Cognitive Functioning In Long-Duration Head-Down Bed Rest

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Introduction: This report is one of a series on the Flight Analog Project, which is designed to lay the groundwork for a standard bed rest protocol. The Spaceflight Cognitive Assessment Tool for Windows (WinSCAT) is a self-administered battery of tests used on the International Space Station for evaluating cognitive functioning. Here, WinSCAT was used to assess cognitive functioning during extended head-down bed rest. ***Methods:*** There were 13 subjects who participated in 60 or 90 d of head-down bed rest and took WinSCAT during the pre-bed rest phase, the in-bed rest phase, and the post-bed rest (reconditioning) phase of study participation. ***Results:*** After adjusting for individual baseline performance, 12 off-nominal scores were observed out of 351 total observations during bed rest and 7 of 180 during reconditioning. No evidence was found for systematic changes in off-nominal incidence as time in bed rest progressed, or during the reconditioning period. ***Discussion:*** Cognitive functioning does not appear to be adversely affected by long-duration head-down bed rest. Individual differences in underlying cognitive ability and motivation level are likely explanations for the current findings.

Keywords: WinSCAT, spaceflight, cognitive function assessment tool.

THIS REPORT IS ONE of a series on the Flight Analog Project, which is designed to lay the groundwork for a standard bed rest protocol. The Spaceflight Cognitive Assessment Tool for Windows (WinSCAT) was originally developed for medical operations at the NASA Johnson Space Center in Houston, TX. WinSCAT has been validated (4) and implemented with astronauts from 15 expeditions on the International Space Station (ISS). It is currently a medical requirement for all U.S. long-duration crewmembers and is administered every 30 d throughout ISS missions and after any physical injury or insult to the central nervous system (e.g., exposure to increased levels of carbon dioxide).

The purpose of the WinSCAT is to provide ISS crew flight surgeons with an objective clinical tool to monitor the astronauts' cognitive status during long-duration spaceflight (2). WinSCAT addresses a critical need because an unexpected event, a medical condition, or the cumulative effects of spaceflight could negatively affect an astronaut's cognitive status. Of particular concern are cognitive changes due to illness, injury, toxic exposure, decompression accidents, medication side effects, or excessive exposure to radiation that could impact an astronaut's ability to successfully perform spaceflight tasks and thus threaten mission success. Risks related to cognitive capabilities, as well as psychosocial adaptation and neurobehavioral problems, have been recognized as critical for exploration missions to Mars (1). WinSCAT is a computer-based, self-administered battery of five cognitive assessment subtests. WinSCAT requires dichotomous responses via mouse or keypad and is designed for repeated-measures applications. In 11 to 15 min, WinSCAT assesses response time, sustained attention/concentration, visual working memory, and verbal working memory, scoring performance in four categories corresponding to specific tasks. Here, WinSCAT was used to assess cognitive functioning in a long-duration bed rest study. Overall cognitive functioning was not expected to be negatively affected by extended head-down bed rest.

METHODS

Refer to Meck et al. (3) for description of the protocol and general conditions of the study, and the use of long-duration head-down bed rest as a model for spaceflight. Bed rest and test protocols were reviewed and approved by the Johnson Space Center Committee for the Protection of Human Subjects, the UTMB Institutional Review Board, and UTMB General Clinical Research Center Science Advisory Committee. Subjects received verbal and written explanations of the bed rest and test protocols prior to providing written informed consent.

There were 13 subjects (5 women and 8 men) who took the WinSCAT test battery on a Dell Latitude D600 laptop computer. The following describes the individual subtests of the WinSCAT test.

Code Substitution Learning (CDS): A memory stimulus task. The test-taker is asked to determine if a symbol-number pair has been correctly matched by evaluating it against a reference grid at the top of the screen. The purpose of this subtest is for the test-taker to learn the correct pairings of symbols and numbers to recall the symbol-number pairs for the Code Memory Delayed (final) subtest in the battery. As this is a learning task, there are no summary results.

Running Memory Continuous Performance (CPT): An attention and concentration task. The test-taker is asked to track the presenta-

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TABLE I. OVERALL INCIDENCE OF OFF-NOMINAL SCORES BY BED REST AND SUBTEST TYPE.

	Accuracy/Response Time	Throughput
In-Bed Rest	12/351	8/156
Post-Bed Rest	7/180	4/80
Total	**19/531**	**12/236**

Note: The total numbers of observations for generalized estimating equation (GEE) analyses are the denominators in the above fractions.

tion of 160 numbers by comparing the number on screen at the moment with the number that immediately preceded it. The summary results consist of median response time, percent correct responses, and number of lapses (failure to respond within 700 ms).

Mathematical Processing (MTH): A mathematics achievement task. The test-taker is asked to perform simple addition and subtraction on three single-digit numbers (e.g., $3 - 5 + 4 = 5 + 3 - 6 =$). The test-taker then indicates whether the resulting answer is less than or greater than five. Summary results consist of median response time and percent of correct responses.

Delayed Matching to Sample (MTS): A visual memory task. The test-taker is asked to identify which of two grids appearing on screen is identical to a sample grid that appeared prior to a delay of 5 s. Summary results consist of median response time and percent of correct responses.

Code Memory Delayed (CDD): A short-term memory task. The test-taker is asked to recall the symbol-number pairs s/he learned earlier during the CDS task and to determine if a symbol-number pairing on the screen is correct. Summary results consist of median response time and percent of correct responses.

During the pre-bed rest (ambulatory) phase, WinSCAT was administered six times. The first three administrations were for orientation and training/familiarization, and the next three administrations established each subject's individual baseline. During the head-down bed rest phase, WinSCAT was scheduled to be administered two times for subjects 1–3 (60 d of bed rest) and four times for subjects 4–13 (90 d of bed rest). During the reconditioning period, WinSCAT was scheduled to be administered twice. Due to a hurricane evacuation affecting subjects 8–11, three WinSCAT tests were administered during the bed rest phase, and two of the subjects took one test during their reconditioning period.

Testing was conducted with the subject seated on his or her bed (during ambulatory periods) or lying on the bed or gurney while head-down. Subjects chose to take the test either with the laptop computer supported on a bedside table at an appropriate height and angle, or propped on their knees. When possible, testing was not conducted within 30 min of eating a meal or within 2 h of taking a similar cognitive test. Efforts were made to minimize distractions to provide a quiet testing environment free from interruptions.

Performance on the WinSCAT is assessed in terms of accuracy scores and response times. Each test administration yields a total of nine scores, including response time for four subtests, accuracy scores for four subtests, and number of lapses (missed items) on the CPT. Improved performance is reflected by increased accuracy, decreased response time, or fewer missed items. Response times and accuracy scores were further reduced into throughput scores. Throughput is a measure of cognitive efficiency, taking both accuracy and response time into account and providing an estimate of correct responses per minute for each subtest. Accordingly, throughput is higher (indicating better cognitive efficiency) when accuracy is high and response time is low, and throughput is lower when accuracy is low and response time is high. Because the hard cutoffs automatically generated by the WinSCAT software to determine off-nominal accuracy scores were developed for astronauts rather than the general population, we revised the definition of "off-nominal" to correct for possible differences in cognitive ability between study participants and astronauts. Therefore, we defined off-nominal performance for accuracy scores as a 20 to 25% decrement from each subject's individual baseline.

RESULTS

Overall incidence of off-nominal scores by bed rest and subtest type (accuracy and response time or throughput) is shown in **Table I**. Statistical inference on the effect of bed rest and subtest category (CPT, MTH, MTS, or CDD) on the incidence of off-nominal responses was made using generalized estimating equations (GEE) with a binomial family, logit link function, and robust variance estimation (5) to account for repeated observations pertaining to the same subject. GEE analyses were made separately for the original nine subtest measures and for the four throughput measures.

Accuracy and Response Time

Table II presents the off-nominal subtest scores for each subject, relative to their individual baseline performance. Using the revised definitions for off-nominal accuracy scores, 5 of the 13 subjects performed consistently throughout head-down bed rest with no off-nominal scores, and 6 subjects had only 1 off-nominal score during bed rest. Subject 7, who had the highest number of off-nominal events, accounted for four off-nominal scores, with three of the off-nominal scores occurring on MTH accuracy and one off-nominal score on CPT response time. Subtest measures with the highest number of off-nominal events were MTH accuracy (33%) and CPT accuracy (17%). MTS accuracy was the only subtest measure that had no off-nominal scores. Regression analysis with GEE showed no significant trend in the incidence rate of off-nominal scores for accuracy and response time measures during bed rest ($z = -0.40$, $P = 0.69$), nor was there any significant difference between incidence rates during vs. post-bed rest ($z = 0.52$, $P = 0.61$). Also, over all time periods, no significant differences were found between incidence rates in the four subtest categories.

Throughput

Table III presents subjects' number of off-nominal throughput scores for four WinSCAT subtests (defined relative to their individual baseline performance). Subject

TABLE II. WINSCAT SUMMARY BY SUBJECT: OFF-NOMINAL SUBTEST SCORES (MEDIANS).

Total Off-Nominal			Off-Nominal Scores by Subtest*								
			≥ 20%	≤ 20 %	> 4	> 25%	≤ 20%	> 25%	≤ 20%	> 25%	≤ 20%
ID	Count	Percent	CPTRT	CPTA	CPTL	MTHRT	MTHA	MTSRT	MTSA	CDDRT	CDDA
1	0	0.0%	0	0	0	0	0	0	0	0	0
2	0	0.0%	0	0	0	0	0	0	0	0	0
3	0	0.0%	0	0	0	0	0	0	0	0	0
4	0	0.0%	0	0	0	0	0	0	0	0	0
5	1	8.3%	0	0	0	0	0	1	0	0	0
6	1	8.3%	0	1	0	0	0	0	0	0	0
7	4	33.3%	1	0	0	0	3	0	0	0	0
8	2	16.7%	0	1	1	0	0	0	0	0	0
9	0	0.0%	0	0	0	0	0	0	0	0	0
10	1	8.3%	0	0	0	0	1	0	0	0	0
11	1	8.3%	0	0	0	0	0	0	0	0	1
12	1	8.3%	0	0	0	0	0	0	0	1	0
13	1	8.3%	0	0	0	1	0	0	0	0	0
	12	**100.0%**	**1**	**2**	**1**	**1**	**4**	**1**	**0**	**1**	**1**
		100.0%	**8.3%**	**16.7%**	**8.3%**	**8.3%**	**33.3%**	**8.3%**	**0.0%**	**8.3%**	**8.3%**

* CPTRT = repeating numbers response time; MTSRT = pattern memory response time; CPTA = repeating numbers accuracy; MTSA = pattern memory accuracy; CPTL = repeating numbers lapses; CDDRT = symbol memory response time; MTHRT = mathematical processing response time; CDDA = symbol memory accuracy; MTHA = mathematical processing accuracy.

7, who accounted for the most off-nominal accuracy and response time scores also had the most off-nominal throughput scores (3 on MTH). Of the 13 subjects, 8 did not produce any off-nominal throughput scores. No evidence was found for increased off-nominal incidence during bed rest ($z = -0.03$, $P = 0.98$) or between in- and post-bed rest overall ($z = -0.05$, $P = 0.96$).

DISCUSSION

WinSCAT is a computer-based test platform designed to assess cognitive functioning of astronauts during spaceflight. Though overall cognitive functioning of bed rest subjects was not expected to change, WinSCAT is a medical requirement for U.S. crewmembers on long-duration spaceflight missions and is, therefore, integrated into bed rest testing.

Using the cutoff rules automatically generated by the WinSCAT software, a number of off-nominal scores were observed, but no consistent patterns were detected. If extended head-down bed rest had a negative effect on overall cognitive functioning, consistent decrements would be expected to be found with all subjects across time. After adjusting for individual baseline performance, no evidence was found for increased off-nominal incidence either during or after bed rest, or as time in bed rest progressed. As expected, overall cognitive functioning does not appear to be adversely affected by long-duration head-down bed rest. Given the small sample size, findings should be interpreted with caution. In general, cognitive tests tend to be sensitive to distractions and motivation of the subjects; therefore, distractions, motivation level, and individual differ-

TABLE III. WINSCAT SUMMARY BY SUBJECT: OFF-NOMINAL THROUGHPUT SCORES (MEANS).

Total Off-Nominal			Off-Nominal Throughput Scores by Subtest *			
ID	Count	Percent	CPT	MTH	MTS	CDD
1	0	0.0%	0	0	0	0
2	0	0.0%	0	0	0	0
3	0	0.0%	0	0	0	0
4	1	12.5%	0	1	0	0
5	2	25.0%	0	0	2	0
6	0	0.0%	0	0	0	0
7	3	37.5%	0	3	0	0
8	0	0.0%	0	0	0	0
9	0	0.0%	0	0	0	0
10	0	0.0%	0	0	0	0
11	0	0.0%	0	0	0	0
12	1	12.5%	0	1	0	0
13	1	12.5%	0	0	1	0
	8	**100.0%**	**0**	**5**	**3**	**0**
		100.0%	**0.0%**	**62.5%**	**37.5%**	**0.0%**

* CPT = repeating numbers; MTS = pattern memory; MTH = mathematical processing; CDD = symbol memory.

ences in underlying cognitive ability are possible explanations for the results found in this study. Further, the apparent differences in the cognitive ability of the average bed rest subject and the average astronaut could limit the generalizability of these findings to the astronaut corps.

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