

Fiscal Year:	FY 2017	Task Last Updated:	FY 09/13/2017
PI Name:	Ryder, Valerie Ph.D.		
Project Title:	Effects of Acute Exposures to Carbon Dioxide upon Cognitive Function		
Division Name:	Human Research		
Program/Discipline:			
Program/Discipline--Element/Subdiscipline:	HUMAN RESEARCH--Behavior and performance		
Joint Agency Name:	TechPort:	No	
Human Research Program Elements:	(1) HFBP :Human Factors & Behavioral Performance (IRP Rev H)		
Human Research Program Risks:	(1) BMed :Risk of Adverse Cognitive or Behavioral Conditions and Psychiatric Disorders		
Space Biology Element:	None		
Space Biology Cross-Element Discipline:	None		
Space Biology Special Category:	None		
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Zip Code:	77058-3607	Congressional District:	22
Comments:			
Project Type:	GROUND	Solicitation / Funding Source:	2014-15 HERO NNJ14ZSA001N-Crew Health (FLAGSHIP & NSBRI)
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No. of Master's Candidates:	0	No. of Bachelor's Degrees:	0
No. of Bachelor's Candidates:	0	Monitoring Center:	NASA JSC
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Flight Program:			
Flight Assignment:	NOTE: Element change to Human Factors & Behavioral Performance; previously Behavioral Health & Performance (Ed., 1/18/17)		
Key Personnel Changes/Previous PI:	April 2016 report: Mathias Basner, Ph.D. and Usha Satish, Ph.D. are new CoInvestigators. September 2017 report: Rob Ploutz-Snyder has taken a position elsewhere and Millennia Young was added as the NASA Biostatistician in his place.		
COI Name (Institution):	Alexander, David M.D. (Co-PI: NASA Johnson Space Center) Lam, Chiu-Wing Ph.D. (Wyle Laboratories/NASA Johnson Space Center) Scully, Robert Ph.D. (Wyle Laboratories/NASA Johnson Space Center) Satish, Usha Ph.D. (State University of New York (SUNY)) Basner, Mathias Ph.D. (University of Pennsylvania) Young, Millennia Ph.D. (NASA Johnson Space Center)		
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Task Description:

Evidence had been published that indicates that CO₂ at concentrations below 2 mm Hg significantly impacted some cognitive functions that are associated with the ability to make complex decisions in conditions that are characterized by volatility, uncertainty, complexity, ambiguity, and delayed feedback – conditions that could be encountered by crews in off-nominal situations, or during the first missions beyond low Earth orbit. Our study will extend the original study by using measures of cognitive domains to determine if astronaut-like subjects are sensitive to concentrations of CO₂ at or below limits currently controlled by flight rules. Human test subjects, selected based on similarities to the current astronaut cohort, will be exposed to 600, 1200, 2500, and 5000 ppm (0.5, 0.9, 1.9, and 3.8 mmHg) CO₂ in a controlled facility. The concentration sequence will be randomized and unknown to study participants, and measures of cognitive function will be collected during exposures. Our use of cognitive measures in a well-controlled, ground-based study that is free of these potential confounding influences will establish a baseline terrestrial data set against which cognitive data collected in flight may be assessed. If confirmed, these findings would provide additional evidence that CO₂ may need to be controlled at levels that are well below current spacecraft limits.

Rationale for HRP Directed Research:

The need to assess safe limits of exposure to CO₂ with respect to adverse effects upon cognitive functions are particularly urgent in a setting in which even small decrements in cognitive functions, such as those utilized in complex decision making, could pose significant risk to outcomes in which substantial resources and even lives are invested. One such setting is human space flight. Crew reports and other anecdotal evidence (Law, et al., 2010; Cronyn et al., 2012; Strangman et al., 2012) suggest that the space flight environment may depress mental faculties. However, it seems probable that the measures historically available to space flight crews (Spaceflight Cognitive Assessment Tool for Windows (WinSCAT) and MiniCog) lacked the sensitivity needed to detect deficits in cognitive functions experienced or observed as instances of “mental viscosity,” due to the ceiling effect, which occurs when subjects achieve perfect scores on subtests in these batteries and so there is no difference measurable among subjects at the ceiling level (Cowings et al., 2006). Thus for several reasons, including small sample size, learning effects, and lack of sensitivity, “our knowledge about cognitive effects of space flight is superficial” (De La Torre et al., 2012). Given that CO₂-like symptoms, such as difficulty in concentrating and headache, are among the most common symptoms reported by crews (Strangman, 2010), are experienced at lower than expected levels of CO₂ (4,000 to 8,000 PPM, or 3 to 6 mm Hg), and resolve when the spacecraft CO₂ is reduced, the possibility exists that CO₂ sensitivity may be enhanced in the space environment (Law et al., 2010, 2014), it is possible that the threshold for cognitive effects attributable to CO₂ in space may be lower than that observed by Satish et al. (2012). If this holds true, it may result in the need to establish lower space flight limits for CO₂ and in turn drive the development of new technologies for CO₂ control onboard spacecraft. Although not impacted by physiological changes associated with microgravity, submariners experience similar isolated quarters with recycled resources and higher than average baseline CO₂ levels. In addition, they are another population where minor effects on cognition and decision-making can have life threatening consequences.

REFERENCES:

Cowings PS, Toscano WB, DeRoshia CW, Taylor B, Hines S, Bright A, Dodds A. (2006). Converging Indicators for Assessing Individual Differences in Adaptation to Extreme Environments: Preliminary Report. NASA/TM-2006-213491.

Research Impact/Earth Benefits:

Cronyn PD, Wakins S, Alexander DJ. (2012). Chronic exposure to Moderately Elevated CO₂ during Long-Duration Space Flight. NASA/TP-20120217358.

De La Torre GG, van Baarsen B, Ferlazzo F, Kanas N, Weiss K, Schneider S, Whiteley I. (2012). Future perspectives on space psychology: Recommendations on psychosocial and neurobehavioural aspects of human spaceflight. *Acta Astronautica* 81(2): 587-599.

Law J, Watkins S, Alexander D. (2010). In-flight carbon dioxide exposures and related symptoms: association, susceptibility, and Operational implications. NASA/TP-2010-216126.

Law J, Van Baalen M, Foy M, Mason SS, Mendez C, Wear M L, Meyers VE, Alexander D. (2014). Relationship between Carbon Dioxide Levels and Reported Headaches on the International Space Station. *Journal of Occupational and Environmental Medicine*, 56(5), 477-483.

Satish U, Mendell MJ, Shekhar K, Hotchi T, Sullivan D, Streufert S, Fisk WJ. (2012). Is CO₂ an Indoor Pollutant? Direct Effects of Low-to-Moderate CO₂ Concentrations on Human Decision-Making Performance. *Environ Health Perspect* 120:1671–1677.

Strangman, G. (2010). Human Cognition and Long Duration Space flight. A literature review on the topic of: “Changes in Cognition and Psychological Well-being in Isolated, Confined and Extreme Environments”. Produced for NASA’s Behavioral Health and Performance (BHP) program element. In: Additional Evidence: Risk of Adverse Behavioral Conditions and Psychiatric Disorders.

Strangman G, Beven G. (2012). Review of Human Cognitive Performance in Space flight. 84th Annual Scientific Meeting of the Aerospace Medical Association; 12-16 May 2013, Chicago, IL, United States.

The task is now complete. This double-blinded cross-over study was conducted with 22 healthy, astronaut-like participants at the Johnson Space Center. Four groups, each comprised of 4-6 individuals, were exposed to each of four concentrations of CO₂ in a sequence that varied for each group so that the order of exposure to the four concentrations (600 ppm, 1200 ppm, and 2500 ppm, 5000 ppm) was balanced among the groups. Volunteer subjects were allowed to acclimate to CO₂ in a human rated chamber for 15 minutes before early effects of CO₂ were assessed through administration of the Cognition battery (~20 min) via Apple iPad. After completion of initial testing and another 15 minute rest period (1 hour total post chamber entry), decision-making competencies were assessed by the Strategic Management Simulations (SMS), which were administered by laptop computer. The SMS lasted for approximately 80 minutes. After a final 15 minute rest period, subjects completed a second Cognition battery. These in-chamber data were compared to Cognition testing pre- and post-exposure results. Data were analyzed using linear mixed effect models with random subject intercept to account for the repeated measure design. Performance across the Cognition battery and on most measures of the SMS were lower at 1200 ppm than at 600 ppm; however, at higher concentrations of CO₂ performance was similar to, or improved, relative to baseline for most

Task Progress:	<p>measures. The complex decision making performance of astronaut-like test subjects in the present study and in naval officers in a separate study was found not to be as severely impacted by CO₂ as it was in younger adults tested previously by Satish et al. (2012). It is possible that the decision making processes of young adults differ from those of older, more experienced, highly motivated and achieving adults; however, similar susceptibility of "professional grade employees" in a more recent study by Allen et al. (2016) suggests that particular experiences rather than age per se may correlate better with differences in decision making performances as measured by the SMS in ground-based studies. While astronaut-like test subjects in our study and naval officers are not affected by these CO₂ levels, studies should be conducted to assess other performance degradation stressors on astronauts, like sleep deprivation and microgravity, together with CO₂ exposures.</p> <p>REFERENCES</p> <p>Satish, U., Mendell, M., Shekhar, K., Hotchi, T., Sullivan, D., Streufert, S., & Fisk, W. (2012). Is CO₂ an indoor pollutant? Direct effects of low-to-moderate CO₂ concentrations on human decision-making performance. <i>Environ Health Perspect</i>, 120(12), 1671-1677.</p> <p>Allen, J., MacNaughton, P., Satish, U., Santanam, S., Vallarino, J., & Spengler, J. (2016). Associations of Cognitive Function Scores with Carbon Dioxide, Ventilation, and Volatile Organic Compound Exposures in Office Workers: A Controlled Exposure Study of Green and Conventional Office Environments. <i>Environ Health Perspect</i>, 124(6), 805-812.</p>
Bibliography Type:	Description: (Last Updated: 01/11/2021)
Abstracts for Journals and Proceedings	<p>Ryder VE, Scully RR, Alexander DJ, Lam CW, Young M, Satish U, Basner M. "Effects of Acute Exposures to Carbon Dioxide upon Cognitive Functions." 2017 NASA Human Research Program Investigators' Workshop, Galveston, TX, January 23-26, 2017.</p> <p>2017 NASA Human Research Program Investigators' Workshop, Galveston, TX, January 23-26, 2017. , Jan-2017</p>
Articles in Peer-reviewed Journals	<p>Scully RR, Basner M, Nasrini J, Lam C, Hermosillo E, Gur RC, Moore T, Alexander DJ, Satish U, Ryder VE. "Effects of acute exposures to carbon dioxide on decision making and cognition in astronaut-like subjects." <i>npj Microgravity</i>. 2019 Jun 19;5:17. https://doi.org/10.1038/s41526-019-0071-6 ; PMID: 31240239; PMCID: PMC6584569 , Jun-2019</p>