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 Behavioral Conditions and Psychiatric Disorders (2) **Sleep**:Risk of Performance Decrements and Adverse Health Outcomes Resulting from Sleep Loss, Circadian Desynchronization, and Work Overload (IRP Rev F)		
Space Biology Element:	None		
Space Biology Cross-Element Discipline:	None		
Space Biology Special Category:	None		
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PI Organization Type:	NASA CENTER	**Phone:**	281-483-4989
Organization Name:	NASA Johnson Space Center		
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City:	Houston	**State:**	TX
Zip Code:	77058-3607	**Congressional District:**	22
Comments:			
Project Type:	GROUND	**Solicitation:**	2014-15 HERO NNJ14ZSA001N-Crew Health (FLAGSHIP & NSBRI)
Start Date:	07/01/2015	**End Date:**	06/30/2017
No. of Post Docs:	0	**No. of PhD Degrees:**	0
No. of PhD Candidates:	0	**No. of Master' Degrees:**	0
No. of Master's Candidates:	0	**No. of Bachelor's Degrees:**	0
No. of Bachelor's Candidates:	0	**Monitoring Center:**	NASA JSC
Contact Monitor:	Williams, Thomas	**Contact Phone:**	281-483-8773
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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)		
Grant/Contract No.:	Internal Project		
Performance Goal No.:			

Performance Goal Text:	
Task Description:	Evidence had been published that indicates that CO_2 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 CO_2 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) CO_2 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 CO_2 may need to be controlled at levels that are well below current spacecraft limits.
Rationale for HRP Directed Research:	
Research Impact/Earth Benefits:	The need to assess safe limits of exposure to CO_2 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 CO_2-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 CO_2 (4,000 to 8,000 PPM, or 3 to 6 mm Hg), and resolve when the spacecraft CO_2 is reduced, the possibility exists that CO_2 sensitivity may be enhanced in the space environment (Law et al., 2010, 2014), it is possible that the threshold for cognitive effects attributable to CO_2 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 CO_2 and in turn drive the development of new technologies for CO_2 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 CO_2 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. 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 CO_2 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 CO_2 in a human rated chamber for 15 minutes before early effects of CO_2 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.

Task Progress:	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 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. REFERENCES 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. Environ Health Perspect, 120(12), 1671-1677. 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. Environ Health Perspect, 124(6), 805-812.
Bibliography Type:	Description: (Last Updated: 01/11/2021)
Abstracts for Journals and Proceedings	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. 2017 NASA Human Research Program Investigators' Workshop, Galveston, TX, January 23-26, 2017. , Jan-2017
Articles in Peer-reviewed Journals	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." npj Microgravity. 2019 Jun 19;5:17. https:// ; PMID: 31240239; PMCID: PMC6584569 , Jun-2019