

## Effects of Acute Exposures to Carbon Dioxide upon Cognitive Functions

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Large quantities of carbon dioxide (CO<sub>2</sub>) originate from human metabolism and typically, within spacecraft, remain about 10-fold higher in concentration than at the earth's surface. There have been recurring complaints by crew members of episodes of "mental viscosity" adversely affecting their performance, and there is evidence from the International Space Station (ISS) that associates CO<sub>2</sub> levels with reports of headaches by crewmembers [1], [2]. Additionally, there is concern that CO<sub>2</sub> may contribute to vision impairment and intracranial pressure that has been observed in some crewmembers [3], [4]. Consequently, flight rules have been employed to control the level of CO<sub>2</sub> below 4 mm Hg, which is well below the existing Spacecraft Maximum Allowable Concentration (SMAC) of 10 mm Hg for 24-hour exposures, and 5.3 mm Hg for exposures of 7 to 180 days [5], [6]. However, the flight rule imposed limit, which places additional demands upon resources and current technology, still exceeds the lower bound of the threshold range for reportable headaches (2 - 5 mm Hg) [1], [2]. Headaches, while sometime debilitating themselves, are also symptoms that can provide evidence that physiological defense mechanisms have been breached [7]. The causes of the headaches may elicit other subtle adverse effects that occur at CO<sub>2</sub> levels well below that for headaches. The concern that CO<sub>2</sub> may have effects at levels below the threshold for headaches appears to be substantiated in unexpected findings that CO<sub>2</sub> at concentrations below 2 mm Hg substantially reduced some cognitive functions that are associated with the ability to make complex decisions [8] in conditions that are characterized by volatility, uncertainty, complexity, ambiguity, and delayed feedback [8], [9]. These are conditions that could be encountered by crews in off-nominal situations or during the first missions beyond low earth orbit. If findings of the earlier study [8] are confirmed in crew-like subjects, our findings would provide additional evidence that CO<sub>2</sub> may need to be controlled at levels that are well below current spacecraft limits.

Our study will extend the earlier study [8] to determine if crew-like subjects are similarly effected by CO<sub>2</sub>. In addition to employing the Strategic Management Simulation tool [8], we will use the *Cognition* [10] battery of psychometric measures that are being utilized aboard the ISS. It will be important to learn, by using *Cognition*, if additional cognitive domains are sensitive to concentrations of CO<sub>2</sub> at or below limits currently controlled by flight rules. While spaceflight *Cognition* data will greatly enhance the knowledge base related to inflight behavioral health and performance, some of the measures may be influenced by fatigue (related to sleep deprivation and or workload) and changes in circadian rhythms [11], [12]. Therefore our use of this battery of tests in a well-controlled, ground-based study that is free of these potential confounding influences will establish a baseline terrestrial data set against which *Cognition* data collected in flight may be assessed.

The findings from this study will be useful to the NASA Toxicology Office and the National Research Council Committee on Toxicology, which assists NASA in setting environmental standards, for revision of the SMAC for CO<sub>2</sub>, and for designing further studies on effects of CO<sub>2</sub> upon cognitive functions.

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