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PI Name:	Wood, Scott J. Ph.D.		
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PI Email:	scott.j.wood@nasa.gov	**Fax:**	FY
PI Organization Type:	NASA CENTER	**Phone:**	(281) 483-6329
Organization Name:	NASA Johnson Space Center		
PI Address 1:	2101 NASA Parkway		
PI Address 2:	Mail code SD2		
PI Web Page:			
City:	Houston	**State:**	TX
Zip Code:	77058	**Congressional District:**	36
Comments:	NOTE: PI returned to NASA JSC in January 2017. PI was at Azusa Pacific University from August 2013 – January 2017; prior to August 2013, PI was at NASA JSC.		
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Contact Monitor:	Brocato, Becky	**Contact Phone:**	
Contact Email:	becky.brocato@nasa.gov		
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COI Name (Institution):	Duda, Kevin Ph.D. (Draper Laboratory) Heineman, Raymond M.S. (NASA Johnson Space Center) Moore, Steven Ph.D. (Central Queensland University, Rockhampton, Australia) Wheelock, Douglas M.S. (NASA Johnson Space Center) Young, Millennia Ph.D. (NASA Johnson Space Center) Bishop, Michael M.S. (NASA Johnson Space Center)		
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Task Description:	Manual control during exploration spaceflight consists of both planned automated supervisory control and unplanned crew override. This crew override capability is critical to enable overall mission success during landing contingencies. However, the introduction of manual override capabilities must be implemented to enable crews to mitigate risks introduced by human error. Adaptive changes in the sensorimotor system can manifest during G-transitions as spatial disorientation. While training and landing aids enable successful landing through disorientation, these adaptive changes may increase cognitive demand that need to be accounted for in the manual control strategy. It is important to characterize these effects as soon as possible following the G-transition. The primary goals of this study are (1) to understand the impact of spaceflight on crew ability to perform manual crew override tasks, (2) to examine how adaptive changes in vestibular and cognitive function relate to changes in manual crew override proficiency, and (3) compare performance during late in-flight "just-in-time" on-board training with early post-flight crew performance. This study will recruit astronauts assigned to either short duration Private Astronaut Missions (PAM, < 30 day) or long duration (6-month) missions to the International Space Station (ISS). Ground matched-control subjects tested with the same schedule will enable us to assess the effects of learning and/or recency independent of spaceflight. Our first aim is to examine the impact of spaceflight on piloting capability will be assessed from pre- versus post-flight changes in a simulated lunar landing during which crewmembers will manually takeover attitude and rate-of-descent to the nominal or re-designated landing aimpoint during the approach phase. This simulation will be conducted on a six degree-of-freedom (6DOF) platform that can provide concurrent vestibular motion cues during the simulation. An alternative inflight simulator using a Pilatus PC-12 aircraft is under evaluation to enable earlier post-flight testing. The outcome measures the crew override tasks include the percent time maintaining actual vehicle states, e.g., attitude and rate-of-descent, within recommended guidance during the landing approach, number and maximum deviation outside limits and root mean square error (RMSE). The cognitive performance measures during the simulation will focus on multi-tasking in which crewmembers will respond to display prompts as a secondary task, as well as eye-head tracking to characterize visual reaction times and areas of visual attention during the simulation. We hypothesize that there will be post-flight increases in the percent time that pilots are outside of the acceptable range for recommended vehicle state parameters. Our second aim is to examine how adaptive changes in vestibular and cognitive function relate to proficiency during supervisory manual control and crew override. The sensorimotor and cognitive test battery will leverage the most sensitive test conditions utilized in our previous manual control study by Moore et al (2019) in which astronauts exhibited significant changes in motion perception, manual dexterity, dual-tasking and sleepiness. We are also including three new measures including quantitative measures of motion sickness symptoms, tilt perceptual precision and eye-hand coordination. We hypothesize that that a higher severity of vestibular alterations will be associated with increased percent time outside of guidance limits during both types of piloting tasks. Given that 'just-in-time" (JIT) on-board training is an operational expectation for the extended exploration missions, all participants will perform late inflight JIT training. Crew proficiency will be captured inflight during JIT training that will be implemented on a laptop with hand controllers to allow the crewmember to practice the landing task procedures, like the approach implemented for JIT training with Shuttle landing and ISS telerobotic tasks. The metrics captured during the JIT lunar landing simulations will match those of the pre- and postflight simulations. We hypothesize that that proficiency on the "just-in-time" laptop trainer late in mission will be positively correlated with early post-flight proficiency on the same task. This project will deliver an operational demonstration of crew override capability following spaceflight and identify potential deficits that may require remediation. Comparison of individual vestibular and cognitive changes with crew override performance will help better characterize the manual control risks associated with sensorimotor alterations. Comparing performance parameters from the JIT training to post-flight performance will help demonstrate transfer of inflight JIT training to post-flight manual crew override performance. The inclusion of "just-in-time" training will ensure we are characterizing changes in override proficiency with this expected countermeasure in place.
Rationale for HRP Directed Research:	This research is directed because it contains highly constrained research. This flight study addresses the sensorimotor research emphasis stated in the Human Research Program (HRP) Integrated Research Plan titled "Risk of Altered Sensorimotor/Vestibular Function Impacting Critical Mission Tasks". One gap associated with this risk (SM-102) is to "characterize the effects of short and long-duration weightlessness on manual control after G-transitions." This research gap led to the solicitation of a manual control study conducted before and after long duration flights on the ISS to map changes in sensorimotor function to manual control decrements. Unfortunately, these results (Moore et al., 2019) were limited due to testing delays related to time required for direct returns from Kazakhstan, with the initial measurements conducted more than 20 hr following landing. The approach of this investigation is to leverage the commercial crew landings in the US to obtain measurements as early as possible. While the Moore study used a T-38 X-plane simulation, we will obtain measures during actual T-38 flights. We will also add a lunar landing simulation based on the current concept of operations for the HLS. Further refinements are also proposed in the sensorimotor and cognitive test battery based on the previous study.
Research Impact/Earth Benefits:	Sensorimotor function is critical for spatial orientation, gaze stabilization, and postural stability. This project examines how adaptive changes in sensorimotor and cognitive function may increase the risk of impaired ability to maintain control of vehicles and other complex systems. The goal is to map changes in physiological function with functional measures of manual control. Establishing these relationships will be relevant to how pathophysiological impairments in sensorimotor processing may affect other vehicular control tasks, such as driving with vestibular patients. This study will also be relevant to the development of strategies of how best to allow individuals with impairments perform a manual control override of autonomous driving vehicles. As Shuttle missions were extended, the on-orbit training countermeasure tool became extremely useful for commanders and pilots to practice the landing task sequence to maintain task proficiency. The ability to retain and/or assess manual control efficiency via a simple laptop-based simulation will impact our crew override approach for extended exploration missions. This approach can be easily adapted to a wide variety of simulated vehicle designs to provide similar assessments in other operational and civilian populations.

Task Progress:

Lunar Landing Simulation: During the initial project year, our project has coordinated closely with the development of other Artemis lunar landing simulation developments that are being developed for both the Human Landing System (HLS) engineering insight and Flight Operations Directorate (FOD) training purposes to utilize an environment that is closely aligned to the HLS planned concept of operations. The specific experimental approach is based on previous lunar simulations performed by Dr. Duda and colleagues during previous ground-based research (Clark et al. 2014; Clark et al., 2011; Duda et al., 2020; Duda et al., 2009). During this simulation, crewmembers will have the responsibility of monitoring the automatic flight trajectory before being tasked to manually take over and control the attitude and rate-of-descent to the nominal or re-designated landing aimpoint during the approach phase. The primary task of the pilot is to control the flight path and attitude of the lunar lander, with a secondary task of responding to system status annunciators and a tertiary task of making verbal callouts of key vehicle states (Hainley et al., 2013). During the re-designation phase, subjects select from alternative landing points based upon avoiding hazards that the onboard system identifies during the landing. The subject makes inputs using a rotational hand controller (i.e., joystick) and a translational hand controller, which are processed by simulated vehicle dynamics to update the vehicle attitude and rate of descent. We are coordinating with the Johnson Space Center (JSC) Dynamic Skills Trainer (DST) Technology Lab to duplicate extra sets of the same hand controllers that are utilized by ROBoT aboard International Space Station (ISS). A new 6DOF platform (W10, CKAS Mechatronics Pty Ltd., Australia) will be implemented, while the current CKAS V7 model will provide an alternate platform for testing PAM crewmembers. The simulated vehicle roll and pitch tilt, and translation accelerations will be synced to provide representative vestibular cues to the subject while performing the task. The simulation incorporated in this 6DOF system at JSC will also utilize the same portable dual laptop design as ROBoT to maximize the transfer from the onboard training.
Subjects will utilize a combination of flight, situation, and status displays to monitor the state of the simulated vehicle. Several Technical Interchange Meetings (TIMs) have been conducted with the Langley Lunar Landing Simulator team and the JSC HLS Crew Compartment Office simulation team to define flight displays, control modes, and design reference vehicle dynamics. All sims expect to start in automatic flight, then transition to manual using two possible flight control modes. The first is referred to as Rate Control Attitude Hold (RCAH) all the way to the surface. The second is RCAH to “low” altitude, then Hover Hold with Incremental Position Command (HH/IPC) to the surface. To fit within the allotted experiment timeframe, two attitude maneuver control powers will be implemented, including low (1.1 deg/sec2) – designed to push at pilot “lead” and prevent pilot-induced oscillations (PIOs), and mid-power (1.6 deg/sec2), although a third high control power (2.9 deg/sec2) will also be evaluated. Each combination of flight control modes and control powers, each performed with a landing point designation, will be repeated three times for a total of 12 trials/session. The landing site will be varied among candidate Lunar South Pole landing regions. The vehicle mass properties will be based on Altair Lander Design Analysis Cycle 2 (LDAC-2) with no gimballed main engine.

Sensorimotor test battery: During this first year, we have implemented the test battery that enables us to examine how adaptive changes in sensorimotor function relate to proficiency during supervisory manual control and crew override. This battery will leverage the most sensitive test conditions utilized in our previous manual control study by Moore et al., (2019), in which astronauts exhibited significant changes in motion perception, manual dexterity, dual-tasking, and sleepiness. We are also including quantitative measures of motion sickness symptoms at the time of testing, tilt perceptual precision and eye-hand coordination used in other flight studies (Field Tests and Sensorimotor Predictors). (1) Motion sickness (used throughout both lunar landing and test battery): Diagnostic indices for characterizing acute motion sickness symptoms have been used extensively in motion sickness research by many laboratories over the past 5 decades (e.g., Graybiel et al., 1968). However, Oman et al., (1986) developed a magnitude-estimation-based subjective discomfort rating that could be easily implemented in a flight operational environment. Subjects will be asked to subjectively rate their motion sickness after each task on a scale of 0-20, where 0 is normal, 10 is halfway to vomiting, and 20 is vomiting. This measure was used in the Field Tests (Reschke et al., 2020) and the ongoing Spaceflight Standard Measures. (2) Motion perception accuracy: The previous motion perception task (Moore et al., 2019) will also be performed with the subject in the motion simulator, seated and restrained. With eyes closed, subjects will be tasked with indicating gravitational vertical with the control stick as the cabin moves in a pseudorandom manner driven by a sum of seven sines with frequencies at 0.12, 0.25, 0.32, 0.43, 0.62, 0.80, and 0.98 Hz in roll for 60 s. A power spectrum analysis will be performed to determine the peak input response at each frequency. (3) Motion perception precision: As reviewed by Diaz-Artiles and Karmali (2021), characterizing vestibular precision as well as accuracy is important to fully understand adaptive changes in vestibular processing. Vestibular precision will be measured with a perceptual direction-recognition task while seated with eyes closed during lateral translations. Test sessions will consist of 75-100 trials. Each trial will be a leftward or rightward 1 Hz (1 s motion duration) single cycle sinusoid of acceleration. At the end of the motion subjects are prompted to report their perceived direction of motion (forced choice) and return to the starting position. The dependent variables (threshold and bias) will be derived from psychometric curve fits. The mean of this curve fit represents the perceptual bias, the point at which a subject is equally likely to perceive a motion as leftward or rightward. The “one sigma threshold” is linearly proportional to the standard deviation of the noise, e.g., the standard deviation of a Gaussian probability density function underlying the psychometric function (Clark et al., 2018; Merfeld, 2011). This test is completed within 10 minutes. (4) Sleepiness scale: The Stanford Sleepiness scale was previously used to quantify significant subjective changes in sleepiness in our returning ISS crewmembers (Moore et al., 2019). Subjects are asked to choose an ordinal value from a list of statements that best describ their state of sleepiness (Hoddes et al., 1973). (5) Manual Dexterity: The Perdue Pegboard test has been used to quantify manual dexterity in a number of recent studies (Koppelmans et al., 2013; Miller et al., 2018; Moore et al., 2019). Subjects are seated and tasked to place as many pins in a vertical row of slots (one at a time) within 30 s, first with the right hand, then with the left. The pins are then removed, and subjects are asked to place pairs of pins (with both hands simultaneously) in two vertical rows of slots within a 30 s period. (6) Manual tracking: Subjects are required to use the joystick controller with their dominant hand to maintain a crosshair target inside a 15mm-diameter circle moving at 20 mm/s on the computer screen and randomly changing direction over a 60 s epoch. The primary measure will be mean tracking error (pixels). (7) Manual Tracking with Dual Tasking: Subjects will then repeat this tracking task while responding to prompts from a second computer monitor for a 4-digit code to be entered on a keypad with the non-dominant hand. The distracting task will be performed continuously, and the time to respond and the number of correct responses will be acquired, in addition to tracking performance. (8) Eye-hand coordination: This test is based on the Field Test assessment (Reschke et al., 2020). Crewmembers will perform this on a tablet fixed at arm's distance where they are presented with a series of circles and squares in different locations on the screen. They will be told to hit only the circles as quickly and accurately as possible with the index finger of their dominant hand. Performance will be evaluated as number of errors (squares hit), response time, and accuracy (distance of finger press to the center of the circle).

Pilatus PC-12 flight field testing: During this initial project year, we evaluated the use of a Glenn Research Center airplane, the Pilatus PC-12, for potential field testing at the rally airport. The versatility of the PC-12 would enable us to functionally assess piloting skills using an operational flight platform close to the planned landing sites. We initially evaluated an automated supervisory control phase followed by a manual control phase using the advanced digital cockpit interface. In this scenario, Foreflight (or similar simulation software) would be used to create a series of waypoints and deviations during flight that the crewmembers would need to detect and override. An onboard PC-12 simulation using Xplane (Laminar Research, Columbia, SC) was developed. Although the flight would limit the bank angles to 30 deg (1.15g resultant) and a medical preflight check was proposed, flight medicine concerns regarding inflight medical care of an incapacitated crewmember in the cockpit caused this protocol to be tabled at the Institutional Review Board. As a potential way forward for rally airport testing, we are evaluating the feasibility of conducting a lunar landing simulation in the rear of the aircraft. The Glenn aircraft operations team is evaluating an interface to the PC-12 instrument landing system (ILS), which could be used to control the aircraft from the rear through the automated navigation system.

Bibliography Type:	Description: (Last Updated: 06/03/2025)