NASA/TM–2006-213491

Converging Indicators for Assessing Individual Differences in Adaptation to Extreme Environments: Preliminary Report

Patricia S. Cowings, William B. Toscano, Charles W. DeRoshia, Bruce Taylor, Seleimah Hines, Andrew Bright, and Anika Dodds
Human Systems Integration Division
Ames Research Center, Moffett Field, California

September 2006

The NASA STI Program Office . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the Lead Center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.
- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.
- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.
- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.
- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.
- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results . . . even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at *http://www.sti.nasa.gov*
- E-mail your question via the Internet to help@sti.nasa.gov
- Fax your question to the NASA Access Help Desk at (301) 621-0134
- Telephone the NASA Access Help Desk at (301) 621-0390
- Write to:
  NASA Access Help Desk
  NASA Center for AeroSpace Information
  7121 Standard Drive
  Hanover, MD 21076-1320

NASA/TM–2006-213491

Converging Indicators for Assessing Individual Differences in Adaptation to Extreme Environments: Preliminary Report

Patricia S. Cowings, William B. Toscano, Charles W. DeRoshia, Bruce Taylor, Seleimah Hines, Andrew Bright, and Anika Dodds
Human Systems Integration Division
Ames Research Center, Moffett Field, California

National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035-1000

September 2006

Available from:

NASA Center for AeroSpace Information
7121 Standard Drive
Hanover, MD 21076-1320
(301) 621-0390

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

CONVERGING INDICATORS FOR ASSESSING INDIVIDUAL DIFFERENCES IN ADAPTATION TO EXTREME ENVIRONMENTS: PRELIMINARY REPORT

Patricia S. Cowings,[1] William B. Toscano,[1] Charles W. DeRoshia,[1] Bruce Taylor,[2] Seleimah Hines,[3] Andrew Bright,[4] and Anika Dodds[5]

Ames Research Center

SUMMARY

This paper describes the development and validation of a new methodology for assessing the deleterious effects of spaceflight on crew health and performance. It is well known that microgravity results in various physiological alterations, e.g., headward fluid shifts which can impede physiological adaptation. Other factors that may affect crew operational efficiency include disruption of sleep-wake cycles, high workload, isolation, confinement, stress and fatigue. From an operational perspective, it is difficult to predict which individuals will be most or least affected in this unique environment given that most astronauts are first-time flyers. During future lunar and Mars missions space crews will include both men and women of multi-national origins, different professional backgrounds, and various states of physical condition. Therefore, new methods or technologies are needed to monitor and predict astronaut performance and health, and to evaluate the effects of various countermeasures on crew during long duration missions. This paper reviews several studies conducted in both laboratory and operational environments with men and women ranging in age between 18 to 50 years. The studies included the following: soldiers performing command and control functions during mobile operations in enclosed armored vehicles; subjects participating in laboratory tests of an anti-motion sickness medication; subjects exposed to chronic hypergravity aboard a centrifuge, and subject responses to 36-hours of sleep deprivation. Physiological measurements, performance metrics, and subjective self-reports were collected in each study. The results demonstrate that multivariate converging indicators provide a significantly more reliable method for assessing environmental effects on performance and health than any single indicator.

STATEMENT OF THE PROBLEM

This paper describes the development and validation of a new methodology for assessing the deleterious effects of spaceflight on crew health and performance. In space, the absence of gravity alone causes unique physiological stress. Significant biomedical changes have been reported across multiple organ systems such as body fluid redistribution, diminished musculoskeletal strength, changes in cardiac function, and sensorimotor control and spatial perception (ref. 1). The time course of development of these disorders and the severity of symptoms experienced by individuals varies widely. Added to our knowledge of these micro-g effects on physiology and potential negative impacts on crew operational efficiency, is the body of research on behavioral effects of isolation, fatigue, workload (ref. 2); adverse environmental conditions (e.g., noise, vibration, extremes in temperature) and psychosocial or interpersonal conflicts. People vary considerably in their abilities to tolerate stress and function effectively. Future space crews will include both men and women of different cultures, different professional backgrounds, and various levels of physical conditioning. Consequently, it will be necessary to develop technologies which examine

[1] Human Systems Integration Division, Ames Research Center, Moffett Field, California 94035.
[2] Professor, Department of Biomedical Engineering, University of Akron, Akron, Ohio 44325.
[3] National Research Council Postdoctoral Associate, Ames Research Center, Moffett Field, California 94035.
[4] Research Associate, Warwick Medical School, Coventry, CV4 7AL, United Kingdom.
[5] Research Assistant, Foothill College, Los Altos, California 94022.

unique characteristics of individuals in extreme environments, the effects on crew operational efficiency, and effective interventions for counteracting adverse effects.

The broad objective of our research program is to study individual characteristics of human adaptation or functional state. The term "functional state" is defined as the physiological and psychological state during which performance is highest (refs. 3-5). To achieve this goal, investigators have developed protocols designed to accurately **assess** and **predict** spaceflight effects on crew health, safety, and operational performance. Once identified, protocols may also be used to evaluate and test countermeasures that will **correct** adverse reactions.

The National Aeronautics and Space Administration's (NASA's) human space program is currently using cognition metrics as the primary method for self-assessing environmental and interpersonal effects on crew functional state or behavioral health (refs. 6–8). There are only two cognitive test batteries in use aboard the International Space Station (ISS); Spaceflight Cognitive Assessment Tool for Windows (WinSCAT) (refs. 9, 10) and MiniCog (ref. 11). The purpose of these test batteries is to allow comparison of preflight baseline performance of astronauts to that observed prior to high-risk activities during flight (e.g., EVA, docking; during periods of heavy workload; during sleep/circadian shifting; and whenever a crewmember desires a self-assessment). These tools are intended to provide an early warning alert to indicate when an astronaut is suffering from stress-related deficits, such as high workload, that may affect performance. They can use the information alone or as part of a team. Users can be warned to pay additional attention and take extra care, take a break, consume food or caffeine, or even take a nap. As a medical tool, it could also be used following adverse events to evaluate the cognitive effects of head trauma, toxic exposure, and side effects of various medications.

A potentially serious flaw identified for both of these cognitive assessment tools is the "ceiling effect," in which performance metrics may peak at the same asymptotic level. This may ultimately result in severely reduced effectiveness for assessing prodromal or sub-clinical spaceflight effects on functional state. The ceiling effect occurs when subjects achieve a perfect score (100% correct) on subtests in these batteries, in which the number of total subtest presentations is constant. Performance ceilings are undesirable because there is no discrimination measurable between subjects at the ceiling level (ref. 12). Often, performance tests will reveal this defect through a gradual reduction in between-subject variance (refs. 13, 14) where the data include ceiling scores. This means that reduced performance variance near the ceiling levels will be an unreliable estimate of population performance variability. These tests may show effects of severe trauma but not be sufficiently sensitive to assess or predict changes in operational efficiency and subsequent impacts on crew health and safety.

Self-report scales, diaries, and post-flight debriefings have been used routinely to evaluate physical symptoms, changes in mood, and interpersonal conflicts between crew members or crew and ground support personnel. With the exception of operational medicine procedures associated with screening candidates for selection as astronauts, and recommended preflight psychosocial education training programs, NASA has devoted very little work to develop behavioral assessment tools and interventions that may be used inflight. Present knowledge of the incidence and severity of abnormal behaviors during spaceflight has been obtained largely anecdotal. At a recent NSBRI workshop on cognition research in space (ref. 15), three concerns were identified as relevant to Behavioral Health Management: (a) Biomarkers—what are the objective physiological correlates of cognition? (b) Modeling—what information is needed to develop predictors of impaired cognition? And (c) Crew Compliance—what can be done to assure crew use of these assessment tools?

A NEW APPROACH—CONVERGING INDICATORS

The underlying premise of this paper is that no single metric, cognitive test, physiological marker or subjective report, is sufficient when used alone to assess an individual crewmember's functional state. A single indicator (e.g., subjective reports) may result in a false positive or negative assessment, whereas multiple indicators enable cross-validation and account for individual variability. During current ISS missions, in-flight physiological measures have been used primarily as a means of diagnosing and/or correcting biomedical problems associated with exposure to microgravity. There is a paucity of data available on the use of physiological measures as correlates of performance and behavioral states of crew in space. Although subjective reports have been standardized, with terms defined and numeric values assigned to "severity" of symptom or mood change experienced, these measures are less reliable since people differ in their ability to interpret, recognize, and willingness to report negative reactions. Gender and cultural differences in the perceived utility or value of these tools impact their efficacy and crew compliance.

In the scientific and medical literature there is a considerable body of work that discusses psychophysiological measures of emotion, performance, workload, and other aspects of operator functional state (refs. 4, 16). A common methodology employed in many of these studies (refs. 17–20) is multiple **converging indicators**: physiological measures, subjective reports, and measures of overt behaviors. In studies of human emotion or affective states (ref. 21), measures of overt behaviors include expressive language, vocalization measures (ref. 22); voice stress measures (ref. 23), performance metrics (e.g., reaction time), and observable facial expressions (ref. 24). Physiological responses add power to the evaluations by providing data that are not readily observable, yet are known to be reliable, objective indicators of emotion (central and peripheral nervous system; neuroendocrine function).

NASA researchers have used ambulatory measures of autonomic responses in combination with performance metrics and subjective self-reports to assess individual differences in functional state in laboratory studies (refs. 25–29) operational field tests (refs. 30, 31), during long and short duration space flight (refs. 32–37), and during studies of small group interactions (refs. 38–40). Other human factors researchers have extensively recorded measures of brain activity associated with fatigue and hazardous states of awareness within aviation environments (ref. 41).

This paper reviews the data of selected test participants from four studies where multiple converging indicators were used to assess individual differences in tolerance to environmental stressors.

METHODS
(Common to all studies described)

Subjects

Both men and women, ages 18 to 50, civilian and active duty military, participated in these studies. All research was approved by the NASA-Ames Human Research Institutional Review Board (and other institutional boards of specific collaborating agencies or universities) before tests were initiated. Voluntary informed consent was obtained in briefings by the Principal Investigator and medical monitors. All subjects were medically approved for participation and excluded if they were pregnant, taking medication, had a chronic medical condition or histories of medical or mental disability.

Physiological Measures

An ambulatory physiological monitoring system was used in all studies. Measures recorded with this system included: (a) electrocardiograph; (b) respiration; (c) finger pulse volume (peripheral vasomotor activity); (d) skin temperature; (e) skin conductance level and (f) a triaxial accelerometer (measuring head and upper body movement). Other non-ambulatory measures included blood pressure and impedance cardiography.

Performance Measures

The Automated Portable Test System (APTS) cognitive performance test battery or its upgraded successor, DELTA, were used in these studies. Both batteries have been shown to have excellent stability and reliability (ref. 13), and exhibited no ceiling effects since the test software provided the opportunity for subjects to achieve higher levels of performance scores by increasing performance test speed (ref. 12). The APTS was developed with emphasis on within-subjects, repeated-measures designs, and has been proven both reliable and valid in a number of investigations, and administration takes approximately 15 minutes or less, depending upon the test battery configuration. The DELTA test battery has been used extensively to study the effects of environmental and chemical stressors on human performance, and measures 67% of the aptitudes and abilities required to perform various real life space shuttle performance tasks (ref. 43), as analyzed by the Position Analysis Questionnaire (ref. 6).

The sub-tests used in the studies described include (a) three-choice reaction time; (b) code substitution; (c) pattern comparison; (d) manual dexterity (preferred and nonpreferred hand tapping); (e) grammatical reasoning ability; and (f) spatial transformation (perceived position). Using the data from this performance battery, the level of impairment experienced by subjects can be expressed as a Blood/Alcohol Level Equivalency (BAL%). A detailed description of test methods is provided in another paper (refs. 31, 44).

Self-Reports of Symptoms

A computer program allowed the subject to rate his/her own symptoms using a standardized diagnostic scoring procedure (table 1) referred to as the Coriolis Sickness Susceptibility Index, or CSSI (refs. 31, 45). The presence or absence and/or strength of symptoms were assessed subjectively by the subject (none “0”, mild "1,” moderate "2,” or severe "3"). These symptoms included drowsiness, sweating, salivation, pallor, and nausea. Other symptoms were scored as “none, mild or moderate” levels only. These included increased warmth, dizziness, and headache. Stomach awareness and discomfort (not nausea) are only rated as “mild.”

Self-Reports of Mood and Sleep

A 10-point Visual-Analog Scale (VAS) mood test was used to input responses to questions. The subject moved a cursor on a slide bar presented on his screen with the left/right arrow keys. There were descriptive adjectives at each end of the slide-bar, and the subject’s task was to position the cursor to enter his/her response (see table 2). A higher score for each mood state corresponds to a more favorable response. The test included eight mood scales and two sleep questions (ref. 46). The Active Mood Dimension reflects readiness to perform and includes a composite of fatigue level, arousal state, motivation to perform, and ease of concentration. The Affective Mood Dimension which reflects the subject’s perception of his readiness to perform included a composite of physical discomfort, elation, psychological tension, and contentedness. The “trouble falling asleep” question was scored from “much worse” (score = 0) to “much better” (score = 10), relative to the sleep quality during the previous night. The other sleep quality scale reported the number of times the subject woke up during the previous night.

TABLE 1. SYMPTOM DIAGNOSTIC SCALE

Severity Level	none	mild	moderate	severe
	0	1	2	3
Are you feeling warmer?				*
Do you have any dizziness?				*
Do you have a headache?				*
Are you drowsy?				
Are you salivating more?				
Do you have facial pallor?				
Are you sweating?				
Do you feel stomach awareness?			*	*
Do you have stomach discomfort?			*	*
Do you have any nausea?				
Have you vomited today?	yes_____		no______	
If yes, how often?				

* indicate the severity level does not apply to these symptoms

TABLE 2. MOOD/SLEEP SCALE

Mood State	Response Scale				
Motivation	Bored	(0) ------------------------	Interested	(10)
Arousal state	Sleepy	(0) ------------------------	Alert	(10)
Fatigue level	Weary	(0) ------------------------	Energetic	(10)
Ease of concentration	Very low	(0) ------------------------	Very high	(10)
Psychological tension	Tense	(0) ------------------------	Relaxed	(10)
Elation	Sad	(0) ------------------------	Happy	(10)
Physical discomfort	Very high	(0) ------------------------	Very low	(10)
Contentedness	Unpleasant	(0) ------------------------	Pleasant	(10)
Trouble falling asleep	Much worse	(0) ------------------------	Much better	(10)
How many times did you wake up last night?		(0–6)?	Amount____________	

STUDY 1: Effects of Command and Control Vehicle (C2V) Operational Environment on Soldier Health and Performance

A demonstration of the practical application of the converging indicator methodology under operational conditions occurred during a study performed in collaboration with the U.S. Army (ref. 31). The purpose of the study was to evaluate the effects of mobile operations on soldier health and performance in the Command and Control Vehicle (C2V, an armored tracked vehicle containing four computer workstations). The planned use for the C2V was to enable command decisions to be made in the field under combat conditions. However, there was a concern that soldiers might experience motion sickness symptoms that could impact their ability to carry out their mission objectives.

In this study, there were three vehicles with different interior configurations: (a) all seats facing forward, (b) all seats perpendicular to the direction of travel, and (c) three seats set at 45 degrees from the front with one seat facing forward. The primary objective was to determine if motion sickness occurred and if so, under what operational conditions. Other objectives were to determine if seat position or orientation was related to severity of symptoms, and what percentage of soldiers showed degradations in performance, health, or mood. Twenty-four soldiers (16 men and 8 women) participated, with each person riding in the C2V during 4-hour operational tests over a varied terrain. Each participant rode 12 times, once in each seat of each vehicle. Prior to these field tests, all participants received classroom instructions on the PC-based performance test battery, symptom and mood scales. Physiological, performance, mood and symptom data were collected during field tests.

Results

Detailed results of this study are reported in another paper (ref. 31). In summary, the results obtained were sufficient to answer the questions posed by the Army, and to successfully validate the assessment methods developed by NASA, thereby accomplishing important goals for both federal agencies. The preponderance of evidence provided by multiple converging indicators used in this study have led to the following conclusions: (a) there was no significant difference between vehicle configurations; (b) there was negative impact on crew performance and health when subjects attended to visual computer screens while the vehicle was moving; (c) the severity of symptoms and performance degradation were not substantially reduced by intermittent short-halts, and (d) performance and mood were impaired in the vehicle during the park condition, relative to pre- and post tests conducted in a classroom facility.

The performance scores of test participants, averaged across all twelve field test exposures, are listed in table 3. The table shows mean test percentages relative to classroom training (left) and these scores converted to BAL% scores (right). Subjects are ranked from best performance to worst (BAL% ≥ 0.85 is the legal limit for automobile operators in most states).

By comparing the three subjects with the highest performance scores and three with the lowest performance scores, we can see how the converging indicator method can be used to describe individual differences. Subjects 12, 17, and 4 had good performance scores, while subjects 22, 14, and 16 had poor performance.

Figure 1 shows the performance scores and self-reported mood and symptoms experienced by six subjects during one 4-hour field test in the C2V. The degree of performance impairment in general (composite) and for each specific sub-test is shown as calculated BAL% scores across conditions of the field test (P = parked, M = moving, S = short halt or stationary). With no ceiling effect, Delta tests allow comparison of skill levels across subjects, enabling a determination of which subject might be best capable of performing specific tasks at any given time. For example, all three "good performers" showed composite scores lower than 0.08 BAL% (double horizontal line), but subject 17 showed more impairment on pattern recognition than either subjects 12 or 4. Because this specific sub-test is relevant to a needed mission skill, in this case map or radar reading, a decision could be made to not assign this task to subject 17 if the other subjects are available. Similarly, although all of the "poor performers" showed composite scores well above the 0.08 level, subject 22 would be better prepared to perform pattern recognition tasks more accurately than either subjects 14 or 16.

TABLE 3. INDIVIDUALS RANKED BY PERCENT PERFORMANCE CHANGES AND BAL%

SUBTEST MEAN PERCENTAGES				BAL% EQUIVALENCE			
Subject	Park	Move	S-halt	Subject	Park	Move	S-halt
4	9.61	0.45	3.85	4	0.000	0.000	0.000
12	8.73	6.99	3.93	12	0.000	0.000	0.000
19	10.42	4.84	7.66	19	0.000	0.000	0.000
17	1.28	–0.79	2.46	17	0.000	0.008	0.000
11	5.21	–3.03	1.95	11	0.000	0.031	0.000
2	3.49	–3.52	3.76	2	0.000	0.036	0.000
5	–0.60	–3.69	–3.71	5	0.006	0.038	0.038
8	–5.20	–4.06	–1.98	8	0.052	0.041	0.020
1	3.86	–5.08	–5.31	1	0.000	0.051	0.053
18	–3.29	–5.19	–5.74	18	0.034	0.052	0.055
9	–3.01	–5.32	–2.94	9	0.031	0.053	0.030
21	2.41	–6.97	–3.69	21	0.000	0.062	0.038
10	–2.88	–8.51	–6.18	10	0.029	0.071	0.058
20	–0.62	–8.81	0.52	20	0.006	0.073	0.000
6	5.87	–8.86	–8.53	6	0.000	0.073	0.071
15	–4.29	–10.53	–5.36	15	0.044	0.083	0.053
13	0.32	–11.66	–4.53	13	0.000	0.089	0.046
3	1.85	–11.98	–6.73	3	0.000	0.091	0.061
24	–5.74	–15.39	–10.54	24	0.055	0.111	0.083
23	–6.00	–15.64	–18.08	23	0.057	0.113	0.127
22	–10.13	–17.70	–11.33	22	0.081	0.124	0.088
14	–15.80	–20.89	–11.98	14	0.113	0.143	0.091
16	–20.43	–32.62	–25.24	16	0.140	0.211	0.168

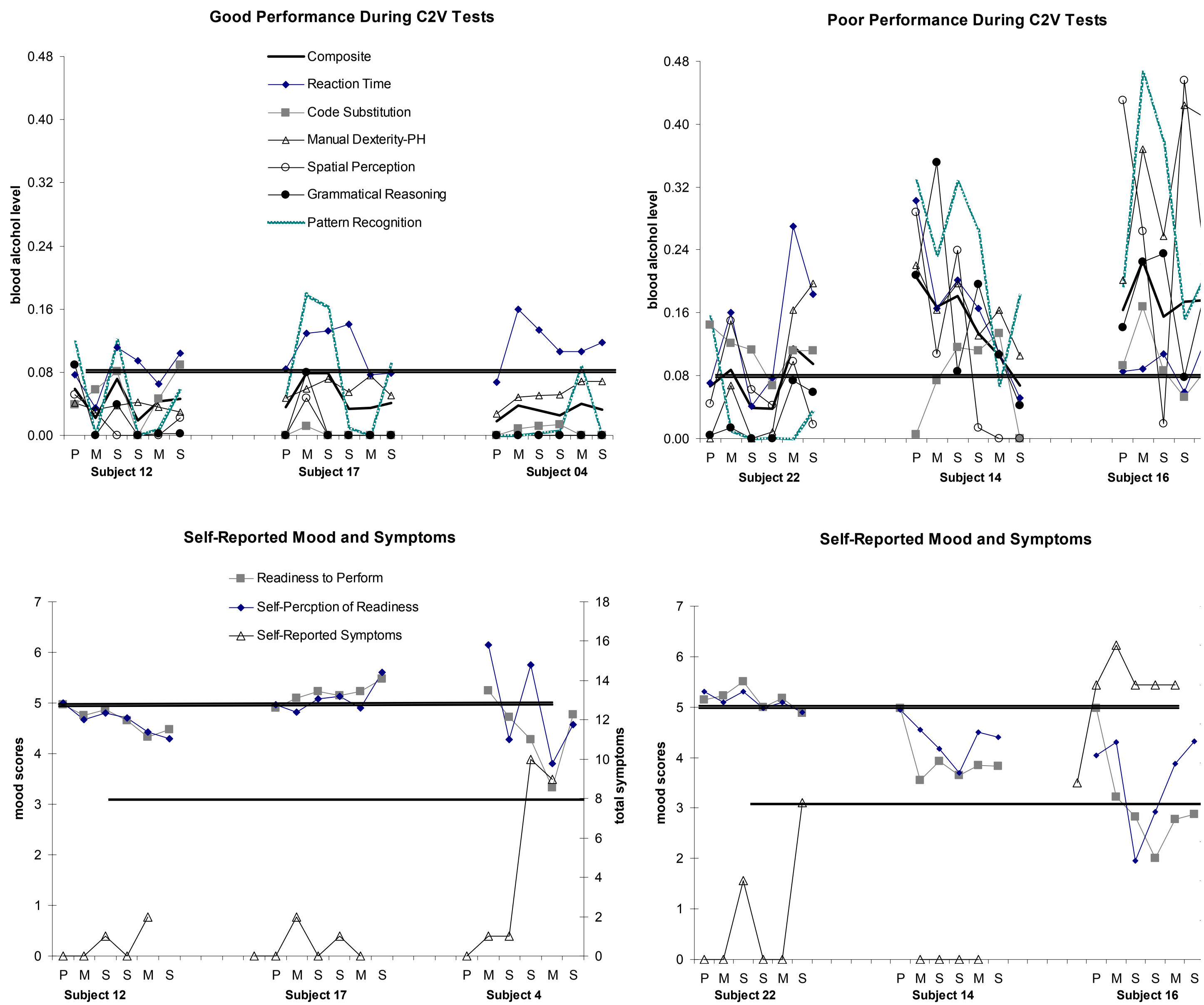


Figure 1. Performance and self-reports during a 4-hour field test in the C2V.

Self reports of mood and symptoms experienced for good and poor performers are graphed below their performance test scores. Mood scores are shown on the left axis (double horizontal line at 5 indicates "normal" mood for each subject), and total symptoms are on the right axis of each graph (dark horizontal line at 8 symptoms indicates severe malaise level). Self reports are, by definition, "subjective" and these graphs show how reliable such reports are as indicators of each individual's ability to perform specific tasks. For the "good performers" both subjects 12 and 14 are showing mood scores (readiness to perform and self-perception of readiness) near to their own normal levels. Similarly, both of these subjects reported very low levels of malaise. Subject 17, however, began to experience severe malaise toward the middle of the field test (symptom scores higher than 8), with a corresponding decline in mood scores which preceded symptom reports. Among poor performers, subject 22 showed no decline in mood yet symptoms experienced tended to wax and wane across the field test. Subject 16 experienced severe malaise throughout the 4-hour field test with a corresponding degradation of mood. Subject 14, however, reported no symptoms at all, even though mood scores for both readiness to perform and perceived readiness showed degradation from the norm.

Figure 2 shows the physiological responses of all six subjects during the same field tests in which their performance, mood, and symptoms were recorded. The graph on the left shows (top to bottom) heart rate, skin conductance, and skin temperature of subjects with good performance scores, and the right side of this figure shows corresponding measures for the poor performers. Although performance tests and self-reports were administered only 6 times during field tests, physiological data were recorded continuously and are displayed as one-minute means across conditions (P = park, M1 = first movement, S1 = first stationary condition, etc.). Good performers produced less variability in response levels for skin conductance and skin temperature than did the poor performers. Further, subject 14, who reported no symptoms but showed degraded performance, produced higher heart rate and skin conductance with greater variability than the other subjects. These physiological levels are indicative of higher stress and are consistent with observed poor performance of this subject.

Previous research (refs. 25, 26, 28, 29) has shown that it is optimal to record at least four physiological measures in order to determine individual stress profiles: heart rate, skin conductance, peripheral vasomotor activity, and respiration rate (not graphed). At least one or more of these parameters can be used to define an individual stress profile.

STUDY 2: Promethazine as a Motion Sickness Treatment: Impact on Human Performance and Mood States

Intramuscular (IM) injections of promethazine in 25 mg or 50 mg dosages are commonly used to treat space motion sickness in astronauts. A recent study examined the effects of IM. injections of promethazine on performance, mood states, and motion sickness in humans (refs. 47, 48). Twelve men, mean age 36 ±3.1, participated in one training day and three treatment conditions: a 25-mg injection of promethazine, a 50-mg injection of promethazine, and a placebo injection of sterile saline. Each condition, scheduled at 7-day intervals, required an 8–10 hr day in which subjects were tested on 12 performance tasks, and were given a rotating chair motion sickness test. On the training day subjects were trained on each task to establish stability and proficiency. Treatment conditions were counterbalanced and a double-blind procedure was used to administer the medication or placebo.

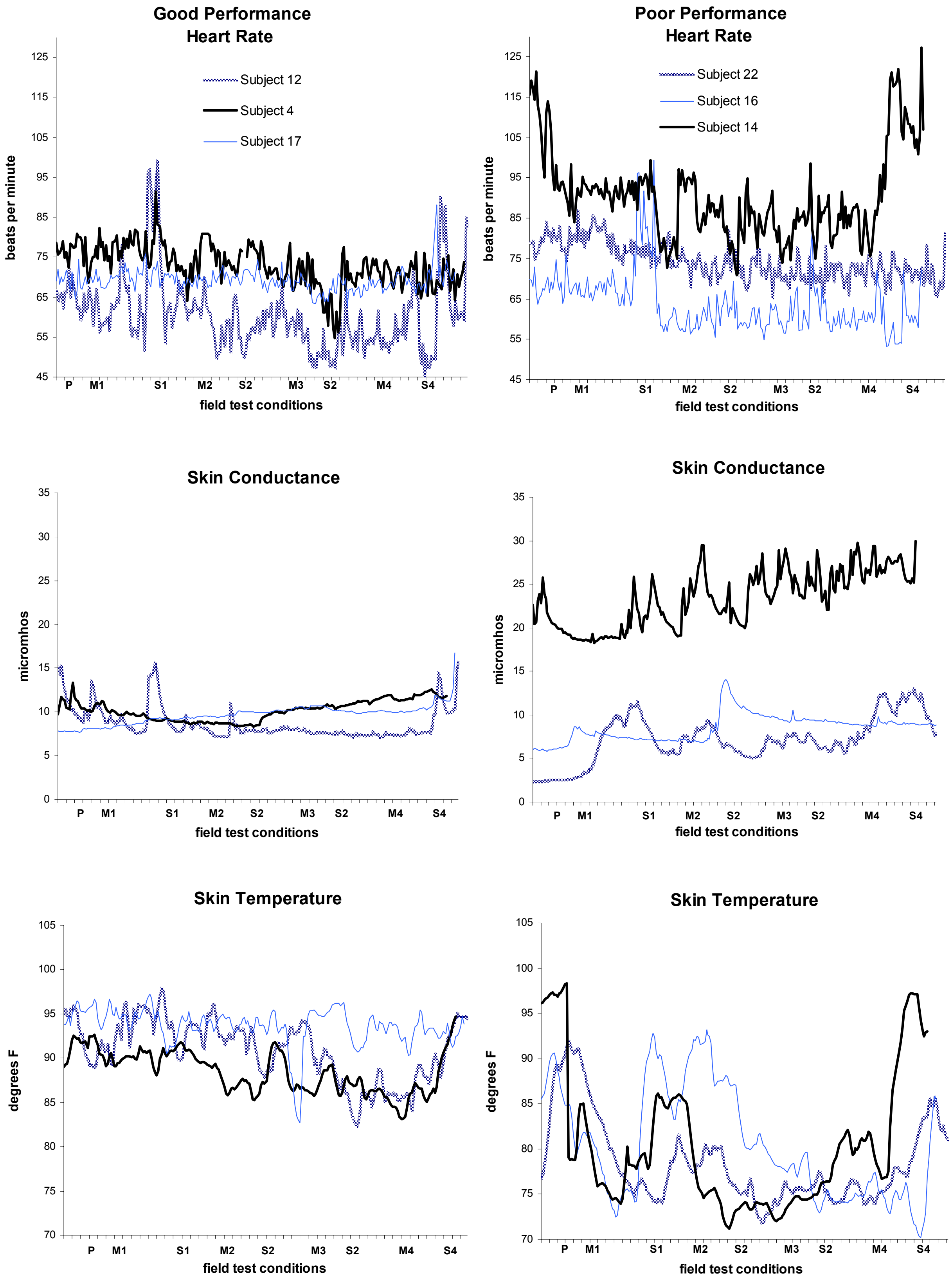


Figure 2. Physiological responses of good and poor performers during a C2V field test.

Results

Table 4 shows the average BAL% scores of each subject recorded at 1 and 4 hours following IM injections of promethazine doses of 25 mg and 50 mg. Analyses of group data found that statistically significant decrements in performance were observed for both dosages of promethazine as compared to the placebo. Performance decrements were associated with mean blood alcohol equivalency levels of 0.085% for 25-mg and 0.137% for 50-mg doses. Mood scale results showed significant changes in individual subjective experiences with maximum deterioration in the arousal state and fatigue level. Only the 25-mg dosage significantly increased motion sickness tolerance when compared to the placebo. These data suggest that the effective doses of promethazine currently used to counteract motion sickness in astronauts may significantly impair task components of their operational performance.

TABLE 4. INDIVIDUAL BAL% FOLLOWING PROMETHAZINE INJECTIONS

	25 mg		50 mg	
Subject	1 hr	4 hr	1 hr	4 hr
1	0.015	0.022	0.076	0.034
2	0.004	0.027	0.063	0.078
3	0.243	0.270	0.429	0.418
6	0.086	0.088	0.093	0.081
8	0.014	0.029	0.288	0.281
9	0.000	0.196	0.000	0.133
10	0.129	0.122	0.086	0.080
11	0.032	0.062	0.091	0.040
12	0.107	0.045	0.128	0.031
13	0.133	0.129	0.212	0.174
14	0.125	0.111	0.110	0.082
15	0.050	0.121	0.044	0.017
Mean =	0.085	0.105	0.137	0.128

The present paper examines individual differences in converging indicators of two subjects who were good performers (subjects 1 and 11) and two poor performers (subjects 3 and 13). Figure 3 shows the performance scores and self-reported mood experienced by these subjects across the test conditions (different days) of placebo, 25-, and 50-mg doses. The top left graph shows the BAL% of two good performers and top right shows poor performers. Note that the horizontal lines at 0.08 on top left and right charts indicate that levels above this line represent performance impairment.

The first performance battery of each day was administered before subjects received an injection and therefore results are near or below the 0.08 BAL%. The next performance test was administered within one hour of the IM injections; the remaining task batteries followed at 2, 4 and 6 hours respectively. The last delta performance battery was conducted at the end of the day and was preceded by a rotating chair motion sickness test. The graphs show that performance scores begin to return to normal baseline levels as the medication wears off at hour 6. In fact, changes in performance of these subjects closely mirror their serum dose-response curves. The bottom left chart shows the mood reports of good performers and the bottom right shows poor performers. In all cases, readiness to perform was degraded more than perceived readiness. This is more pronounced for subject 13 who showed the largest discrepancy for these self-reported mood states.

These data clearly demonstrate that cognitive tests like Delta can be used to track the negative effects of this medication on an individual's performance over time. Crews in space could use these tests to determine which of its members might be "best fit" to perform specific mission critical tasks and how an individual's fitness to perform may be degraded or improved by any given countermeasure.

Individual differences in physiological responses to this medication may help elucidate how and why subjects respond as they do. The overall group effect was that promethazine, an anticholinergic, suppressed the skin conductance level (SCL) response (refs. 47, 48). SCL is only innervated by sympathetic pathways and is therefore a good index of arousal (i.e., sympathetic activation); however, the transmitter substance for this response is cholinergic. Figures 4 and 5 show the physiological responses measured during Delta performance tests for good and poor performers respectively. What is immediately apparent from these charts is that no two people respond in precisely the same way. To

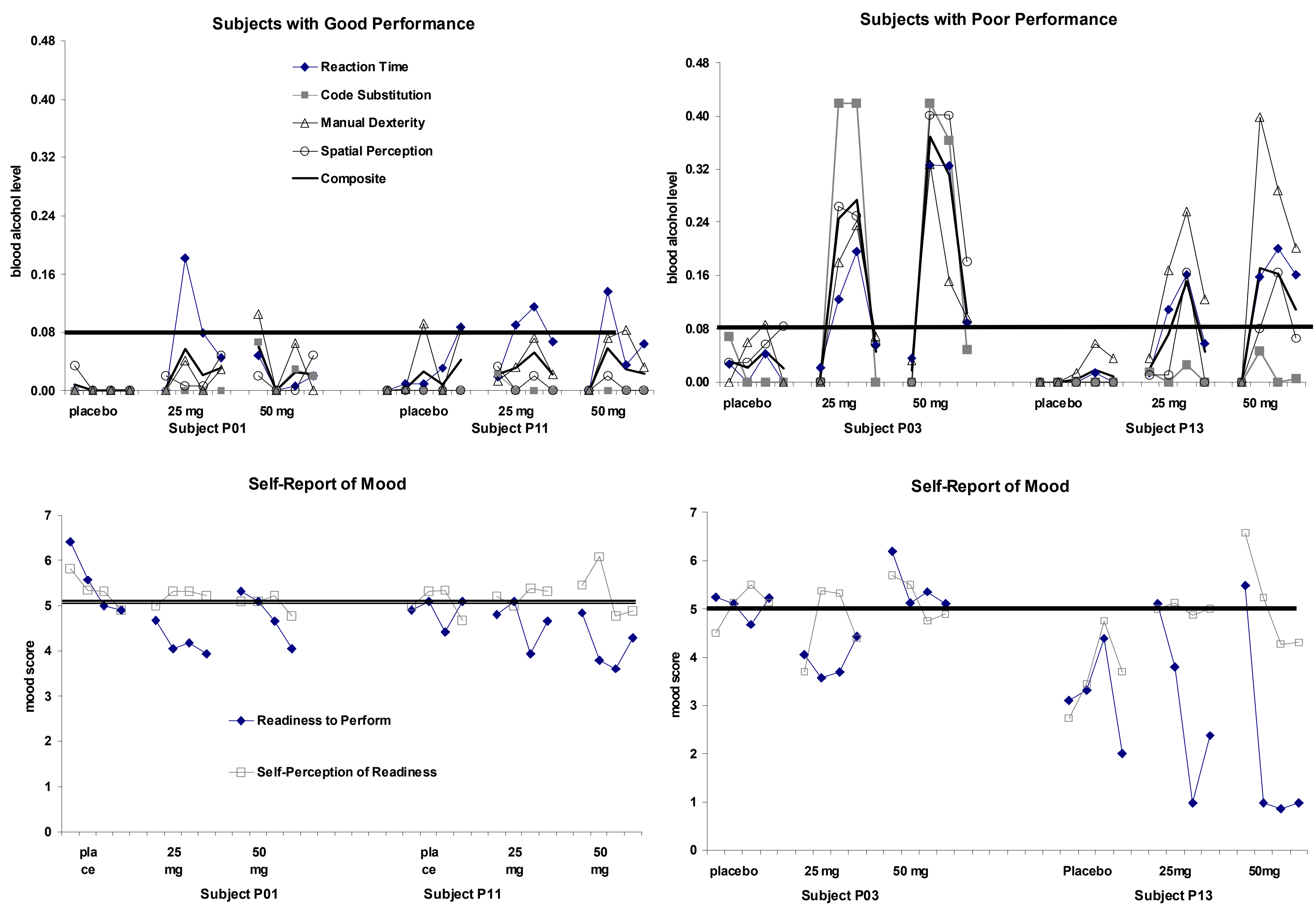


Figure 3. Performance mood of good and poor performers given promethazine.

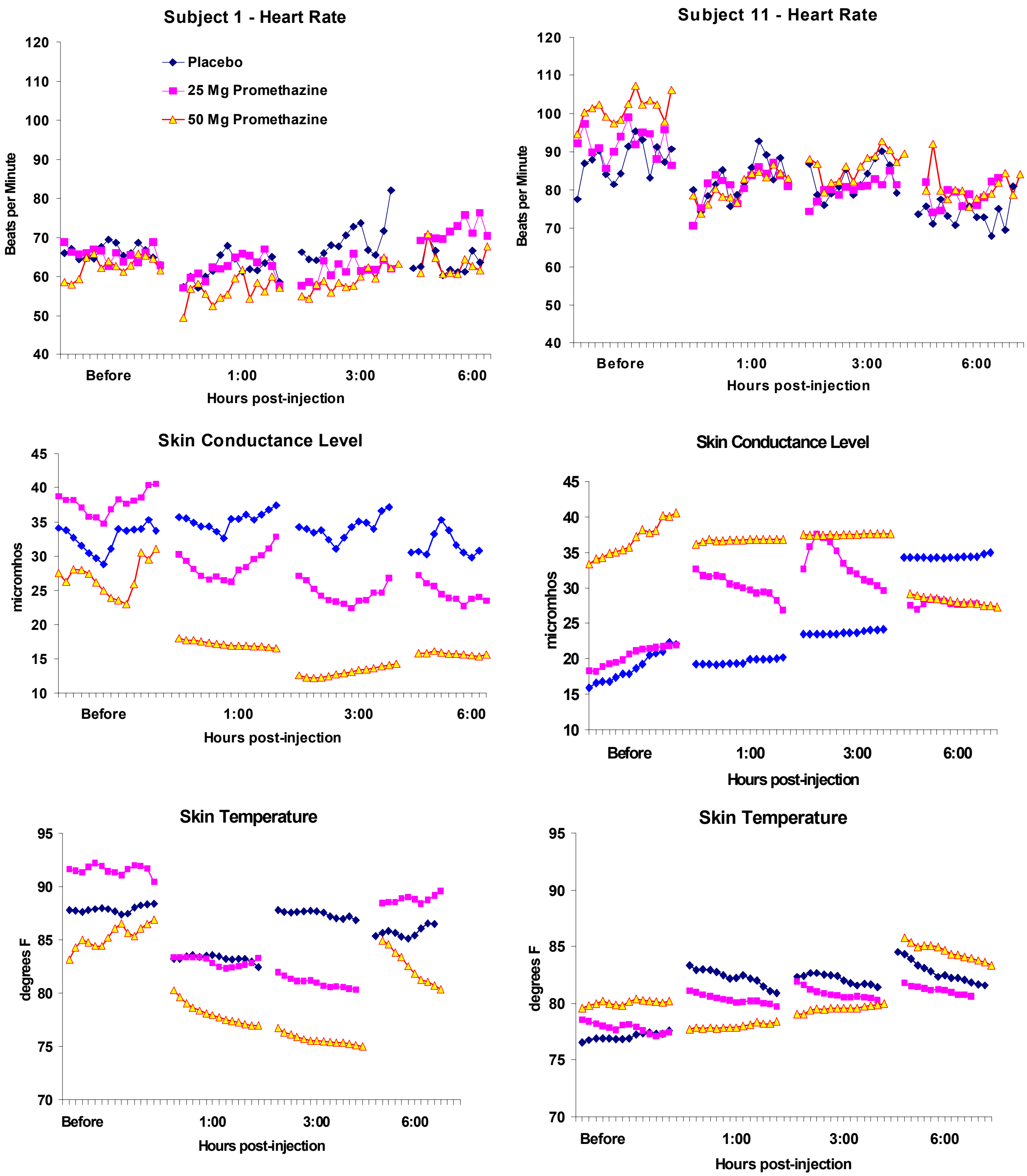


Figure 4. Physiological responses of subjects with good performance when given promethazine.

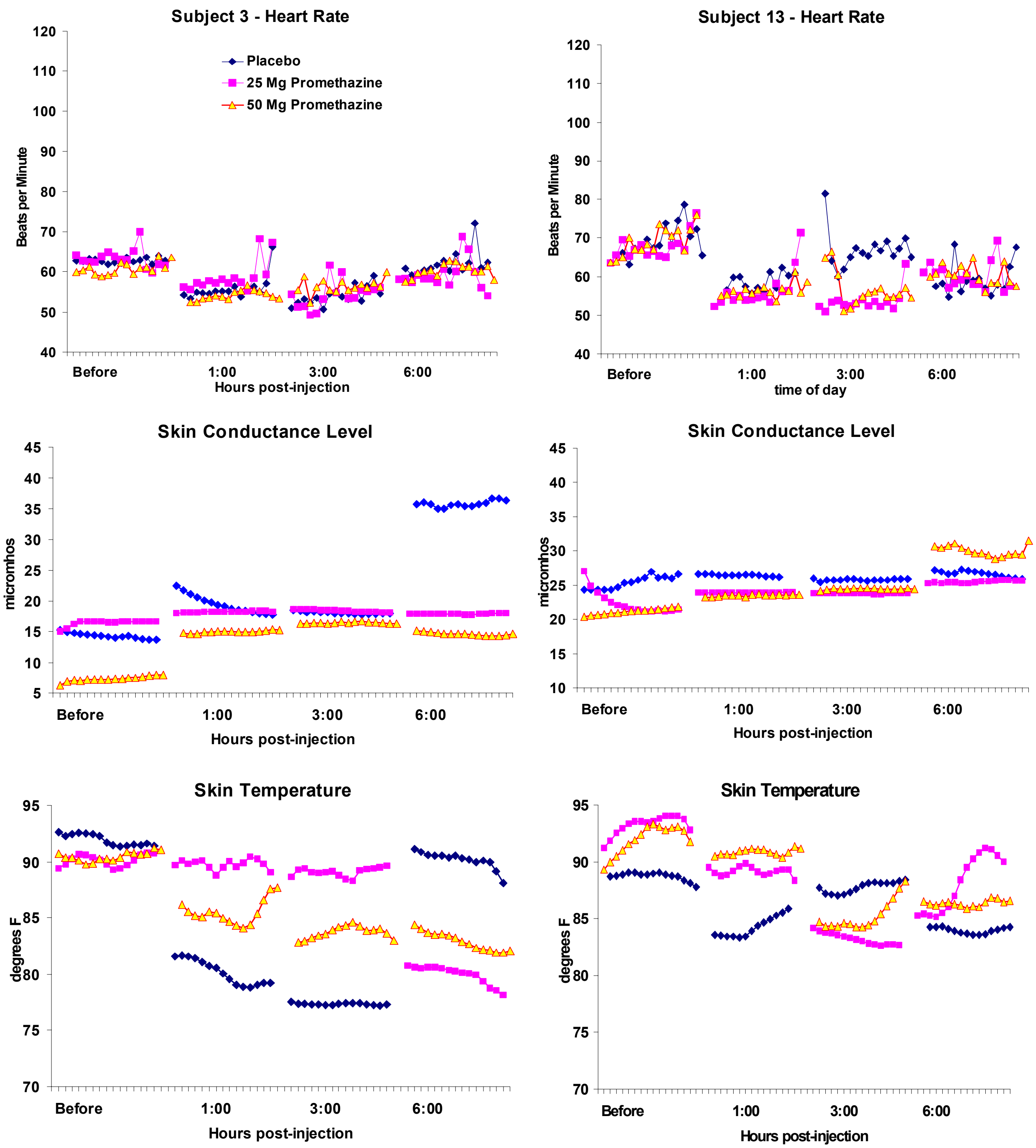


Figure 5. Physiological responses of subjects with poor performance when given promethazine.

evaluate the relationship between performance and physiology, emphasis should be placed on examining subject differences, rather than between subjects. In general, when a subject's performance was better (i.e., placebo day), his physiological responses were different than on those days when medication was given and performance was impaired. Psychophysiological research has demonstrated that an individual physiological stress profile can be determined that will allow assessment and potential prediction of performance. Further, this research supports the assertion that responses to environmental stressors are highly idiosyncratic and therefore countermeasures must be tailored to meet an individual's needs.

Figure 6 shows changes in motion sickness tolerance during rotating chair tests administered before the final delta test battery on each day, at approximately 4 hours post-injection. Of the two good performers, only subject 11 showed an appreciable increase in motion sickness tolerance when given the 25 mg dose of promethazine. There was no change observed with the 50 mg dose. When administering this, or any countermeasure, consideration must be given to the "risks versus benefits." The performance of subjects 1 and 11 were not degraded by this medication, but only subject 11 showed an observable increase in his motion sickness tolerance. This leads to the conclusion that the benefit to subject 11 was worth the "risk," but there was no benefit to subject 1 and therefore he should not be medicated. Of the two subjects whose performance was severely degraded by this medication, there were smaller improvements in motion sickness tolerance (50-mg dose for subject 3 and 25-mg dose for subject 13). Therefore, there was a greater risk that performance would be degraded compared to the relatively small benefit of an anti-motion sickness medication.

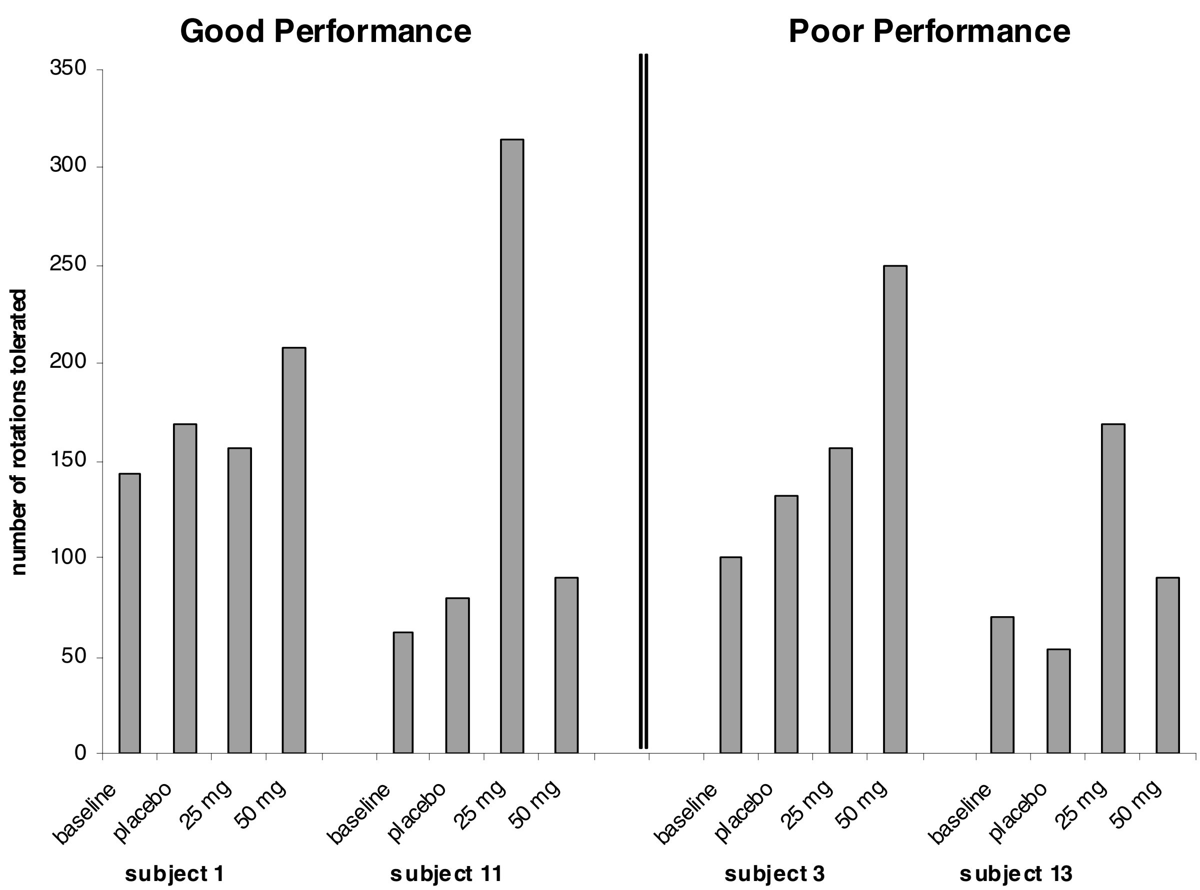


Figure 6. Motion sickness tolerance when given promethazine.

STUDY 3: Individual Differences in Adaptational Capacity During Sustained Exposure to Hypergravity

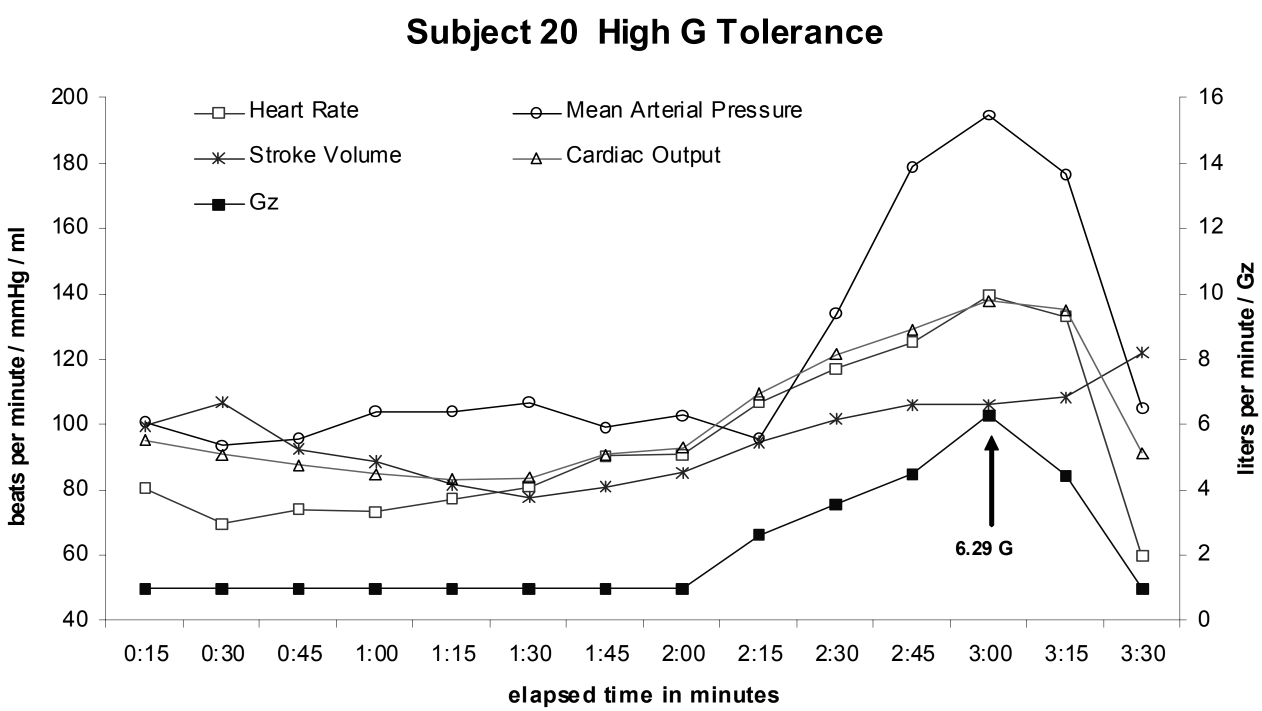
The purpose of this study was to determine if 22-hour exposures to sustained hypergravity in a centrifuge would improve g-tolerance of individuals. Four men, ages 20–34 years old, participated in this study. The present paper discusses the data of two subjects with the highest and lowest g-tolerance. G-tolerance tests were conducted before and after each 22-hour centrifuge run. During g-tolerance tests subjects were seated upright with the gravity vector oriented from chest to back (Gz) while the centrifuge was rotating. Tests were terminated when subjects reported a significant loss of peripheral vision, commonly referred to as gray-out. Physiological measurements provided a means of evaluating individual differences in g-tolerance and the individual's capacity to adapt to this environmental stressor. In addition to the four standard ambulatory measures of heart rate, skin conductance level, respiration rate and peripheral vasomotor activity, other measures of cardiovascular function, mean arterial pressure and impedance cardiography, were recorded. These parameters provided continuous measurements of cardiac output, stroke volume and total peripheral resistance. In space, these measurements are obtained using echocardiography, which can only provide a static "snap-shot" of a crewmembers cardiac function, and it requires a highly trained technician.

Figure 7 shows the physiological responses of these subjects during one g-tolerance test. The left Y-axis shows beats per minute for heart rate and mmHg for mean arterial pressure. The right Y-axis shows Gz (g-level) liters per minute for cardiac output and liters (converted from ml) for stroke volume. The X-axis shows elapsed time. Subject 20 (top graph) was able to tolerate 6.29 g before terminating the test, while subject 23 (bottom graph) had lower g-tolerance, stopping at 3.91 g. Both subjects were well within the normal range of g-tolerance for men of their age and health.

Both subjects responded to the increased g-load with compensatory increases in cardiac output and mean arterial pressure. However, the way in which the subjects achieved compensation was different. Subject 20 (high-g tolerance) experienced an increase in heart rate which was greater than his increase in stroke volume. Subject 23, however, had a greater increase in stroke volume (contractility of the myocardium) relative to his increase in heart rate. In the Earth norm of 1 g, these responses serve as an example of how the level of cardiovascular conditioning will affect an individual's response to increased metabolic demands (environmental stressors). The more physically fit individual will likely show a compensatory mechanism that favors a greater increase in stroke volume relative to a low (resting) heart rate because the myocardium is better adapted to producing a greater ejection fraction. This also means that there is less of a decrease in diastole and therefore greater ventricular and coronary artery filling times. This enables such a person to have a greater reserve in his or her cardiac output.

But what happens in an unusual environment, where there is an altered gravitational load than normally experienced? Subject 20 with labile, larger magnitude physiological response levels, where heart rate and cardiac output began to increase prior to the onset of the Gz stimulus (anticipatory responses) showed better tolerance than the more athletic subject 23.

After determining differences between these individuals in tolerating an "acute" stress of a g-tolerance test, we examined their abilities to adapt to a "chronic" stress of sustained exposure to altered gravity. Ambulatory subjects were tested individually during chronic 22-hour exposures to constant gravitational loads: 1.0, 1.25, and 1.5 g, with 7-day intervals between exposures. Subjects were housed within a habitat cab (dimensions: 6 ft wide x 8 ft deep x 7 ft high) at the end of a long-arm centrifuge. The habitat cab contained a bed, a collapsible toilet, storage areas for food and water, a television set, and a laptop computer. Physiological responses were measured continuously and the subjects were monitored by close-circuit television with two-way voice communication.



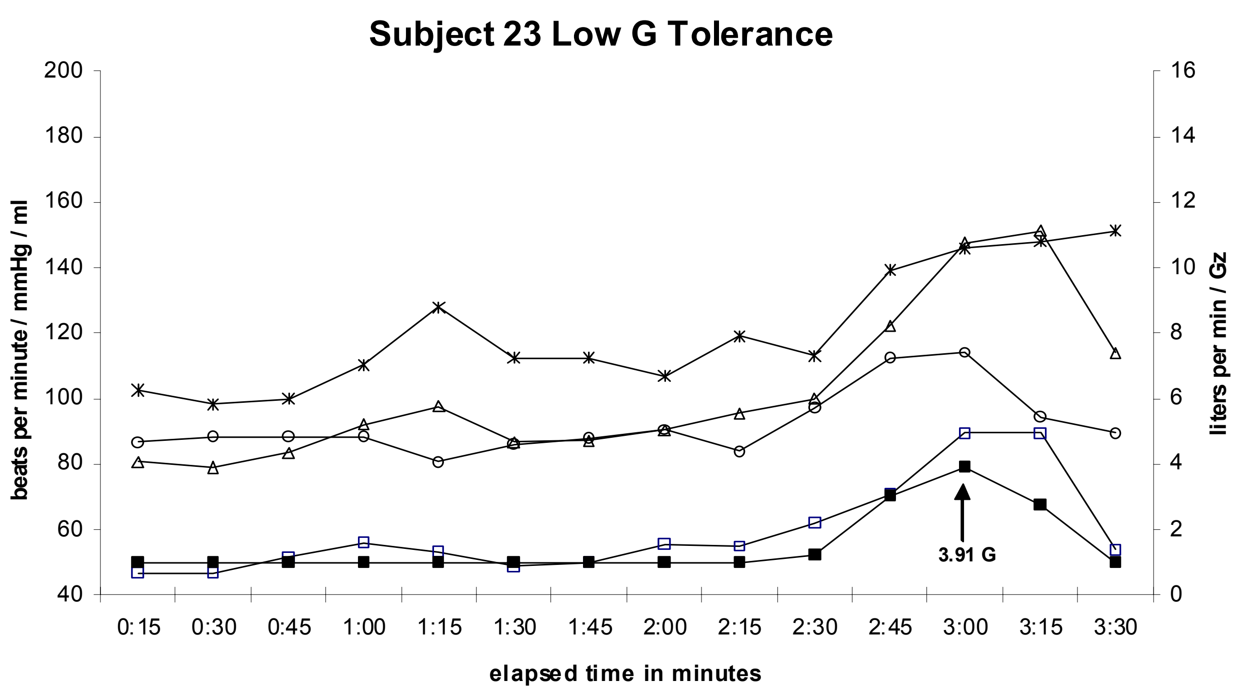


Figure 7. Physiological response of subjects with high and low g tolerance.

At 4-hour intervals throughout chronic exposures, subjects self-administered a mood test, symptom diagnostic report, and the Delta performance battery (spatial perception, grammatical reasoning and manual dexterity) using their laptop computers. Then, changes in their orthostatic tolerance were examined during a stand test where the subject was supine, sitting and standing for 3-min in each position. The result of this study was that subject 20, who tolerated a higher g-load during chronic tests, was also able to complete chronic 22-hr exposures to 1.25 and 1.5 g, while subject 23 experienced vasovagal syncope after 16 hours at 1.25 g. Figure 8 shows a detail of these subjects' physiological responses during stand tests after 16 hours at 1.25 g. In the upper graphs, the Y-axis on the left shows beats per minute (heart rate) and mmHg (blood pressure), the Y-axis on the right shows liters per minute (cardiac out put) and liters (converted from ml) for stroke volume. The lower graphs show each subject's heart rate relative to changes in his thoracic fluid volume (also derived from impedance cardiography) that occur as the subject shifts position. The cardiovascular dynamics show how these subjects compensated differently for thoracic fluid shifts.

Subject 20 (good g-tolerance) makes the adjustment from supine to sitting and to standing with compensatory increases in heart rate during each shift of position. Heart rate is lower for Subject 23 (vagatonic profile), and despite increased stroke volume, he experiences orthostatic intolerance. The more labile responses of subject 20 (sympathetic profile) may have protected him from orthostatic intolerance but made him more susceptible to motion sickness experienced during 1.5-g confinement for 22 hours.

Figure 9 shows the performance, mood and symptom reports of these subjects while in the centrifuge habitat. BAL% scores were not calculated because of an insufficient number of sub-tests. Raw data were converted to accuracy scores (number correct minus number wrong) for spatial perception and grammatical reasoning and for manual dexterity, the number of finger taps made with the non-preferred hand. Accuracy scores for subject 20 on both spatial perception and grammatical reasoning tasks decreased during 1.25-g and 1.5-g conditions relative to 1.0 g, while there was no notable change for the manual dexterity task across conditions. Subject 23's scores on both spatial perception and grammatical reasoning were lower than for subject 20, while there were no changes across conditions. Self reports mood show a small decline across g-load conditions for subject 20 with increased reports of malaise, resulting in vomiting during 1.5 g. Subject 23 showed no discernable changes in mood and very mild malaise, even in tests conducted just prior to syncope at 1.25 g.

STUDY 4: Individual Differences in Response to Sleep Deprivation

In this study, test participants were subjected to 36 hours of sleep deprivation. Physiological responses were measured continuously and performance tests and self report scales (mood and symptoms) were administered at 3 hour intervals. Three subjects are described in this study (2 men and 1 woman, ages 25–35). All subjects were given 8 training sessions (15-min. each) distributed over two days before the start of sleep deprivation to establish a learning plateau. Twenty-four hours following sleep deprivation when subjects were rested and recovered, an additional post-test task battery was administered. and data were detrended for practice effects. Figure 10 shows the blood alcohol equivalencies calculated for these subjects.

Figure 11 shows a comparison of specific Delta subtests to comparable tests within Minicog and Winscat. Delta tests show scores for accuracy (number correct minus the number of wrong answers) and both Mini cog and Winscat are shown as percent correct. The ceiling effect of Winscat and Minicog is demonstrated when scores equal 100% correct. The ceiling effect is based on the fact that Winscat and Minicog have a fixed number of presentations whereas the Delta battery is based on a fixed subtest duration so that a subject may perform different numbers of presentations depending upon his performance speed. Subject 33 shows a performance decrement for Mental Rotation (MiniCog) and Code substitution (Winscat) that is related to duration of sleep deprivation. The Minicog data for

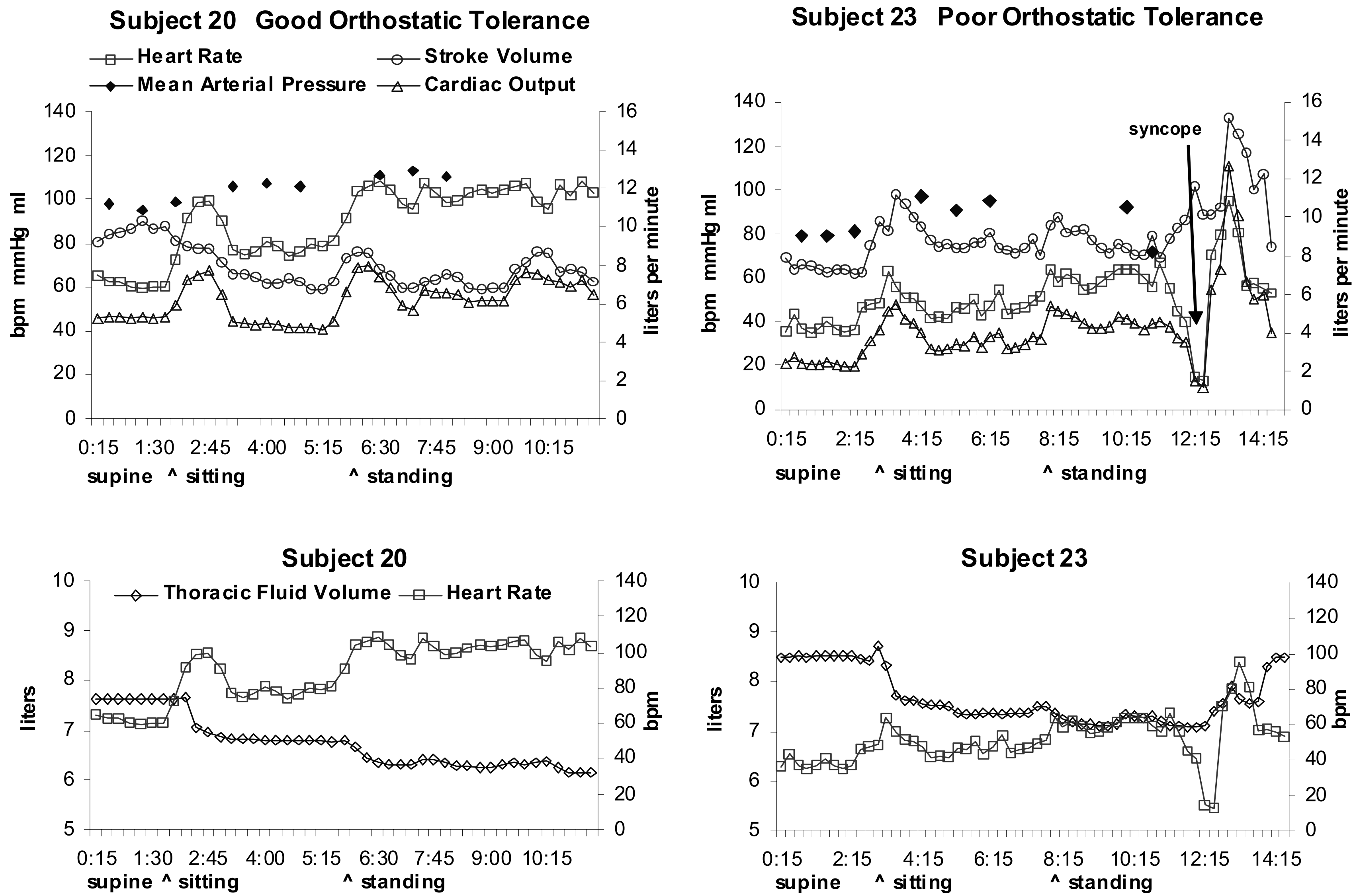


Figure 8. Physiological responses to a stand test after 16 hours at 1.25 g.

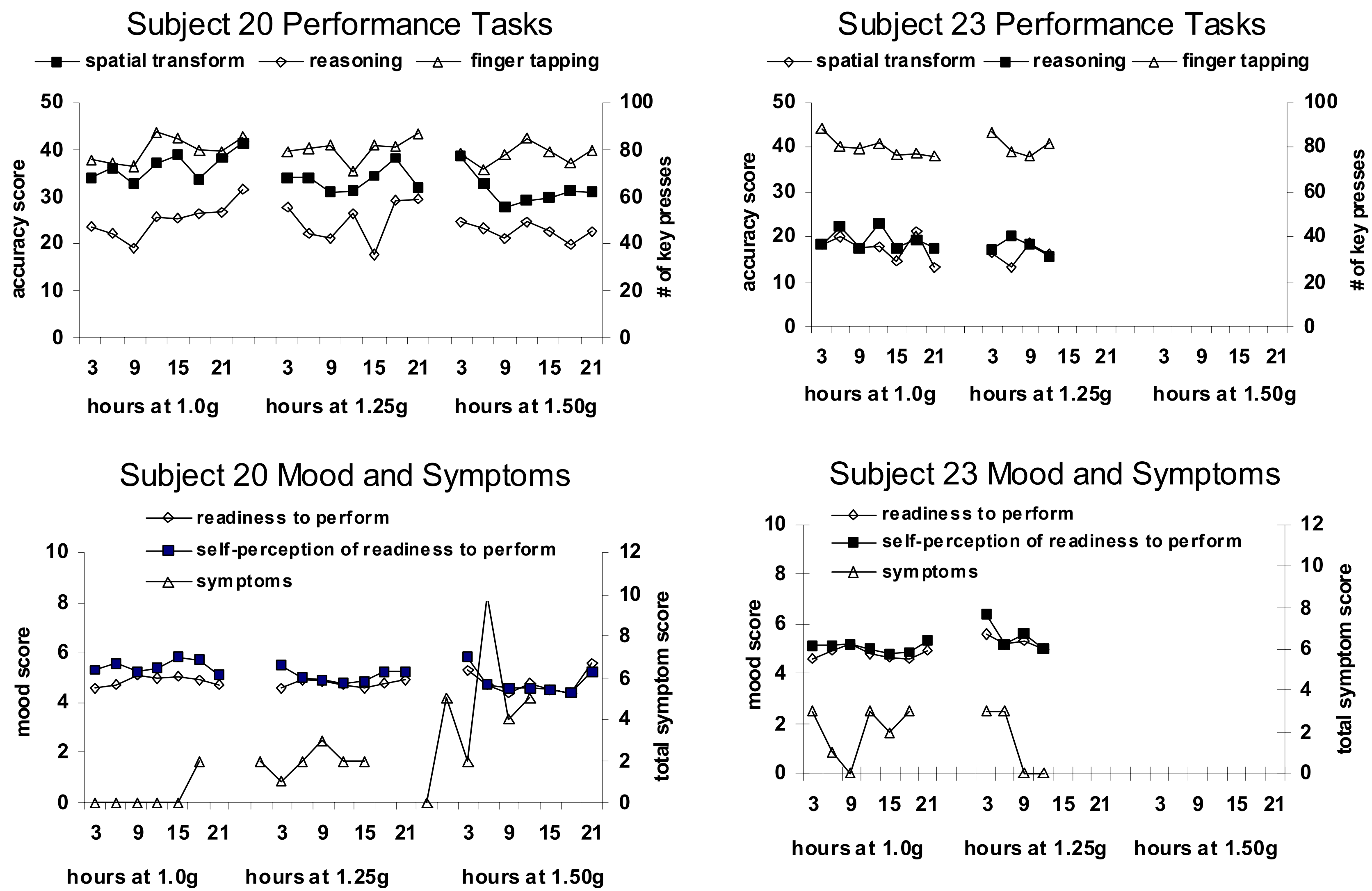


Figure 9. Performance mood and symptom reports during 22-hr centrifuge tests.

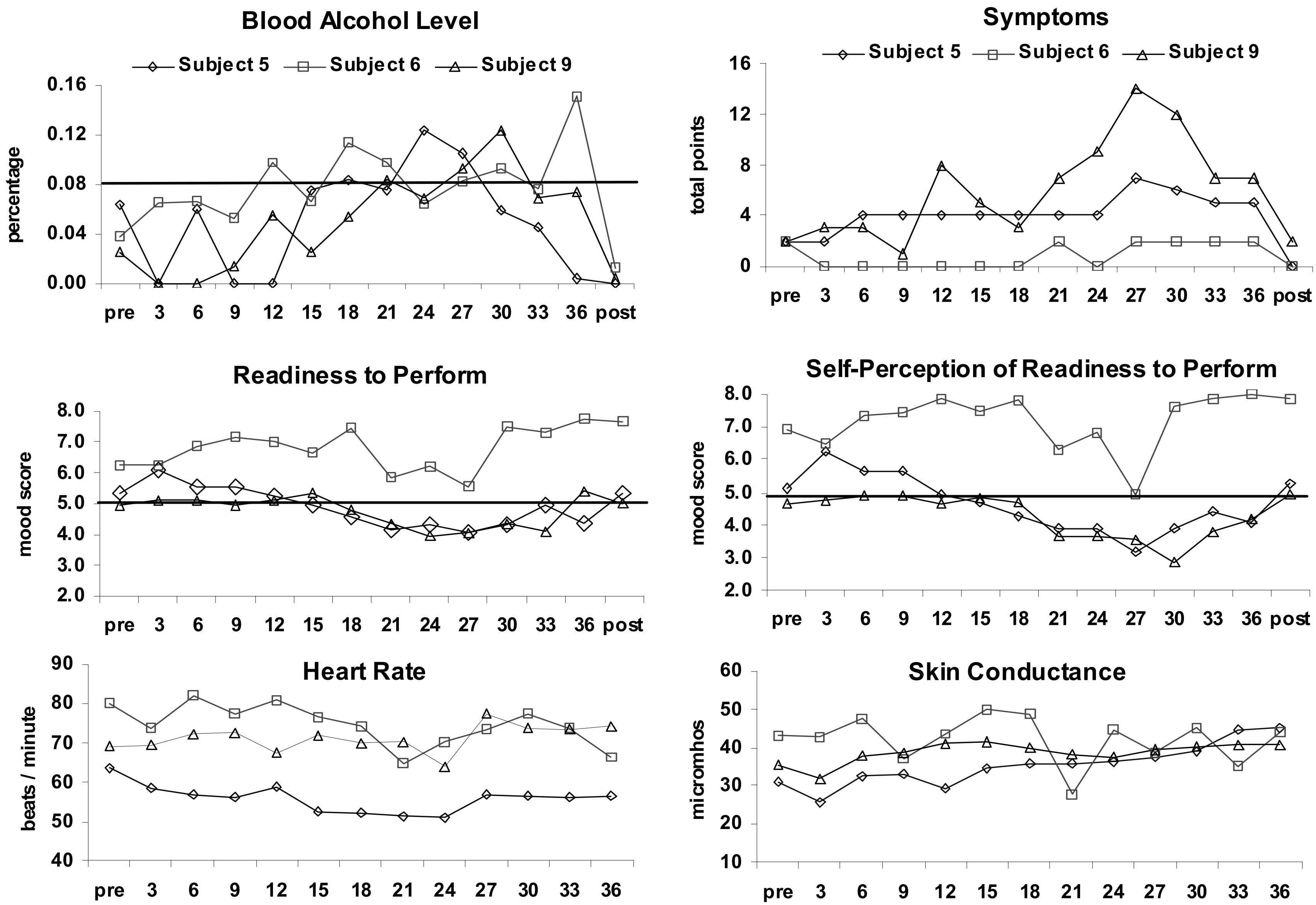


Figure 10. Performance, mood, symptoms, heart rate and skin conductance level during 36 hours of sleep deprivation.

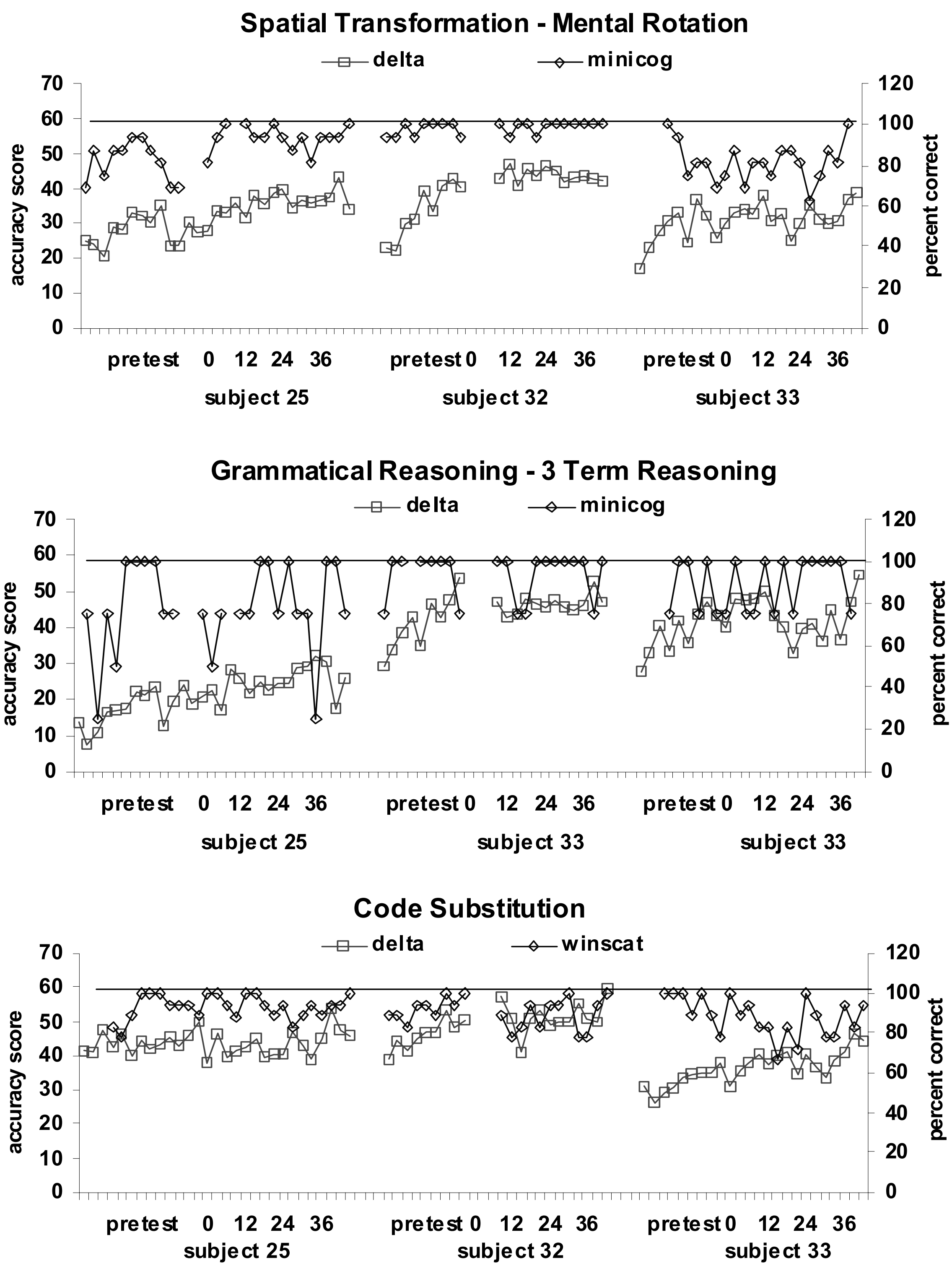


Figure 11. Comparison of Delta, Winscat, and Minicog during sleep deprivation.

Logical reasoning (middle graph) tells us nothing about absolute changes in this subtest for any of the subjects because most tests have reached the ceiling level, in which performance proficiencies above the ceiling level cannot be documented. The incidence of ceiling effects was similar between Minicog (22.6%) and Winscat (26.8%).

DISCUSSION—CONCLUSIONS

The intent of this paper was to describe in detail the methodology of coverging indicators and its application for assessing performance effects in both laboratory and operational environments. The four studies described demonstrate that objective physiological measures, quantifiable performance metrics, and subjective self-report scales, can be used to characterize individual differences in operational efficiency, as well as an individual's ability to adapt to extreme environments. These metrics can also be used to assess the beneficial effects or unwanted side effects of pharmacological or behavioral countermeasures. By selecting subjects at the extreme range of good and poor performance, it was possible to show how the metrics co-vary across individuals.

The time required to record, evaluate, and decide how to act on multiple metrics in an operational environment would appear to make it an impractical approach. A real-time operational assessment and prediction tool should be non-obtrusive, non-invasive, and yet make use of multiple indicator data without requiring the operator to attend to and interpret their meaning. Our own research suggests that physiological responses can be used to develop an individual profile that depicts how bodily responses change with operator state. If converging indicator data are collected during baseline (or preflight) conditions (e.g., mission simulations), a "stress profile" can be calculated that reflects an individual's performance readiness in operational environments on the basis of his or her own physiological changes. Crewmembers could then be trained to recognize their responses to stressful events with the aid of real-time physiological feedback. Alternatively, ambulatory physiological data could be used as input variables for a real-time neural network model (e.g., with a wearable PC) to automatically "warn" the operator of predicted state changes. The crewmember can then verify the predicted state changes (e.g., perform Minicog or Winscat) and either reschedule or reassign tasks to another available crewmember, or initiate a countermeasure. A potentially powerful behavioral countermeasure would involve training crewmembers to change their own physiological response levels to maintain performance efficiency.

Our research group first used the converging indicators approach in earlier studies on assessment and treatment of motion sickness. In these studies (refs. 42, 48–52) the method involved measuring an individual's physiological responses and self-reports of malaise as symptoms were elicited during a motion sickness test. Then a physiological training program, referred to as Autogenic-Feedback Training Exercise (AFTE), was introduced. The training goal for subjects was to mimic their own resting physiological response levels during subsequent motion tests, and thereby significantly reduce or eliminate their symptoms. Following this logic, it was hypothesized that it would be possible to improve performance in stressful environments by monitoring changes in physiology, and training subjects to control their responses. One study performed with Coast Guard Search and Rescue pilots was an operational demonstration of the effectiveness of this approach (ref. 30). Pilots who were trained to monitor and regulate their own bodily responses demonstrated significant improvements on Federal Aviation Administration performance metrics compared to their untrained counterparts. These results indicate that such training may serve as a valuable adjunct to the current standard cockpit-crew-resource management training. In the centrifuge study, it is possible that if subject 20 was trained to regulate his own heart rate, syncope might not have occurred. Subject 23, who experienced motion sickness, may have been able to control his symptoms with training.

Because AFTE training involves both increasing and decreasing physiological response levels it should be applicable in a variety of situations. Fatigue related performance decrements caused by sleep loss or sustained operations might be improved if subjects were trained to regulate their own responses including autonomic and central nervous system parameters. Enabling subjects to monitor, interpret, and regulate their own cardiovascular dynamics could improve their orthostatic tolerance and health, thereby facilitating the successful completion of critical mission operations (refs. 36, 42).

Converging indicators should be included in new research studies planned with crews on ISS. Ambulatory physiological monitors are unobtrusive, comfortable to wear, easy to operate, and are currently available through commercial vendors. Development of sensors that do not require skin contact would improve crew comfort and compliance for self-monitoring and assessment. Baseline converging indicator data of individual crew could begin immediately and should be obtained prior to missions during simulations, physical exercise, and in aircraft. These data should be collected during screening for side-effects of medications. This information should be used by the autonomous crewmember in space to compare his own pre-flight data to his current physiological levels and performance metrics.

Space flight analog studies are needed to further test countermeasure effects and other assessment techniques that will be used by autonomous crews during future planned missions in space. Studies that compare cognitive assessment batteries like Winscat, Minicog, and Delta should be used to determine procedures for administering and scoring performance tests, without ceiling effects, and enable crews to decide which of their members is best fit (or when they themselves are ready) to perform specific mission tasks. Analog environments, with small groups, isolated in enclosed habitats and subject to environmental stressors, could be used to study and perfect assessment, training techniques, and countermeasures planned for future space crews. Such environments could include isolation studies (e.g., Antarctica, undersea labs) or operational military vehicles on land, sea or air. Analog crews, such as military officers, using these tools would go far to demonstrate their efficacy to the astronaut office, before they are flight tested on the International Space Station and in subsequent planetary missions.

REFERENCES

1. Sandler, H.; and Vernikos, J. (eds.): Inactivity: Physiological Effects. Academic Press, 1986.

2. Connors, M.; Harrison, A.; and Akins, F.: Living Aloft: Human Requirements for the Extended Spaceflight. NASA SP-483, 1985, pp. 107-143.

3. Bayevskiy, R. M.; and Semenova, T. D.: Evaluation of the Functional State of an Operator Undergoing Sensory Deprivation. Fiziologia Cheloveka, vol. 12, no. 4, 1986, pp. 676-678.

4. Nechayev, A. P.; Ponomareva, I. P.; Khideg, Y.; Bognar, L.; and Remesh, P.: On the Additional Capacities of the Methodology for Studying Human Psychological Work Capacity (Russian). In: Gazenko, O. G., ed., Aerospace Medicine: Abstracts of Papers Delivered at the Eighth All-Union Conference, Kaluga, 1986, pp. 191-193.

5. Siminov, P. V.: Monitoring Man's Work Capacity in Aviation and Space Flight. Paper delivered at the NASA Space Life Sciences Symposium, Washington, D. C., June 21-22, 1987.

6. Jeanneret, P. R.: Position Requirements for Space Station Personnel and Linkages to Portable Microcomputer Performance Assessment. NASA CR-185606, 1988.

7. Jex, H. R.: The Critical Instability Tracking Task—Its Background, Development and Application. In: Rouse, W. B., ed., Advances in Man Machine Systems Research, Greenwich:Jai Press, vol. 5, 1988.

8. Manzey, D.; and Lorenz, B.: Human Performance During Prolonged Spaceflight, J. Human Per Extreme Environ., vol. 2, 1997, p. 68.

9. Kane, R. L.: Spaceflight Cognitive Assessment Tool for Windows: Development and Validation. Proc. of the New Directions in Behavioral Health Workshop: Integrating Research and Application, University of California, Davis, Calif., Dec 2-3, 2003.

10. Kane, R. L.; Shor, P.; Sipes, W.; and Flynn, C. F.: Development and Validation of the Spaceflight Cognitive Assessment Tool for Windows (WinSCAT). Aviat. Space Environ. Med., vol. 76, no. 6 (suppl.), June, 2005, pp. B183-191.

11. Shephard, J. M.; and Kosslyn, S. M.: The Minicog Rapid Assessment Battery: Developing a "Blood Pressure Cuff for the Mind." Aviat. Space Environ. Med., vol. 76, no. 6 (suppl.), June, 2005, pp. B192-197.

12. Kennedy, R. S.; Wilkes, R. L.; Dunlap, W. P.; and Kuntz, L. A.: Development of an Automated Performance Test System for Environmental and Behavioral Toxicology Studies. Percept. Mot. Skills, vol. 65, 1987, pp. 947-962.

13. Turnage, J. J.; Kennedy, R. S.; Smith, M. G.; Baltzley, D. R.; and Lane, N. E.: Development of Microcomputer-based Mental Acuity Tasks. Ergonomics, vol. 35, 1992, pp. 1271-1295.

14. Turnage, J; and Kennedy, R. S.: The Development and Use of a Computerized Human Performance Test Battery for Repeated-Measures Applications. Human Perform., vol. 5, 1992, pp. 265-301.

15. Fielder, E. R.: Operational Processes and Cognitive Mapping. Aviat. Space Environ. Med., vol. 76, no. 7 (suppl.), 2005, pp. C4-6.

16. Nasoz, F.: Emotion Recognition From Physiological Signals for Presence Technologies. Int. J. Cognition, Technology and Work, Special Issue on Presence, vol. 6, no. 1, 2003.

17. Cacioppo, J. T.; Tassinary, L. G.; Berntson, G. G. (eds.): Handbook of Psychophysiology, 2nd ed., Cambridge, U. K.:Cambridge University Press, 2001.

18. Duffy, E.: Activation. In: Greenfield, N. S., Sternbach, R. A. (eds.). Handbook of Psychophysiology. New York:Holt, Rhinehart, and Winston, Inc., pp. 577-622.

19. Engel, B. T.: Response Specificity. In: Greenfield, N. S., Sternbach, R. A., eds. Handbook of Psychophysiology, New York:Holt, Rhinehart, and Winston, Inc., 1972, pp. 571-576.

20. Wenger, M. A.; and Cullen, T. D.: Studies of Autonomic Balance in Children and Adults. In: Greenfield, N. S., Sternbach, R. A., eds. Handbook of Psychophysiology, New York:Holt, Rhinehart, and Winston, Inc. 1972, pp. 535-570.

21. Bradely, M. M.: Emotion and Motivation. In: Cacioppo, J. T., Tassinary, L. G., Berntson, G. G., eds. Handbook of Psychophysiology, 2nd ed., Cambridge, U. K.:Cambridge University Press, 2000, pp. 602-642.

22. Scherer, K. R.: Vocal Affect Expression: A Review and a Model for Future Research. Psych. Bull., vol. 99, 1986, pp. 143-165.

23. Wittles, P.; Johannes, B.; Enne, R.; Kirsch, K.; and Gunga, H.: Voice Monitoring to Measure Emotional Load During Short Term Stress. European J. of Applied Physiology, vol. 87, no. 3, 2004, pp. 278-282.

24. Ekman, P.: Facial Expression. In: Dalgleish, T., Power, T., eds. The Handbook of Cognition and Emotion, Sussex, U. K.:John Wiley & Sons, Ltd., 1999, pp. 301-320.

25. Stout, C. S.; and Cowings, P. S.: Increasing Accuracy in the Assessment of Motion Sickness: A Construct Methodology. NASA TM-108797, 1993.

26. Stout, C. S.; Toscano, W. B.; and Cowings, P. S.: Reliability of Psychophysiological Responses Across Multiple Motion Sickness Stimulation Tests. J. Vestib. Res., vol. 5, no. 1, 1993, pp 25-33.

27. Cowings, P. S.; and Toscano, W. B.: The Relationship of Motion Sickness Susceptibility to Learned Autonomic Control for Symptom Suppression. Aviat Space Environ. Med., vol. 53, 1982, pp. 570-575.

28. Cowings, P. S.; Naifeh, K. H.; and Toscano, W. B.: The Stability of Individual Patterns of Autonomic Responses to Motion Sickness Stimulation. Aviat. Space Environ. Med., vol. 61, no. 5, 1990, pp. 399-405.

29. Cowings, P. S.; Suter, S.; Toscano, W. B.; Kamiya, J.; and Naifeh, K.: General Autonomic Components of Motion Sickness. Psychophys., vol. 23, 1986, pp. 542-551.

30. Cowings, P. S.; Keller, M. A.; Folen, R. A.; Toscano, W. B.; and Burge, J. D.: Autogenic Feedback Training and Pilot Performance: Enhanced Functioning Under Search and Rescue Flying Conditions. Int. J. Aviat. Psych., vol. 11, no. 3, 2001, pp. 305-315.

31. Cowings, P. S.; Toscano, W. B.; DeRoshia, C.; and Tauson, R.: Effects of Command and Control Vehicle (C2V) Operational Environment on Soldier Health and Performance. Human Perform. Extreme Environ., vol. 5, no. 2, 2001, pp. 66-91.

32. Kornilova, L. N.; Cowings, P. S.; Arlaschenko, N. I.; Toscano, W. B.; and Kozlovskaya, I. B.: Effect of Autogenic Feedback on Cosmonauts' Vestibular Function and Autonomic Responses. Aviaspace & Ecology Medicine, (Russian journal: Aviakosmicheskaya I Ekologicheskaya Meditsina), 1999.

33. Kornilova, L. N.; Cowings, P. S.; Toscano, W. B.; Arlaschenko, N. I.; Korneev, D. J.; Ponomarenko, A. V.; and Kozlovskaya, I. B.: Monitoring and Correction of Cosmonauts' Autonomic Responses by Autogenic Feedback Techniques. Aviaspace & Ecology Medicine (Russian journal: Aviakosmicheskaya I Ekologicheskaya Meditsina), 1998.

34. Kornilova, L. N.; Cowings, P. S.; Toscano, W. B.; Arlaschenko, N. I.; Korneev, D. J.; Ponomarenko, A. V.; Sagalovitch, V.; Sarantseva, A.; and Kozlovskaya, I. B.: Correction of the Parameters of Autonomous Reactions in the Organism of Cosmonaut with the Method of Adaptive Biocontrol. Aviaspace & Ecology Medicine (Russian journal: Aviakosmicheskaya I Ekologicheskaya Meditsina). vol. 34, no. 3, 2000, pp. 66-69.

35. Cowings, P. S.; Toscano, W. B.; Kamiya, J.; Miller, N. E.; and Sharp, J. C.: Final Report. Spacelab-3 Flight Experiment 3AFT23: Autogenic-Feedback Training as a Preventive Method for Space Adaptation Syndrome. NASA TM- 89412, 1988.

36. Cowings, P. S.; Toscano, W. B.; Taylor, B; and DeRoshia, C.: Cosmonaut Physiological and Performance Data: Six Months on MIR. NASA TM–99-208768, 1999, pp. 140-141.

37. Toscano, W. B.; and Cowings, P. S.: The Effects of Autogenic-Feedback Training on Motion Sickness Severity and Heart Rate Variability in Astronauts. NASA TM-108840, 1994.

38. Orasanu, J. M.: Crew Collaboration in Space: A Naturalistic Decision Making Perspective. Aviat. Space Environ. Med., vol. 76, no. 6 (suppl.), 2005, pp. B154-163.

39. Orasanu, J. M.; Backer, P.: Stress and Military Performance. In: Stress and Human Performance. Mahwah, NJ:Lawrence Erlbaum Assoc., 1996, pp. 89-125.

40. Orasanu, J. M.; Fischer, U. M.; Kraft, N.; Tada, Y.; and Paletz, S.: Enhancing Team Performance for Long Duration Space Missions. Poster presentation at the Amer. Psych. Soc. Mtg., 17th Annual Convention, Los Angeles, Calif., May 26-29, 2005.

41. Mallis, M. M.; and DeRoshia, C. W.: Circadian Rhythms, Sleep, and Performance in Space. Aviat. Space Environ. Med., vol. 76, no. 6 (sec. II), 2005, pp. B94-107.

42. Cowings, P. S.; Toscano, W. B.; and Taylor, B. et al.: Psychophysiology of Spaceflight. Paper presented at Humans in Space Symposium, Banff, Canada, May 18-22, 2003.

43. Kennedy, R. S.; Dunlap, W. P.; Ritter, A. D.; and Chavez, L. M.: Comparison of a Performance Battery Implemented on Different Hardware and Software: APTS versus DELTA. Ergonom., vol. 39, 1996, pp. 1005-1016.

44. Kennedy, R. S.; Turnage, J. J.; Wilkes, R. L.; and Dunlap, W. P.: Effects of Alcohol on Nine Computerized Repeated-Measures Tests. Ergonom., vol. 36, 1993, pp. 1195-1222.

45. Graybiel, A.; Wood, C. D.; Miller, E. F.; and Cramer, D. B.: Diagnostic Criteria for Grading the Severity of Acute Motion Sickness. Aerospace Med., vol. 39, 1968, pp. 453-455.

46. Ellis, B. W.; Johns, M. W.; Lancaster, R; and Raptopoulos, P.; et al.: The St. Mary's Hospital Sleep Questionnaire: A Study of Reliability. Sleep, vol. 4, 1981, pp. 93-97.

47. Cowings, P. S.; Toscano, W. B.; DeRoshia, C.; and Miller, N. E.: Promethazine as a Motion Sickness Treatment: Impact on Human Performance and Mood States. Aviat. Space Environ. Med., vol. 71, no. 10, 2000, pp. 1013-1032.

48. Cowings, P. S.; and Toscano, W. B.: Autogenic Feedback Training Exercise is Superior to Promethazine for the Treatment of Motion Sickness. J. Clin. Pharm., vol. 40, no. 10, 2000, pp. 1154-1165.

49. Cowings, P. S.; Toscano, W. B.; Timbers, A.; Casey, C.; and Hufnagel, J.: Autogenic-Feedback Training Exercise: A Treatment for Airsickness in Military Pilots. Int. J. Aviat. Psych., vol. 15, no. 4, 2005, pp. 395-412.

50. Cowings, P. S.: Autogenic-Feedback Training: A Treatment for Motion and Space Sickness. In: Crampton, G. H., ed., Motion and Space Sickness, Boca Raton, FL:CRC Press, 1990, pp. 353-372.

51. Cowings, P. S.; Billingham, J.; and Toscano, W. B.: Learned Control of Multiple Autonomic Responses to Compensate for the Debilitating Effects of Motion Sickness. Therapy Psychosom. Med., vol. 4, 1977, pp. 318-323. And In: Luthe, W.; Antonelli, F. (eds.): Autogenic Methods: Application and Perspectives. Rome:Luigi Pozzi S.P.A., 1977. Also In: Barber, T. X. et al. (eds.) Biofeedback and Self-Control. Chicago: Aldine Publishing Co., 1978.

52. Toscano, W. B.; and Cowings, P. S.: Reducing Motion Sickness: Autogenic-feedback Training Compared to an Alternative Cognitive Task. Aviat. Space Environ. Med., vol. 53, no. 5, 1982, pp. 449-453.

REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Department of Defense, Washington Headquarters Services, Directorate for information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.
PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE *(DD-MM-YYYY)*
09-2006

2. REPORT TYPE
Technical Memorandum

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Converging Indicators for Assessing Individual Differences in Adaptation to Extreme Environments: Preliminary Report

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Patricia S. Cowings, William B. Toscano, Charles W. DeRoshia, Bruce Taylor, Seleimah Hines, Andrew Bright, and Anika Dodds

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
466-199-02-01

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Human Systems Integration Division
Ames Research Center, Moffett Field, CA 94035-1000

8. PERFORMING ORGANIZATION REPORT NUMBER
A-0600010

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

U.S. Department of Energy, Washington, DC 20585

10. SPONSORING/MONITOR'S ACRONYM(S)
NASA, ESMD, AMD

11. SPONSORING/MONITORING REPORT NUMBER
NASA/TM–2006-213491

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified — Unlimited   Distribution: Nonstandard
Subject Category: 03, 12, 51
Availability: NASA CASI (301) 621-0390

13. SUPPLEMENTARY NOTES
Point of Contact: Patricia S. Cowings, Ames Research Center, M.S. 262-2, Moffett Field, CA 94035-1000
(650) 604-3085

14. ABSTRACT
This paper describes the development and validation of a new methodology for assessing the deleterious effects of spaceflight on crew health and performance. It is well known that microgravity results in various physiological alterations, e.g., headward fluid shifts which can impede physiological adaptation. Other factors that may affect crew operational efficiency include disruption of sleep-wake cycles, high workload, isolation, confinement, stress and fatigue. From an operational perspective, it is difficult to predict which individuals will be most or least affected in this unique environment given that most astronauts are first-time flyers. During future lunar and Mars missions space crews will include both men and women of multi-national origins, different professional backgrounds, and various states of physical condition. Therefore, new methods or technologies are needed to monitor and predict astronaut performance and health, and to evaluate the effects of various countermeasures on crew during long duration missions. This paper reviews several studies conducted in both laboratory and operational environments with men and women ranging in age between 18 to 50 years. The studies included the following: soldiers performing command and control functions during mobile operations in enclosed armored vehicles; subjects participating in laboratory tests of an anti-motion sickness medication; subjects exposed to chronic hypergravity aboard a centrifuge, and subject responses to 36-hours of sleep deprivation. Physiological measurements, performance metrics, and subjective self-reports were collected in each study. The results demonstrate that multivariate converging indicators provide a significantly more reliable method for assessing environmental effects on performance and health than any single indicator.

15. SUBJECT TERMS
Performance, Perception, Self-reports, Physiological measures, Behavioral health, Sleep deprivation, Motion sickness, Hypergravity

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON / 19b. TELEPHONE (Include area code)
Unclassified	Unclassified	Unclassified	Unclassified	30	Patricia S. Cowings / (650) 604-3085