidence in support of this approach appears remarkably strong. As a first step, a thorough and objective literature review of the domain is warranted and, if promising, support should be made available for pilot studies in animals or humans to investigate the feasibility of this type of preventative countermeasure development.

11. Conclusions

To date, humankind has embarked on more than 300 missions, and logged well over 31,200 person-days in space. Approximately two thirds of these person-days were from missions lasting longer than 21 days. Despite this, the evidence regarding cognitive effects of spaceflight and its various stressors in low earth orbit (LEO) has no less than four notable limitations: (1) extremely small subject populations, particularly for missions lasting more than 90 days, (2) experimental designs afflicted by learning confounds, and inadequate or non-existent control groups, (3) tasks that are rarely comparable across studies and hence cannot be pooled, and (4) certain key cognitive functions remain completely untested. While the available data suggests which cognitive capacities may be affected during spaceflight, the current body evidence is inconclusive. Moreover, essentially nothing is known about what effect multi-year flights into deep space might have on cognitive capacities.

The opportunity now exists, however, to develop a solid understanding of the cognitive effects of long-duration LEO missions—at least 6 months, and ideally 12 months or longer—using experiments and monitoring aboard the International Space Station and ground-based analogs. Such work should be initiated soon, since such studies require time to design and conduct and, if serious concerns are identified, prevention methods and countermeasures need to be developed. Appropriate use of key Earth analogs—principally Antarctica and submarines, but others as well—may help greatly speed the knowledge gathering process. Parallel work on the ISS is essential, however, given the unique mix of stressors during flight.

Knowledge gathering and countermeasure development efforts for cognitive alterations in LD spaceflight are likely to be as important as protection from radiation and prevention of bone and muscle loss. Intact brain and cognitive functioning will be critical to astronaut health and mission success in all future long duration spaceflights; hence, NASA should do all it can to understand and mitigate the risks to the brain and cognitive functioning in support of exploration class missions.

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