Fiscal Year:	FY 2011	**Task Last Updated:**	FY 02/14/2012
PI Name:	Oman, Charles M. Ph.D.		
Project Title:	Advanced Displays for Efficient Training and Operation of Robotic Systems		
Division Name:	Human Research		
Program/Discipline:	NSBRI		
Program/Discipline--Element/Subdiscipline:	NSBRI--Sensorimotor Adaptation Team		
Joint Agency Name:		**TechPort:**	No
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Human Research Program Risks:	(1) **HSIA**:Risk of Adverse Outcomes Due to Inadequate Human Systems Integration Architecture (2) **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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Zip Code:	02139-4301	**Congressional District:**	7
Comments:			
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No. of Master's Candidates:	2	**No. of Bachelor's Degrees:**	0
No. of Bachelor's Candidates:	2	**Monitoring Center:**	NSBRI
Contact Monitor:		**Contact Phone:**	
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Key Personnel Changes/Previous PI:			
COI Name (Institution):	Young, Laurence (Massachusetts Institute of Technology) Natapoff, Alan (Massachusetts Institute of Technology) Liu, Andrew (Massachusetts Institute of Technology) Tomlinson, Zakiya (NASA Johnson Space Center)		
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Task Description:	The long term objectives of this 4 year NSBRI Sensorimotor Team project addressed three specific aims related to astronaut performance during space telerobotics training. We collaborated with the JSC Robotic Systems Training Group (DX-2). Astronaut robotics trainees vary significantly in their initial performance, ability, learning rate, and level of mastery. Because the process of training astronauts to be qualified robotics operators is so long and expensive, NASA needs tools to predict performance and customize training. Our principal scientific goal has been to understand how individual differences in spatial and bimanual control abilities impact learning and performance. Aim 1. Astronaut applicants currently take an Aptitude for Robotics Test (ART) and those selected proceed to Generic Robotics Training (GRT). Using a logistic modeling approach we investigated how well an astronaut's ART scores and an additional set of mental rotation, perspective taking and visualization tests predicted spatial performance in subsequent training. We found ART was not a reliable predictor and proposed changes in ART metrics to improve the predictive power. These were implemented and used in the last round of astronaut testing and GRT training. Logistic regression analysis of mental rotation and visualization scores allowed us to predict who will achieve a top score in qualification evaluations, but not those who fail (partly because very few do). Model predictions were reliable enough to use in customization of regular and remedial training, but not to make career defining decisions. Aim 2: Our second objective was to study performance and learning using a standardized pedagogy in controlled laboratory settings using a space telerobotics training simulator at MIT. The simulator recreated the BORIS training environment used in GRT, and eventually also the ISS docked Shuttle and Progress rendezvous spacecraft environment. In a series of five previous experiments, we consistently found that a trainee's early performance and learning in relatively simple GRT-like "fly-to" and pregrapple tasks correlated with their spatial abilities. We believe this is because mental rotation and visualization abilities are important for integrating the multiple video camera views used when performing robotics tasks. Robotics operators are encouraged to move the arm on more than one axis at a time, beginning in the earliest phases of training. This year we conducted an experiment to see whether multi-axis movement feedback improved learning, and whether real time visual, real time aural or post-trial feedback was best. We studied the performance of 16 subjects learning to perform a specific fly-to telerobotics task (Forman, et al. 2011). Performance (movement time, % multi-axis movement, % bimanual movement) improved with practice as expected, but improvement differed between subjects. Subjects preferred the real time visual feedback modality. However we were unable to show reliable effects of the particular display modality options we tested. Nonetheless, the development and evaluation of quantiative fly-to task performance metrics has been valuable. We believe quantitative performance metrics based on our research should be built into both the JSC Dynamic Skills Trainer (DST) and the inflight ROBoT laptop trainer used by ISS astronauts for training in orbit. Aim 3: In space telerobotic tasks, the right hand controls rotational velocity and the left hand controls translational velocity, each with a unique three-axis control stick (interceptor). This arrangement compels the operator to decompose the desired 6 DOF arm motion into a pair of 3D rotational and translational components, and execute them with different hands, but in coordinated fashion. Unfortunately, simultaneous movement of both hands can result in undesired inter-manual neural cross-coupling, as exemplified by the difficulty of the pat your head while rubbing your stomach task. In addition to inter-manual cross coupling due to neuromotor causes, intra-manual CC within interceptors can occur due to joystick mechanical design, which can cause the operator to have difficulties when attempting to actuate a single axis. To quantify effects and separate inter- and intra-manual effects, this year we developed a Bimanual Cross-Coupling Test (BCCT). Our BCCT consists of six trials of a 3D simulated tracking task projected onto a 2D display. The subject uses a pair of interceptors to control the cursor in tracking the target, which for each trial moves in a different combination of two of the six axes, always with one axis per hand. Each hand thus tracks a pseudorandom signal with frequency content separable from that of the other hand. Through Fourier analysis on all six axes for each trial and compiling the information from the entire forty-minute test, we generate a six-by-six matrix of coupling percentages between each pair of axes. An eighteen-subject study with three sessions over two weeks per subject was conducted to validate the BCCT. Inter-manual cross coupling (CC) exhibited learning effects across sessions, and was significantly different across subjects. Principal component analysis combined with matrix-wise elimination of first-order indirect effects allowed us to characterize intermanual CC by a linear combination of yaw to lateral translation and pitch to vertical translation, which is often greater than 10% even among fully trained subjects. Intra-manual CC was characterized by high roll to yaw coupling, indicating poor ergonomics of the joystick used – this study should be repeated with NASA's rotational control interceptor, which has different ergonomics due to the handle angle and pitch axis location. This final report also includes a 4 year overview of research results.
Rationale for HRP Directed Research:	
Research Impact/Earth Benefits:	Our goal is to improve the efficiency of robotic training via improvement of current pedagogies and performance metrics. Improved training methods provide a framework for designing future in-flight training procedures during long duration missions. The project will also demonstrate how individual differences in spatial and manual control skills affect performance of critical operational skills, including complex robotics tasks associated with post-Shuttle era ISS operations. The project results also inform the design of telerobotic displays and bimanual control inceptors (control sticks). The Bimanual Cross Coupling Test method for quantifying neural cross coupling between hands during movement has potential research and clinical applications.
	Spatial Ability Tests Predict Training Performance To see whether spatial ability scores predicted an astronaut's performance in their initial robotics training course we have tested the spatial abilities of 50 current astronauts (10 astronauts added this year) who had finished at least one robotics training course. We found a significant correlation between the astronauts' spatial test scores and performance in their first robotics course using logistic regression models. We concluded that our spatial ability test score predictors are suitable for identifying trainees who may require extra or remedial sessions. Multiaxis Feedback during Fly-To Training Robotics operators are trained to move the arm on more than one axis. We conducted a second experiment to see whether real time visual, real time aural, or post-trial feedback of multi axis was best when 16 subjects learning to perform a specific fly-to telerobotics task. Performance improved with practice as expected, but differed between subjects. Subjects preferred the real time visual feedback, but no reliable performance differences of feedback mode were found. Nonetheless, we believe providing quantitative metrics of other aspects of performance during training will assist both trainees and trainers in improving performance.

Task Progress:	Bimanual Cross-Coupling Test In typical telerobotic tasks, the right hand controls rotational velocity and the left hand controls translational velocity, each with a unique three-axis control stick (interceptor). Simultaneous motion of both hands can result in undesired motions through cross-coupling (CC), as shown by the pat your head and rub your stomach task. In space telerobotics, in addition to intermanual CC between interceptors due to these neuromotor causes, intramanual CC within interceptors occurs due to ergonomic difficulties in isolating actuation to a single axis. We developed a Bimanual Cross-Coupling Test (BCCT) to quantify intra- and inter-manual CC effects. The BCCT consists of six trials of a 3D simulated tracking task projected onto a 2D display. The subject uses a pair of interceptors to control the cursor in tracking the target, which for each trial moves in a different combination of two of the six axes, always with one axis per hand. Each hand thus tracks a pseudorandom signal with frequency content separable from that of the other hand. An 18-subject study with three sessions over two weeks per subject was conducted. Intermanual CC exhibited learning effects across sessions, and was significantly different across subjects. Principal component analysis allowed us to characterize intermanual CC by a linear combination of yaw to lateral translation and pitch to vertical translation, which is often greater than 10% even among trained subjects. Intramanual CC was characterized by high roll to yaw coupling, indicating poor ergonomics of the joystick used.
Bibliography Type:	Description: (Last Updated: 12/18/2024)
Abstracts for Journals and Proceedings	Liu AM, Wang V, Forman RE, Galvan RC, Natapoff N, Oman CM. "Advanced Displays for Efficient Training and Operation of Robotic Systems." 2012 NASA Human Research Program Investigators' Workshop, Houston, TX, Feb 14-16, 2012. 2012 NASA Human Research Program Investigators' Workshop, Houston, TX, Feb 14-16, 2012. , Feb-2012
Abstracts for Journals and Proceedings	Pontillo TM, Liu AM, Natapoff A, Oman CM. "Spatial ability, joystick configuration, and handedness as predictors of space teleoperation performance." 18th IAA Humans in Space Symposium, Houston, TX, April 11-15, 2011. 18th IAA Humans in Space Symposium, Houston, TX, April 11-15, 2011. , Apr-2011
Abstracts for Journals and Proceedings	Forman RE, Lowenthal CS, Oman CM, Liu AM, Natapoff A. "A review of space robotics metrics and proposed performance metrics for improved telerobotics training." 18th IAA Humans in Space Symposium, Houston, TX, April 11-15, 2011. 18th IAA Humans in Space Symposium, Houston, TX, April 11-15, 2011. Abstract and poster 2241. , Apr-2011
Articles in Peer-reviewed Journals	Liu AM, Oman CM, Galvan R, Natapoff A. "Predicting space telerobotic operator performance from human spatial ability assessments." Updated (n=50) and submitted to Acta Astronautica, November 2011. , Nov-2011
Awards	Oman CM. "International Academy of Astronautics. Elected to full membership, April 2011." Apr-2011
Dissertations and Theses	Forman RE. "Objective performance metrics for improved space telerobotics training." SM dissertation, Massachusetts Institute of Technology, Department of Aeronautics and Astronautics, September 2011. , Sep-2011