The Effects of Training on Anxiety and Task Performance in Simulated Suborbital Spaceflight

Rebecca S. Blue; Frederick Bonato; Kimberly Seaton; Andrea Bubka; Johnené L. Vardiman; Charles Mathers; Tarah L. Castleberry; James M. Vanderploeg

INTRODUCTION: In commercial spaceflight, anxiety could become mission-impacting, causing negative experiences or endangering the flight itself. We studied layperson response to four varied-length training programs (ranging from 1 h–2 d of preparation) prior to centrifuge simulation of launch and re-entry acceleration profiles expected during suborbital spaceflight. We examined subject task execution, evaluating performance in high-stress conditions. We sought to identify any trends in demographics, hemodynamics, or similar factors in subjects with the highest anxiety or poorest tolerance of the experience.

METHODS: Volunteers participated in one of four centrifuge training programs of varied complexity and duration, culminating in two simulated suborbital spaceflights. At most, subjects underwent seven centrifuge runs over 2 d, including two $+G_z$ runs (peak +3.5 G_z, Run 2) and two $+G_x$ runs (peak +6.0 G_x, Run 4) followed by three runs approximating suborbital spaceflight profiles (combined $+G_x$ and $+G_z$, peak +6.0 G_x and +4.0 G_z). Two cohorts also received dedicated anxiety-mitigation training. Subjects were evaluated on their performance on various tasks, including a simulated emergency.

RESULTS: Participating in 2–7 centrifuge exposures were 148 subjects (105 men, 43 women, age range 19-72 yr, mean 39.4 $\pm$ 13.2 yr, body mass index range 17.3–38.1, mean 25.1 $\pm$ 3.7). There were 10 subjects who withdrew or limited their G exposure; history of motion sickness was associated with opting out. Shorter length training programs were associated with elevated hemodynamic responses. Single-directional G training did not significantly improve tolerance.

DISCUSSION: Training programs appear best when high fidelity and sequential exposures may improve tolerance of physical/psychological flight stressors. The studied variables did not predict anxiety-related responses to these centrifuge profiles.

KEYWORDS: acceleration, G exposure, spaceflight participant, commercial spaceflight, anxiousness, anxiety, panic, layperson, emergency, tolerance.

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As the advent of commercial suborbital spaceflight draws closer, specific challenges facing the industry, particularly regarding human physiology and psychology, have been raised.[1–3] Information regarding the physical tolerance of laypersons to suborbital spaceflight has historically been quite limited, particularly regarding individuals of advanced age or concerning medical conditions. Recently, there have been studies directed toward attempting to bridge this knowledge gap, particularly with the use of centrifuge-simulated suborbital acceleration profiles.[4,5,18] These studies have successfully demonstrated that, in general, individuals of a wide age range and controlled medical conditions are likely to tolerate suborbital spaceflight well.[4,5]

However, the same studies have demonstrated somewhat unexpected rates of adverse psychological responses; in some cases, subjects have experienced panic attacks and high anxiety

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From the Department of Preventive Medicine and Community Health, University of Texas Medical Branch, Galveston, TX; the Department of Psychology, Montclair State University, Montclair, NJ; and the Department of Psychology, Saint Peter's University, Jersey City, NJ.

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Address correspondence to: Rebecca Blue, M.D., M.P.H., Department of Preventive Medicine and Community Health, University of Texas Medical Branch, 301 University Blvd, Galveston, TX 77555-1110; rsblue@utmb.edu.

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responses to centrifugation.[18,19] Commercial spaceflight participants (SFPs), unlike career astronauts, are not likely to receive rigorous screening, a prolonged training course, or numerous preparatory experiences prior to their flights, which may place them at higher risk for psychological stress during the experience. Should such responses occur during commercial suborbital flight, anxiety and panic might adversely affect the experiences of others on the flight, including those piloting the vehicle. As a result, there is a need to identify and mitigate anxiety in future SFPs before it becomes significant enough to impact the experience of the SFP or those around them. Further, there is a need to develop effective training techniques and identify best cost effective and efficient practices to prepare SFPs for the physiological and psychological stressors of spaceflight.

To address these concerns, we sought to examine layperson responses to highly varied training programs, ranging from 1 h to 2 d of preparation, prior to centrifuge-simulated suborbital spaceflight. Our study sought to identify predictors of anxiety or panic responses in individuals exposed to acceleration (G forces) in the head-to-toe ($+G_z$) and chest-to-back ($+G_x$) direction, at levels similar to those anticipated for suborbital flight. We examined subject responses to various tasks, including simulated in-flight tests and emergency scenarios, to evaluate their responses and task performance under simulated high-stress conditions. Finally, we sought to identify any trends in demographics, hemodynamics, or any other predictive factors in subjects at highest risk for anxiety, panic, or withdrawal from the experience.

METHODS

Subjects

A prospective cohort study, approved by the University of Texas Medical Branch Institutional Review Board, was designed to recruit volunteers for participation in physiological training in a centrifuge at the National Aerospace Training and Research (NASTAR) Center centrifuge (Southampton, PA). Volunteer registrants, minimum age 18, were asked to complete a medical history questionnaire and undergo a physical exam by their personal physicians with guidance and forms provided for this purpose. The instructions, process, and forms used were similar to the guidance and materials provided for FAA approved exams performed by Aviation Medical Examiners and were identical to the guidance and documentation used in prior studies of this type.[4,5,21] All participants were required to provide a resting electrocardiogram (EKG).

A study investigator and aerospace medicine specialist reviewed all medical documentation. Participants could be approved directly, be requested to undergo further tests or provide more records, or be excluded altogether depending upon their medical status, history, and physical findings. The screening process was similar to that described in previous similar publications.[4,21] The study medical monitors had final decision-making authority regarding any subject's participation. In general, participants with significant risk factors beyond age, such as a history of medical diseases, including but not limited to hypertension, diabetes, back and neck disorders, pulmonary disease, dysrhythmias, and other heart conditions, were required to provide further information, including laboratory values, pertinent imaging, documentation of prior surgery or intervention, or similar demonstration of effective disease control. All participants signed informed consent before taking part in the centrifuge runs.

Equipment and Materials

The NASTAR Center centrifuge was used for the experiment. The centrifuge is a sustained-G simulator that incorporates a traditional long-arm (arm length = 7.6 m) centrifuge motion base with a gimbaled cockpit module. For the current study, the cockpit module was configured as a generic, single-seat space vehicle with a 120° horizontal × 68° vertical field-of-view with a projected dome display. All subjects were secured in the cockpit with a five-point harness. Monitoring and communication were facilitated using a cockpit-mounted video camera and intercom system. Hemodynamic parameters were recorded through an integrated hemodynamic monitoring system and other noninvasive monitoring equipment described below.

Procedures

Resting blood pressure (BP) and heart rate (HR) were measured upon subject arrival at the testing facility. All subjects were advised to take all medication as per their usual schedule, with the exception of alpha-adrenergic antagonists and peripheral vasodilators, which were held a minimum of 24 h prior to participation. Subjects who regularly use antiemetics or vertigo-mitigating medications (including ondansetron, dimenhydrenate, promethazine, and meclizine) for prevention of motion sickness symptoms were allowed to do so if desired, provided that they reported what medications they used, when they administered the medication, and any side effects they were experiencing at any time of the study.

Prior to centrifuge runs, participants were taught a basic anti-G straining maneuver (AGSM) and the "hook" (L-1 closed-glottis variant) maneuver. They were advised to use muscular strain during $+G_z$ exposure, but to use the hook maneuver only in the event of grayout or light-headedness. They were further advised against provocative head movements during centrifuge trials to avoid triggering Coriolis symptoms. Finally, all subjects were thoroughly oriented to the centrifuge gondola and its components as well as the gondola restraint system prior to each spin.

Approved participants were subdivided into one of four cohorts. Subjects were allowed to express preference to length of time of participation (half-day, 1-day, or 2-day programs were offered) but were otherwise not informed of any of the training details or differences between programs. Whenever possible, subjects were given a study group that matched the length of time requested. While all cohorts culminated in the same final two centrifuge-simulated spaceflight experiences (described as "Run 6" and "Run 7" below), the length and type of training differed. There was a maximum of seven possible runs, as shown in **Table I**.

Table I. Centrifuge Exposures Included in the Four Training Cohorts.

	RUN #	DURATION	PEAK G	DURATION AT PEAK G
Single-Direction Training Runs	1	2 min	2.15 $+G_z$	15 s
	2	2 min	3.5 $+G_z$	15 s
	3	2 min	3.0 $+G_x$	15 s
	4	2 min	6.0 $+G_x$	15 s
Simulated Spaceflights	5	7 min	3.0 $+G_x$, 1.7 $+G_z$	5 s
	6	7 min	6.0 $+G_x$, 3.8 $+G_z$	5 s
	7	6 min	4.5 $+G_x$, 4.0 $+G_z$	5 s
			R = +6 G	

Note that single-direction exposures were only experienced by the Cognitive and Acceleration (CAT) and Cognitive/Psychological/Acceleration (CPAT) training cohorts; the Cognitive/Psychological (CPT) cohort received only runs 5–7, and the Minimal Training (MT) cohort experienced only runs 6–7. $+G_z$: head-to-toe acceleration, $+G_x$: chest-to-back acceleration, R = resultant vector.

Cognitive and acceleration cohort. The cognitive and acceleration (CAT) cohort underwent all seven centrifuge runs over a 2-d time period, with exposures 1–4 completed on Day 1 and the final 3 exposures on Day 2. Prior to centrifuge runs, the subjects received the AGSM training as well as short didactics regarding the nature of acceleration exposure and physiological sequelae. Subjects remained in the gondola during the < 1-min break between Run 1 and Run 2 and the < 1-min break between Run 3 and Run 4.

The final three exposures were combined acceleration profiles using the $+G_z$ and $+G_x$ forces designed to simulate acceleration profiles anticipated for future suborbital spaceflights. The first two of these runs simulate a flight where passengers would be seated upright during launch and supine during re-entry, first at half (50%) G intensity (Run 5) then repeated at full intensity (Run 6) after a short pause of less than or equal to 5 min, during which the subjects remained in the gondola (Table I). The final profile (Run 7) was designed to imitate anticipated acceleration profiles of a suborbital spaceflight with an occupant seated upright for both launch and re-entry, resulting in combined and simultaneous $+G_x$ and $+G_z$ exposures during re-entry. This profile was performed at full intensity only. Exposure to each phase of acceleration for all three of the final runs did not exceed 2 min and onset rates always remained less than 0.5 $G \cdot s^{-1}$ in the $+G_z$ direction and 1.5 $G \cdot s^{-1}$ in the $+G_x$ direction. The duration of time at the peaks of $+G_x$ and $+G_z$ was less than 5 s. The combined profiles are presented graphically in **Fig. 1**. Audiovisual simulation was provided during each trial by the multimedia system of the centrifuge gondola to enhance the realism of the experience. It should be noted that true suborbital flight profiles will include a short period of weightlessness between acceleration peaks that could alter the physiological response, but cannot be simulated in a ground-based analog.

Cognitive/psychological/acceleration training. The cognitive/psychological/acceleration (CPAT) cohort received the entirety of the two-day CAT training program as in Table I, with the addition of dedicated psychological training didactics and exercises with the intent of mitigating stress prior to the centrifuge experience. In addition to lectures, CPAT subjects were provided a 30-min guided stress relief exercise just prior to Day 1 spins. Psychologists were available throughout the 2-d course for one-on-one discussion, retraining as needed, and monitoring for any additional signs of stress.

Cognitive/psychological training. The cognitive/psychological training (CPT) cohort received a 1-day course including AGSM training, all didactics, and the psychological lectures and training exercise as in the CPAT group, but did not experience the Day 1 single-directional acceleration exposures. Instead, immediately after didactics and the stress relief exercise, subjects underwent Runs 5–7.

Minimal training. Finally, in the minimal training (MT) cohort, subjects received a short description of the acceleration profile of the simulated spaceflight experience followed by the AGSM training, and then were immediately subjected to the full-scale acceleration profile of the combined spaceflight simulations (Runs 6 and 7) without the step-wise acceleration training program or any didactics or psychological training. Subjects were provided a break between the two centrifuge exposures of no less than 30 min. Training as included in each of the four cohorts is outlined in **Table II**.

Subjects were monitored at all times in the gondola by video, and subjects and medical monitors were able to access two-way voice communication as needed. Hemodynamic data, including continuous EKG, were monitored and recorded in real time by medical monitors. HR was recorded at predetermined times before, during, and after each centrifuge run. BP was recorded immediately before and after each centrifuge run. Following each run, subjects were administered data collection questionnaires regarding the occurrence of symptoms that could indicate increasing levels of anxiety. The postflight survey queries are provided below, answered on a Likert scale:

1. I felt sick or had stomachache or belly complaints.
2. I had a fear of dying.
3. I had chest discomfort.
4. I couldn't tell what was going to happen and that made me feel very anxious.
5. I was sweating.
6. The idea that something would go wrong was constantly on my mind.
7. I attended to every sound or movement of the centrifuge and wondered whether everything was ok.
8. I was afraid that I was losing control of the situation or felt nervous trusting the staff.
9. I had a dry mouth.
10. I thought the gondola was going to malfunction and injure me.
11. I thought that I would faint from fear.

During Run 6, each subject was administered a variation of the classic Stroop test.[13] The Stroop test consisted of a list of 25

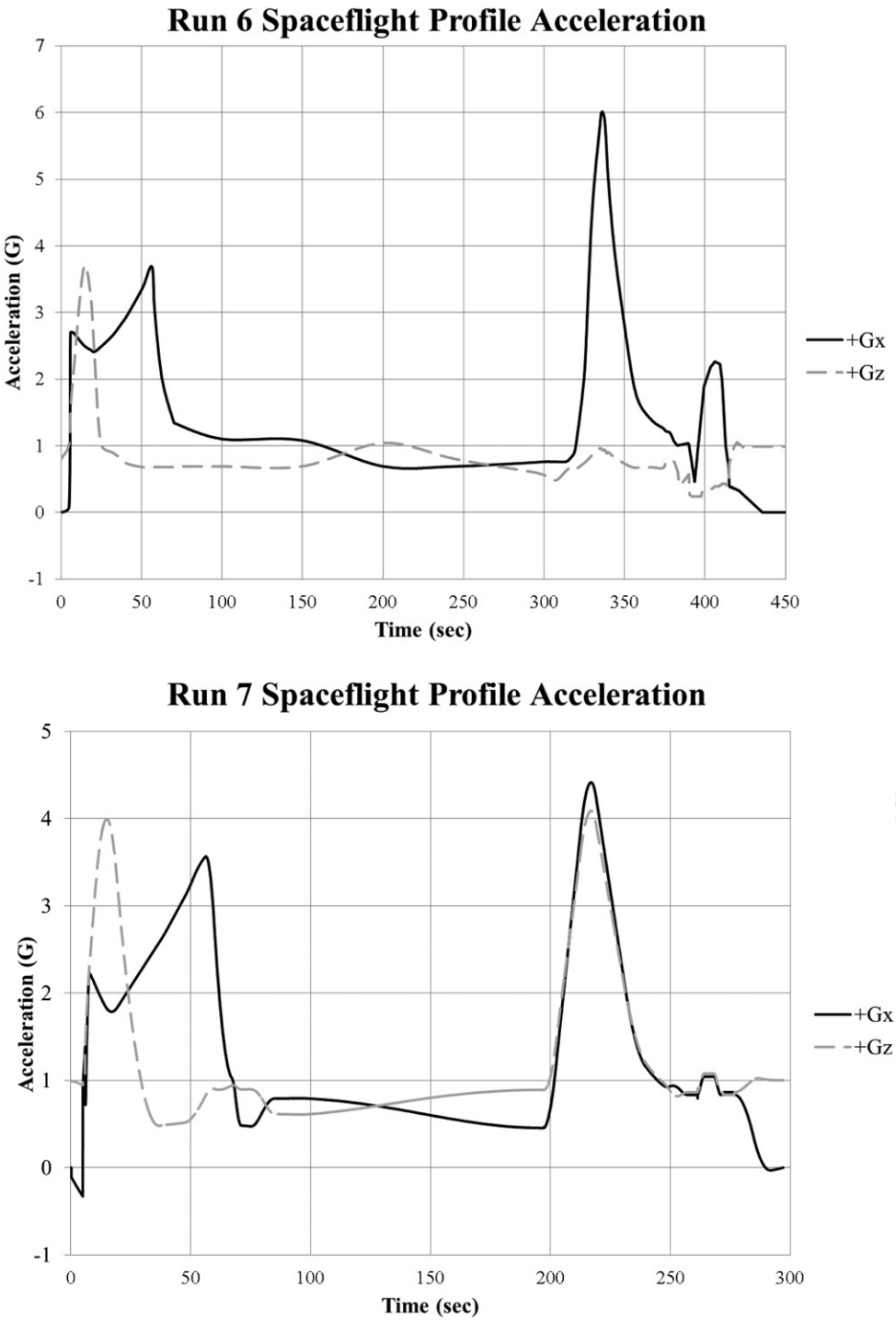

Fig. 1. Combined spaceflight profiles. Top: combined profile simulating a flight where passengers would be seated upright during launch and supine during re-entry. Bottom: combined profile demonstrating forces anticipated for a vehicle requiring upright, seated passengers during launch and re-entry. $+G_z$: head-to-toe acceleration, $+G_x$: chest-to-back acceleration.

printed color names with discordant ink coloring (for example, the word "red" printed in "green" ink). Subjects were asked to name the ink color aloud, as quickly as possible; time to completion and the number of errors made were recorded. Subjects were introduced to the test prior to Run 6 and they were familiarized with a "control" card (where the color of ink matched the name of the word). All subjects then took a baseline test to serve as their own control. The test was then repeated during the "spaceflight" period of Run 6 between the "boost" and "reentry" G exposures.

Finally, subjects were informed they might be asked to perform one or more simulated emergency tasks during one of their flights. All subjects were given an emergency task at the end of Run 6; nonspinning subjects were isolated from all audiovisual feeds during this scenario and were not aware, other than the generalized warning, that the scenario would occur at this time. When the gondola came to a stop, auditory alarms sounded and subjects were verbally instructed to complete a series of tasks (total of 12 steps), including removing their harness, reorienting gondola air vents, signaling one of the gondola cameras, and replacing their harnesses. While subjects were not explicitly told that they could request repetition of the instructions, they were allowed to hear the instructions a second time if requested. Subjects were evaluated based on adherence to instructions, order of tasks, and effective completion of each task, as well as the time to completion.

Statistical Analysis

Data analysis followed collection, using descriptive statistics, ANOVA, Student *t*-tests, Chi-squared analysis, and nonparametric Mann-Whitney U.

RESULTS

A total of 691 volunteers registered for the study. Of these, 369 completed the prescreening medical questionnaire and 220 submitted sufficient medical documentation to be considered for the study. There were seven subjects who were disqualified due to weight [study maximum was 250 lb (114 kg) due to equipment limitations] and eight due to medical reasons (conditions including uncontrolled hypertension and coronary artery disease, severe muscle wasting disorders, and recent surgery).

Table II. Training Lectures, Exercises, and Centrifuge Exposures Included in the Four Training Cohorts.

	AGSM	DIDACTICS	PSYCHOLOGICAL TRAINING AND EXERCISE	SINGLE-DIRECTION EXPOSURES	50% SPACEFLIGHT SIMULATION	100% SPACEFLIGHT SIMULATION	NUMBER OF CENTRIFUGE RUNS
MT	X					X	2
CAT	X	X		X	X	X	7
CPT	X	X	X		X	X	3
CPAT	X	X	X	X	X	X	7

AGSM: Anti-G straining maneuver; MT: minimal training, CAT: cognitive and acceleration, CPT: cognitive/psychological, CPAT: cognitive/psychological/acceleration.

Due to scheduling conflicts, 39 approved subjects were unable to participate. The remaining 157 subjects were scheduled to participate in centrifuge trials. Of these subjects, nine did not participate the day of their trials—one had a personal emergency, two reported significant acute illness that would prevent their participation, and the remainder did not provide any reason or notification before failing to arrive for training. There was no correlation between sex or the cohort assigned and those who failed to arrive for training. The final 148 subjects (105 men, 43 women) participated and are included in statistics reported below.

Subjects were further assigned to each of the four cohorts based on schedule availability and length-of-training preference expressed by subjects, as follows: MT: 39 (24 men, 15 women); CAT: 36 (27 men, 9 women); CPT: 35 (22 men, 13 women); CPAT: 38 (32 men, 6 women). Age ranged from 19 to 72 yr, median 35 yr, with average age of 39.4 ± 13.2. Women were significantly more likely to request participation in shorter training programs (1/2 or 1-d commitments) than longer (2-d) programs (0.5–1 d = 65% of women, 2 d = 35%, $\chi^2 = 5.53$, df = 1, $P = 0.02$). There was no such preference demonstrated by men. There was no significant difference between age ranges of sexes (Men: 39.6 ± 13.0 yr, Women: 39.1 ± 13.7 yr) and there was no significant difference between age differences among any of the cohorts (overall or by sex). Average body mass index (BMI) for all subjects was 25.1 ± 3.7, range 17.3–38.1. Cohort- and sex-specific BMI ranges and averages are presented in **Table III**; there was no significant difference in BMI by sex or cohort. Subjects self-reported their exercise tolerance ranging from minimal (2% subjects), moderate (21% subjects), and high (77% subjects). No subjects chose to take antiemetics of any kind before their centrifuge spins, nor were any subjects taking alpha-adrenergics or peripheral dilators. There was no significant difference in exercise tolerance, overall or by sex or age, between any cohort. **Table IV** lists common disease histories reported by subjects included in the study.

Baseline hemodynamics demonstrated no significant difference in HR or BP among the cohorts. Men demonstrated significantly higher systolic BP at baseline than women (men: 123 ± 13.1 mmHg, women: 117 ± 10.8 mmHg, df 146, $P = 0.01$). There was no sex-specific difference in baseline diastolic BP or HR.

Cohort hemodynamic trends were analyzed on Run 6, as this was one of two spins (Run 6 and Run 7) included in all training cohorts. Further, Run 6 had a lower likelihood of subject loss, as subjects who withdrew most often opted out of Run 7. Examining just Run 6 hemodynamic data, prespin HR was found to be significantly elevated in both the MT and CAT cohorts compared to subject baseline HR (MT baseline: 70.8 ± 13.8 bpm, prespin: 78.6 ± 13.8 bpm, df 76, $P < 0.01$; CAT baseline 68.4 ± 9.6 bpm, prespin 73.9 ± 12.9, df 69, $P = 0.04$); no such trend was identified in the CPT or CPAT cohorts. Postspin HR was significantly increased in the MT cohort when compared to the CAT and CPAT cohorts (MT: 78.8 ± 14.7 bpm, CAT: 71.4 ± 11.4 bpm, df 72, $P = 0.02$; MT: 78.8 ± 14.7 bpm, CPAT: 68.9 ± 12.1 bpm, df 73, $P < 0.01$). During Run 6, HR was significantly elevated during the reentry phase (+6 G_x exposure) in the MT and CPT groups compared to the CAT and CPAT cohorts (MT: 103.5 ± 25.6 bpm, CPT:100.9 ± 17.9 bpm, CAT: 89.2 ± 19.2 bpm, CPAT: 86.8 ± 19.2 bpm; df 68, $P < 0.05$). There were no further significant hemodynamic differences at any other time of flight between cohorts during Run 6.

When examining Run 7, there were no significant differences in hemodynamic responses at any time of flight in the MT group compared to any other cohort. The CPAT cohort was found to have lower HR during the combined reentry (+6 G resultant) compared to either the CPT or the CAT cohorts

Table III. Age (in yr) and Body Mass Index of Subjects by Cohort.

AGE	ALL SUBJECTS (MEAN)	ALL SUBJECTS (RANGE)	MEN (MEAN)	MEN (RANGE)	WOMEN (MEAN)	WOMEN (RANGE)
MT	41.7 ± 14.3 yr	19-68 yr	42.1 ± 13.8 yr	25-68 yr	41.1 ± 15.4 yr	19-68 yr
CAT	37.9 ± 11.4 yr	21-63 yr	37.7 ± 10.9 yr	22-63 yr	38.4 ± 13.7 yr	21-59 yr
CPT	39.0 ± 13.2 yr	25-72 yr	41.7 ± 14.2 yr	25-72 yr	34.3 ± 10.1 yr	25-59 yr
CPAT	39.0 ± 13.6 yr	20-69 yr	37.9 ± 13.2 yr	20-69 yr	45.2 ± 15.4 yr	26-69 yr
BMI	**ALL SUBJECTS (MEAN)**	**ALL SUBJECTS (RANGE)**	**MEN (MEAN)**	**MEN (RANGE)**	**WOMEN (MEAN)**	**WOMEN (RANGE)**
MT	25.1 ± 3.6	18.6-33.5	26.4 ± 3.4	21.8-33.5	23.2 ± 3.0	18.6-31.0
CAT	25.4 ± 3.9	19.1-35.1	25.3 ± 3.1	21.0-34.5	25.9 ± 5.9	19.1-35.1
CPT	25.4 ± 3.2	19.7-33.0	26.1 ± 3.4	21.7-33.0	24.0 ± 2.5	19.7-28.3
CPAT	24.4 ± 2.9	19.4-30.4	24.9 ± 2.8	19.6-30.4	21.7 ± 2.0	19.4-25

Mean, standard deviation, and range presented for all subjects and by sex. BMI: Body Mass Index; MT: minimal training, CAT: cognitive and acceleration, CPT: cognitive/psychological, CPAT: cognitive/psychological/acceleration.

Table IV. Medical Conditions Reported by Subjects Included in Centrifuge Trials.

MEDICAL CONDITION	NUMBER OF SUBJECTS
Motion Sickness (propensity toward)	5
Anxiety	5
Major Depression Disorder	10
Attention Deficit Disorder	4
Gastroesophageal Reflux Disease (GERD)	7
Hypertension	9
Cardiac disease	6
Hypercholesterolemia	7
Thyroid dysfunction	4
Reactive airway disease	2
Cancer	2
Back pain/disorder	13

(CAT: 129.5 ± 20.6 bpm, CPT: 133.7 ± 23.7 bpm, CPAT: 115.6 ± 21.0 bpm, df 62, $P < 0.01$). There were no further significant hemodynamic differences at any other time of flight between cohorts during Run 7.

Responses to the postflight anxiety symptom questionnaire varied by training cohort. Subjects who completed 2-d training programs (CAT and CPAT cohorts) reported significantly fewer symptoms after their first simulated spaceflight (Run 6) than those who participated in shorter training programs (number of symptoms reported after Run 6, 0.5–1 d: 1.6 ± 2.0, 2 d: 0.4 ± 0.9, df = 143, $P < 0.001$). There was a significant improvement noted in reported symptoms between Run 6 and Run 7 in the shorter (MT and CPT) training cohorts; no such improvement was noted in the longer training cohorts (symptoms reported by 0.5–1 d cohorts, Run 6: 1.6 ± 2.0, Run 7: 0.6 ± 1.3, df = 141, $P < 0.001$).

There were no episodes of near or complete G-induced loss of consciousness (A-LOC or G-LOC) during any centrifuge exposure. Nausea was a common complaint by subjects, generally following the completion of a centrifuge run; 5% of subjects reported significant nausea (to the point of adversely affecting their experience) during at least one of the runs. One subject reported a panic attack during Run 3; two subjects reported vomiting after the completion of Run 6.

Of the 148 subjects who arrived and participated in training, 138 subjects completed all centrifuge runs scheduled for their training group. The remaining 10 subjects (3 men, 7 women) chose to either opt out of one or more of the spins (8 subjects, 3 men and 5 women) or to reduce their spin to 50% strength and receive only half the planned G exposure (2 subjects, both women). The opt-out subjects were dispersed across the four cohorts; there was no significant correlation between cohort training group and likelihood of opting out, nor was there correlation with any medical or psychological history and the likelihood of opting out. There was no significant difference in baseline BP of those who chose not to complete their centrifuge runs compared to those who did. However, baseline HR was lower in those who chose to opt out or reduce compared to those who completed all runs (opted out: 63.1 ± 10.1 bpm, completed: 70.0 ± 10.3, df 146, $P = 0.04$). There was no sex- or cohort-specific hemodynamic trend associated with those who opted out compared to those who did not. Male subjects who opted out of later runs or reduced their experiences were significantly older than those who completed all runs (opted out: 53.3 ± 13.5 yr, completed: 39.2 ± 12.8 yr, df 103, $P = 0.03$). There was no significant difference in the age of women who opted out compared to those who completed all runs.

Of the 148 subjects who participated in the centrifuge trials, 145 completed the Stroop test before and during Run 6. Two subjects were unable to complete the Stroop because of equipment failure, one opted out of Run 6 secondary to motion sickness and, therefore, did not complete the test. There was no cohort- or sex-specific difference in errors or time to completion of the test. Subjects ≥ 50 yr of age made significantly more errors than subjects < 50 yr (number of errors, < 50 yr: 0.55 ± 0.89, ≥ 50 yr: 1.08 ± 1.2, df 143, $P < 0.01$). However, in the ≥ 50 yr subjects, performance remained consistent when comparing the prespin baseline Stroop to the test administered during the spin; there was no significant difference in number of errors or time to completion when subjects were compared to their own control test.

A total of 137 subjects were given the emergency scenario as planned. Eight subjects were excluded because of equipment failure and the inability to provide the alarms and the scenario as planned. One subject opted out of Run 6 secondary to motion sickness and one opted out of the emergency scenario secondary to motion sickness after Run 6 completion. Finally, one subject declined to participate in the simulated emergency scenario at the time that the scenario and tasks were presented.

Subjects demonstrated a marked elevation in HR at the onset of the simulated emergency scenario (initiated by auditory alarms), with an average of 34.0 ± 25.5% increase in subject HR. On average, subjects made 2.8 ± 3.1 errors during the scenario. Average time to completion of the 12 tasks was 51.8 ± 19.5 s. There was no correlation between subject hemodynamics at any time of Run 6 prior to the emergency scenario and performance during the scenario; similarly, there was no correlation between percent elevation of HR at the start of the scenario and performance during the scenario. Only 28 individuals made no mistakes during the scenario; there was no correlation to sex, age, or cohort to performance.

Emergency scenario performance was relatively improved in those subjects who did not receive psychological training compared to those who did, with significantly increased numbers of errors in subjects who participated in the psychological training program (number of errors, psychological training cohorts: 3.4 ± 3.3, nonpsychological training cohorts 2.1 ± 2.7, df 135, $P = 0.01$). However, subjects who participated in the psychological training program demonstrated less time to completion of the task (independent of number of errors) than those in the nonpsychological training cohorts (time to completion, psychological training cohorts: 48.1 ± 13.1 s, nonpsychological training cohorts 53.4 ± 16.1 s, df 135, $P = 0.03$).

Only seven subjects (three men and four women) requested repetition of instructions; there was no significant difference in the number of errors in the persons who requested repeat compared to those who did not, nor was there any sex-, age-, or cohort-related difference. The time to completion was

significantly longer for those requesting repeat compared to those who did not, though it should be noted that the time for repetition of instructions was included in their overall time-to-completion (repeat: 78.9 ± 26.9 s, no repeat: 49.0 ± 11.9 s, df 135, $P < 0.001$).

DISCUSSION

Overall, subjects performed quite well during centrifuge training and simulated spaceflights, despite differences in the training programs experienced by each of the cohorts, and most appeared to enjoy the experience. Similar to previous studies,[21] prescreening requirements were generally felt to be effective in identifying subjects who would physically tolerate the centrifuge exposures. Despite the wide range of ages and medical histories included in the study, no clinically significant or symptomatic cardiac, cerebrovascular, or respiratory events occurred during the study.

Nine subjects did not arrive for training on the day of their scheduled participation—three gave reasonable explanations, but the remaining six gave no explanation for their absence. Interestingly, there were no apparent predictors to those who failed to arrive for training, nor any indication that it was anxiety or fear of participation that provoked their absence. While not particularly disruptive during this study, such an absence would be significant for an actual commercial spaceflight, as last-minute substitutions for training or flight would likely be difficult to coordinate, and a SFP's absence would impact weight-and-balance vehicle issues as well as being financially concerning, as that SFP might expect a refund for a flight not taken.

In this study, subjects were allowed to indicate their preference of training dates and length of training program, and most of the subjects did have a preference. In most cases, this preference was met; it was felt that this was more representative of an actual commercial spaceflight experience, as SFPs who are purchasing a flight will certainly have schedule requests as well as preconceived expectations for training and time commitments. However, this allowance of time preference may have caused some confounding factors or in other ways affected our results. Women did request shorter time commitments more often (65% compared to 35%); there was no such preference exhibited by men. It is unclear why women showed a preference for the shorter time commitment. There did not seem to be any correlation between other demographics and time or schedule preferences, nor were there any indicators that those who ultimately proved to be more anxious about the experience expected or preferred a longer period of training or higher number of centrifuge exposures.

There were numerous hemodynamic trends noted between cohorts. Overall, HR was lower before the simulated spaceflight centrifuge exposures in the psychological training cohorts (CPT and CPAT) compared to those who received no psychological training. This may suggest that the psychological training program effectively calmed the subjects prior to their centrifugation, or this could be related to other vagal-mediated responses, including even fear. However, it is worth noting there was no other significant difference noted in hemodynamic response in these groups—subjects followed normal hemodynamic trends at all other phases of flight. This indicates that a lower resting preflight HR does not blunt the physiological tolerance of the flight that follows, nor does it appear to decrease the subject hemodynamic response to the experience that follows. This is an important point—any mitigation strategy that effectively relaxes participants should avoid negatively impacting the tolerance or excitement expected during the spaceflight that follows. These hemodynamic trends suggest that a calming preflight relaxation experience would not impair the physiological tolerance or enjoyment of the participant during the flight itself.

There were few differences noted in subjects' physical tolerance or performance during centrifugation among the various cohorts. Interestingly, even those with severely truncated training (the MT cohort) performed quite well and generally tolerated the combined G exposures of the simulated spaceflights despite having no preparation with single-directional or half-strength exposures. Shorter training-duration cohorts (MT and CPT) did report more symptoms on the postrun questionnaire that would suggest anxiety after Run 6 when compared to subjects who completed the 2-d course, but this significantly improved by Run 7. This suggests that symptoms did rapidly improve with training, even without the single-directional exposures of Day 1.

In a possibly related finding, the MT cohort demonstrated a significantly elevated preflight, postflight, and re-entry HR when compared to other cohorts during Run 6. This suggests that the MT program resulted in a higher stress response (suggested by the HR elevations) during the first centrifuge exposure compared to those who experienced Run 6 only after other centrifuge experiences. Even so, this did not lead to higher incidence of subjects opting out, nor was there higher incidence of any adverse physiological reactions or anxiety in the MT training cohort. This was surprising, as it was expected that there would be higher rates of anxiety or poor tolerance with less training or centrifuge exposure. Further, hemodynamic responses to the dynamic phases of flight, as well as pre- and postrun HR, normalized within the MT cohort compared to the other cohorts by Run 7. It is difficult to interpret these factors regarding recommendations for future SFP training programs; hemodynamic responses normalized in the MT cohort after only one centrifuge exposure, suggesting that number of exposures may not be linearly related to comfort with the experience. Similarly, symptoms of anxiety as reported postflight were high after Run 6 for the 0.5–1 d training cohorts, but improved dramatically with Run 7. We interpret this to suggest that experience of high-fidelity exposures (for example, Run 6 being far closer to a spaceflight experience than Runs 1–4) may be more effective as a training modality than step-wise, single-directional G-exposure or prolonged but less convincing experiences.

Other hemodynamic results showed that the longest training program, the CPAT cohort, demonstrated lower HR

responses to dynamic phases of later flights when compared to the other cohorts. This was particularly evident in the Run 7 combined reentry, where the CPAT cohort demonstrated significantly lower HR than the CAT or CPT cohorts. Even during Run 6, HR was lower in the 2-d training groups (CAT and CPAT) during reentry when compared to shorter training programs. These data suggest that longer training programs do tend to improve physiological tolerance in later runs; perhaps the overall theme is that longer and repetitive training in high-fidelity simulation is more effective than single-directional exposures, and perhaps even more so with the inclusion of a calming exercise prior to flight.

Only 7% of subjects who arrived for training were unable to complete the entire program. Subjects who opted out or reduced their experience had lower resting HR when compared to those who completed all centrifuge exposures. It is possible that the hemodynamic difference may have resulted in increasing symptoms in the subjects who opted out, prompting their withdrawal. Further, the men who withdrew from the study were significantly older than the cohort or study average; it is possible that older men experienced increased symptoms (for example, dizziness or greyout, nausea), prompting their withdrawal, though this is not consistent with previous studies. Prior studies demonstrated that age tends to be related to higher resting blood pressure and, subsequently, fewer symptoms of dizziness or greyout during acceleration exposure;[4,5] in this way, age can be protective. It is unclear whether this finding is incidental; a larger study population could provide more information regarding the role of age in subject withdrawal.

As with previous studies, there were a number of episodes of anxiety, motion sickness, and subject discomfort that did occasionally interfere with the affected subject's ability to continue. It is worth noting that nausea experienced during centrifugation may not indicate that such symptoms should be expected during spaceflight, as nausea is frequently reported during rotational motion.[15,20,22] In fact, the rotational motion of the centrifuge is far more likely to provoke nausea than the linear trajectory of a suborbital spaceflight. It remains unclear whether the single hypergravity-microgravity-hypergravity transitions of a suborbital flight will induce nausea symptoms as such gravitational changes cannot be simulated by ground-based analogs.

There were no significant differences in subject performance on the Stroop test when comparing against their own baseline performance. This was an interesting finding, as it was anticipated that subjects would perform poorly secondary to stress imposed by the environment or the Stoop test itself.[11,12] However, there are some confounding variables in this test—first, subjects were administered a baseline test just prior to the spin; they had not familiarized themselves with the test prior to the day of the centrifugation and each subject was only tested once, thereby providing no aggregate or average performance value. The lighting within the gondola is not ideal, as overhead lighting is provided only by the audiovisual display system, which during the testing period is subdued and blue-tinted. Subjects anecdotally reported that, due to lighting, the words themselves were difficult to read, while color of ink was relatively easy to identify; this may have led to a falsely improved score during flight. Finally, the nature of the Stroop test is not an ideal evaluation modality for in-flight activities during a suborbital spaceflight.

Subjects appeared to be sufficiently stressed by the simulated emergency scenario, as demonstrated by the universal elevation in heart rate at the initiation of the scenario. Only 19% of subjects were able to perform the scenario without error; subjects were given 12 different steps to complete and, on average, made at least 3 mistakes. This is an interesting finding, and suggests a number of issues. It has been well demonstrated that, while stress can occasionally improve performance by elevating focus,[8,10] long lists of tasks or instructions are often poorly received or understood under stress,[23,24] and anxiety and stress tend to adversely affect processing efficiency, particularly of unfamiliar tasks.[7,9] Given that HR was not associated with performance, we suspect that the balance between improving performance by elevating focus and disrupting performance from adverse effects on processing is highly individualized.

In addition, communications during emergencies can be limited by auditory alarms, and tasks may be poorly interpreted. A request for subjects to delay their response (for example, perform this task but only after all instructions are completed) was a common source of error. Further, subjects appeared to have most difficulty with specific elements of tasks (for example, when asked to signal a specific camera, subjects would signal the wrong camera but perform the signal correctly), suggesting that fine details or multiple options tend to confuse. These important findings do suggest specific guidelines regarding instructions provided to SFPs in the case of an emergency. First, instructions should be few and clearly presented without room for interpretation. SFPs should not be provided anticipatory instruction but should only be asked to do a task at the time it is needed. Finally, practice of any emergency tasks, identifying any misleading alternatives or sources of confusion, would likely improve performance.

It is unclear why subjects who received psychological training demonstrated more errors than the other cohorts in the emergency scenario. This may be related to the decreased time-to-completion found for these subjects—they may have rushed through the instructions and, as a result, made more errors overall. Further, it is possible that the psychological training provided a higher level of comfort with the experience as a whole and, as a result, they may not have taken the exercise as seriously as subjects in other cohorts.

Finally, very few factors were demonstrated to be predictive of those who would have difficulty with the centrifuge experience as a whole. Overall, a propensity toward motion sickness tends to be associated with a higher likelihood of withdrawal from the study. There is no association between past medical history of anxiety, major depression, or any other psychological disorder and overall subject tolerance, withdrawal, or enjoyment of the experience. This is consistent with prior studies that demonstrated no association with psychological

history and anxiety during centrifuge exposures.[4,18] As motion sickness may only be predictive during rotational motion, it is unclear whether motion sickness will be similarly predictive of SFP intolerance of suborbital spaceflight. It is likely that this may only be fully explored by evaluating real performances of SFPs at the commencement of suborbital flight.

The limitations of the current study are mainly due to the use of centrifugation as an analog. Although acceleration forces were replicated using the most technologically advanced method possible in a terrestrial study, centrifugation can lead to artifacts such as Coriolis effects that will not occur during actual spaceflight.[20] Due to weight and space limitations inherent to the centrifuge, we are unable to replicate conditions of a multipassenger spacecraft. Moreover, we cannot replicate on Earth the 3–4 min of weightlessness that will occur during anticipated actual commercial spaceflights. While alterations in hemodynamics have been noted during microgravity analogs, such as parabolic flight, most individuals tolerate the hemodynamic challenges of the hypergravity-microgravity transitions without difficulty, particularly when repetition of parabolas is limited.[14,16,17] Less well studied are the psychological effects of microgravity and spaceflight experience, particularly in laypersons, though, unsurprisingly, studies have demonstrated a propensity toward increased sensation-seeking behavior in individuals attracted to such experiences.[6] It is unclear whether this behavioral pattern will alter the occurrence of anxiety in commercial spaceflight. However, actual spaceflight, by virtue of it being 'real' and accompanied by actual risk, may lead to responses different than the ones obtained in the current study. Even so, the analog used in the current study may be the most realistic simulation currently available and it is not unreasonable to assume that the pattern of obtained results will be helpful in developing effective training protocols for commercial SFPs.

To the authors' knowledge, this is the largest study to date of layperson centrifugation. The study has demonstrated overall good tolerance of acceleration exposures in the minimally trained layperson population. Prescreening and medical evaluation remain important to ensure that subject medical diseases are well-controlled prior to flight, though physical requirements are likely minimal. Training programs are most effective when high fidelity and sequential exposures may help SFPs feel increasingly comfortable with the physical and mental strains of flight. SFP instructions in case of emergency should be brief, concise, timely, and preferably practiced prior to any actual emergency. Finally, there are very few indicators of an individual's ability to tolerate, particularly psychologically, the stress of suborbital flight. SFP anxiety, panic, and withdrawal, and identifying those at greatest risk, will continue to be a challenge for the suborbital spaceflight industry.

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Authors and affiliations: Rebecca S. Blue, M.D., M.P.H., Kimberly Seaton, Ph.D., Johnené L. Vardiman, M.S., Charles Mathers, M.D., M.P.H., Tarah L. Castleberry, D.O., M.P.H., and James M. Vanderploeg, M.D., M.P.H., Department of Preventive Medicine and Community Health, University of Texas Medical Branch, Galveston, TX; Frederick Bonato, Ph.D., Department of Psychology, Montclair State University, Montclair, NJ; and Andrea Bubka, Ph.D., Department of Psychology, Saint Peter's University, Jersey City, NJ.

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