Fiscal Year:	FY 2024	**Task Last Updated:**	FY 11/02/2023
PI Name:	Clark, Torin K. Ph.D.		
Project Title:	A Non-Pharmacological Countermeasure Suite for Motion Sickness Induced by Post-Flight Water Landings		
Division Name:	Human Research		
Program/Discipline:			
Program/Discipline--Element/Subdiscipline:			
Joint Agency Name:		**TechPort:**	No
Human Research Program Elements:	(1) **HHC**:Human Health Countermeasures		
Human Research Program Risks:	(1) **Sensorimotor**:Risk of Altered Sensorimotor/Vestibular Function Impacting Critical Mission Tasks		
Space Biology Element:	None		
Space Biology Cross-Element Discipline:	None		
Space Biology Special Category:	None		
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Comments:	NOTE: PI moved to University of Colorado after NSBRI Postdoctoral Fellowship concluded in late 2015 (Ed., 9/1/17)		
Project Type:	GROUND	**Solicitation / Funding Source:**	2019-2020 HERO 80JSC019N0001-HHCBPSR, OMNIBUS2: Human Health Countermeasures, Behavioral Performance, and Space Radiation-Appendix C; Omnibus2-Appendix D
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No. of PhD Candidates:	2	**No. of Master' Degrees:**	1
No. of Master's Candidates:	1	**No. of Bachelor's Degrees:**	0
No. of Bachelor's Candidates:	3	**Monitoring Center:**	NASA JSC
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Flight Program:			
Flight Assignment:			
Key Personnel Changes/Previous PI:	November 2023 report: None.		
COI Name (Institution):	DiZio, Paul Ph.D. (Brandeis University) Lawson, Benton Ph.D. (Self) Oman, Charles Ph.D. (Massachusetts Institute of Technology)		
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Task Description:	To mitigate astronaut motion sickness during capsule water landings, we aim to assess the benefit of providing Earth-fixed, external visual references, and enabling active postural control to increase head and torso stability, in a series of ground-based laboratory experiments. Re-exposure to Earth gravity, combined with the passive motion of the capsule in the sea is expected to cause varying degrees of motion sickness in most astronauts. In our laboratory experiments, we will use sustained hyper-gravity centrifugation and a visual reorientation paradigm to mimic adaptive responses to gravity-transitions experienced by astronauts. Immediately following, we will use our motion simulators to expose subjects to passive motions relevant for those expected for a capsule at sea. With the standard Motion Sickness Questionnaire, we will first quantify the prevalence, severity, and time course of resulting motion sickness. Next, we will systematically evaluate approaches which have been reported, mostly anecdotally, to benefit terrestrial seasickness, theoretically by helping anticipate the incoming sensory information and reducing the resulting sensory conflict. This includes 1) providing external visual reference cues within the capsule and 2) requiring the subject to try to keep their head and/or torso upright during the passive simulated sea-motion. We hypothesize external visual references will help subjects anticipate inertial motion cues (e.g., vestibular) that are otherwise unpredictable in a closed capsule. Given the emerging relationship between posture and motion sickness, we hypothesize subjects with their head and torso unrestrained and required to maintain alignment with upright during the passive motion stimulation will again help reduce sensory conflict and thus mitigate motion sickness. While these approaches are anecdotally-promising and grounded in sensory conflict theory, they have not been systematically assessed for the scenario of post-flight water landings. Through our experimental evaluations, we will develop a better scientific understanding of the mechanisms of motion sickness induced by post-flight water landings. Our planned countermeasure approaches are readily implementable within the capsule (e.g., providing external visual cues with projection displays or virtual reality) and should have no side effects. In fact, we hypothesize our non-pharmaceutical approaches can lead to reduced dosages of anti-motion sickness medications (e.g., promethazine), which do have undesirable side effects. If successful, these approaches will have substantial significance in reducing astronaut motion sickness post-water landings, which can otherwise impair mission performance and egress.
Rationale for HRP Directed Research:	
Research Impact/Earth Benefits:	This project focuses on developing countermeasures to mitigate motion sickness experienced by astronauts during water landings post-flight. While our focus is on the unique combination of astronauts experiencing a gravity transition (microgravity to 1 Earth g) along with the passive motion of the capsule produced by ocean waves, our approaches are likely to translate well to terrestrial motion sickness scenarios (e.g., seasickness, carsickness). While terrestrial motion sickness does not include the gravity transition experienced by astronauts, the passive, ocean wave motion is similar to that which often causes some forms of terrestrial motion sickness. Thus, we anticipate that our most promising countermeasures may be effective in helping mitigate some forms of terrestrial motion sickness. To help assess this, we will perform testing with subject cohorts that are exposed to 1) the gravity transition analog, 2) the wave-like motion analog, and 3) the combination of both, which will help us disambiguate the relative contributions of each, but also evaluate the countermeasures during just wave-like motion without the gravity transition (which may be more applicable for terrestrial motion sickness). Since motion sickness is commonly experienced in cars, boats, airplanes, and other paradigms like virtual reality, countermeasures to mitigate motion sickness could have substantial terrestrial benefits.
Task Progress:	In the last year, we made substantial progress on our human subject experiments to assess countermeasures to motion sickness associated with water landings. Programmatically, we have had intermittent virtual team meetings to discuss integrating project objectives, protocol choices, and planned analyses. In Spring 2023, we had an opportunity to meet with some Co-Investigators (Co-Is), NASA scientific advisors, and potential stakeholders (i.e., commercial spaceflight providers). In addition, we had an in-person meeting with some of the Co-Is in Boulder in June 2023, providing an opportunity to review results and plan upcoming experiments, but also to visit laboratory facilities and experience experimental protocols. Then the bulk of the effort has been on implementing, refining, and performing our human subject testing protocols to evaluate countermeasures effectiveness for mitigating motion sickness. We have performed extensive data analysis on our series of experiments. As a major accomplishment, we have published our first peer-reviewed journal paper assessing the impact of virtual reality on reducing motion sickness incidence. At the University of Colorado-Boulder, we completed testing in two cohort groups, each with 15 subjects enrolled: 1) a visual countermeasure group, which was provided a rich visual scene in virtual reality that moved congruently with their self-motion during the simulated “wave-like” motion, and 2) a control group, who also wore a head-mounted display, but which displayed a stationary (in the field of view) fixation point, and thus no cues regarding self-motion. All subjects experienced the “sickness induced by centrifugation” (SIC) paradigm on our short-radius centrifuge, providing 2Gs for approximately 1 hour. SIC aims at mimicking a gravity transition relevant to spaceflight. Immediately following the SIC paradigm, subjects experience up to 1 hour of the wave-like motion on our Tilt-Translation Sled. These profiles are representative of buoy data near potential water landing sites in terms of frequency content, amplitudes, and coherence of tilt motion versus lateral translation. The results of these studies were published in Experimental Brain Research. In addition, we have begun testing on two additional potential countermeasures. In one, termed the “postural control” group, subjects have their head and torso unrestrained and are instructed to make postural motions to attempt to keep their head aligned with the direction of down during the wave-like motion. We hypothesized that this would engage postural control circuitry and enable subjects to reduce the sensory conflict associated with the wave-like passive motion. To date, we have tested 11 (of the planned 15) postural control subjects. We have found that 6 of these 11 subjects (55%) reached our stopping criteria of reporting “moderate” nausea on two successive reports, before the end of the hour of wave-like motion. This is slightly less but roughly similar to the control group where 10 of 15 subjects (67%) were unable to complete the hour of wave-like motion without reaching moderate nausea. This tentatively suggested the postural control countermeasure is unable to reduce the propensity of moderate motion sickness. In the second group, termed the “anticipatory cueing” group, we designed a novel display which not only provides a rich visual scene that moves congruently with self-motion (as in the visual countermeasure group previously), but also provides a figurine that moves in an anticipatory manner, providing cues of the upcoming motion 1 second into the future. Specifically, the display includes a transparent notional figurine of a person, which tilts and translates laterally along a track to convey upcoming motion. In addition, an arrow points relative to the person in the direction (and magnitude) of the net gravito-inertial (i.e., the combination of linear acceleration and gravity) which is how the person may “feel” the net force acting upon them. We hypothesized that this would help subjects build a proper expectation of

upcoming sensory information, reducing sensory conflict, and helping to mitigate motion sickness. To date, we have tested 5 subjects in this group (of the planned 15). As preliminary results, we have found that while 1 subject was stopped prematurely due to a technical issue, all subjects completed the wave-like motion (i.e., 0% of subjects reached moderate nausea). While tentative, this suggests that the anticipatory cueing in virtual reality may be an effective means of reducing the propensity of motion sickness, potentially even beyond the visual countermeasure condition (without anticipatory cueing).

The Brandeis arm of this project employs a virtual rendition of the visual reorientation levitation illusion introduced by Howard to partially simulate orbital microgravity, and a six-degree-of-freedom Stewart platform to simulate a water landing sea state (heave ±42 cm centered on 0.17 Hz and roll ±10° centered on 0.4 Hz). Data collection is complete for three within-subject counter-balanced treatment conditions (n=15). All three sessions begin with the microgravity analog: one hour in which supine subjects make paced roll head movements in a fully articulated virtual room pitched back 90°. This is then followed by an immediate transition to the sea state analog: reorientation to the upright with head restraint and the onset of platform oscillation. For the next hour, subjects viewed either 1) a completely dark field, 2) a head-fixed single fixation point in a dark field, or 3) a virtual spatially stabilized horizon line. Separate overall motion sickness and anxiety self-ratings (both 0-10 scales) were prompted every 60 seconds, and postural stability (standing in tandem stance on a narrow beam, arms crossed, eyes open/closed) was measured at the beginning and end. We found that the availability of a horizon-fixed visual reference mitigated motion sickness severity, relative to viewing a head-fixed visual target and being in complete darkness during exposure to partially simulated wave motion following sensitization by active head movements in a 0g analog environment. To determine whether active postural stabilization is an incremental countermeasure to an Earth-fixed visual reference, we are currently assessing motion sickness severity in the same ground-based 0g-to-sea state sequence, with the same horizon-fixed visual reference, when subjects are instructed to either hold their head and torso upright versus when head and torso are restrained in the upright orientation. To date, 7 subjects have completed at least one of the two conditions in the repeated measures design, and we plan to run a total of 10.

Bibliography Type:	Description: (Last Updated: 12/01/2023)
Abstracts for Journals and Proceedings	Clark TK, Lonner TL, Allred A, Gopinath A, Bonarrigo L, Oman CM, Lawson BD, Groen EL, Lackner J, and DiZio P . "Countermeasures to reduce sensory conflict and mitigate motion sickness from ground-based analogs of a gravity transition and sea state motion." 2023 NASA Human Research Program Investigator's Workshop, Galveston, Texas, February 7-9, 2023. Abstracts. 2023 NASA Human Research Program Investigator's Workshop, Galveston, Texas, February 7-9, 2023. , Feb-2023
Abstracts for Journals and Proceedings	Lonner TL, Gopinath G, Bonarrigo L, and Clark TK. "The effect of virtual reality on motion sickness and balance in astronauts during post-flight water landings." 2023 NASA Human Research Program Investigator's Workshop, Galveston, Texas, February 7-9, 2023. Abstracts. 2023 NASA Human Research Program Investigator's Workshop, Galveston, Texas, February 7-9, 2023. , Feb-2023
Abstracts for Journals and Proceedings	Lonner TL, Allred A, Gopinath A, Bonnarigo L, and Clark TK. "Using virtual reality as a countermeasure for astronaut motion sickness and sensorimotor impairment in post-flight water landings." 93rd Annual Scientific Meeting of the Aerospace Medical, New Orleans, Louisiana, May 21-25, 2023. Abstracts. 93rd Annual Scientific Meeting of the Aerospace Medical, New Orleans, Louisiana, May 21-25, 2023. , May-2023
Articles in Peer-reviewed Journals	Lonner TL, Allred AR, Bonarrigo L, Gopinath A, Smith K, Kravets V, Groen E, Oman C, DiZio P, Lawson BD, and Clark TK. "Virtual reality as a countermeasure for astronaut motion sickness during simulated post-flight water landings." Exp Brain Res. 2023 Dec;241(11-12):2669-2682. https://doi.org/10.1007/s00221-023-06715-5 ; PubMed PMID: 37796301 , Dec-2023
Papers from Meeting Proceedings	Lonner T and Clark TK. "The Efficacy of Virtual Reality as a Countermeasure for Astronaut Motion Sickness during Post-Flight Water Landings." IEEE Aerospace Conference, Big Sky, Montana, March 4-11, 2023. IEEE Aerospace Conference, Big Sky, Montana, March 4-11, 2023. , Mar-2023