Assessing effects of robot control mode on performance and situation awareness in a maze navigation task

Jennifer Riley and Laura Strater

SA Technologies, Inc.

Marietta, GA

SA technologies
Situation Awareness

Situation awareness in HRI

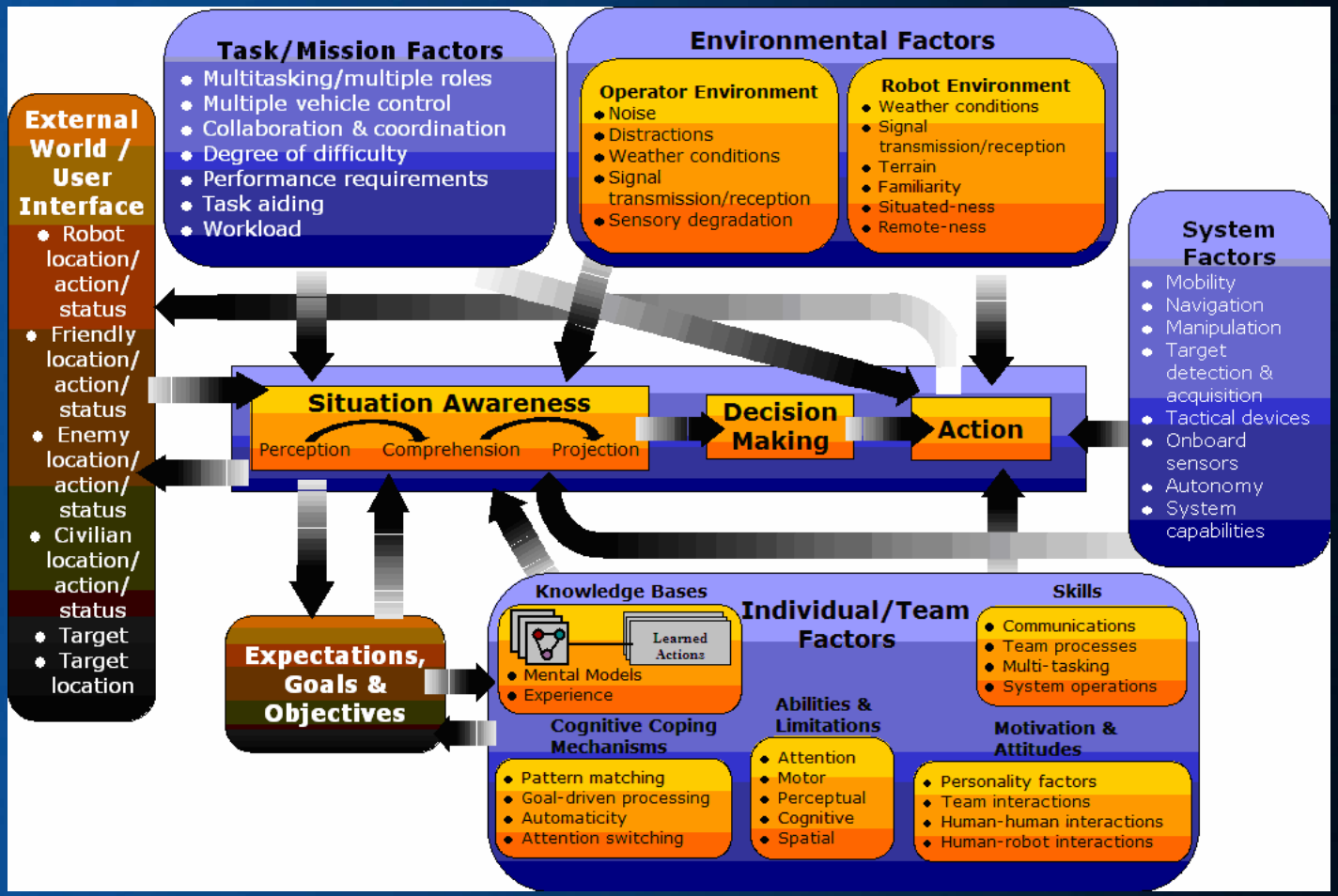
- Ability to complete remote tasks has improved with more sophisticated unmanned vehicles (UVs).
- UVs used to facilitate perception and project operator intent on space.
- Effective use of UVs dependent upon:
  - User skills
  - System design and capabilities
  - Knowledge that user is able to acquire for task completion

SA technologies
Situation Awareness

Situation awareness in HRI

- Situation awareness (SA) is knowing what's going on around you.
  - Endsley (1988) defines it as perception, comprehension, and projection.
  - For robotic system it's awareness of:
    - Local environment
    - Remote environment
    - System status
    - Current task state / robot actions
    - Task requirements
    - Other team members (robots and/or humans)
  - SA critical because it is the framework for plans and action, the foundation for decision making.

HRI Situation Awareness model



- Impact of external inputs
- Challenges of task, system, and environmental factors
- Mediating effects of individual and team factors
- All influencing SA acquisition

Useful introduction into issues of SA in UV taking and control.
Basis for research interests and investigations.

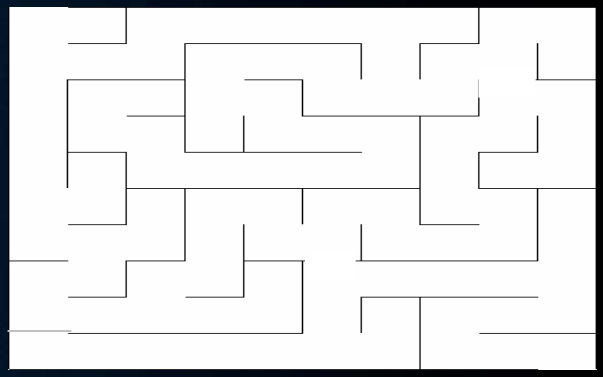
SA technologies
Situation Awareness

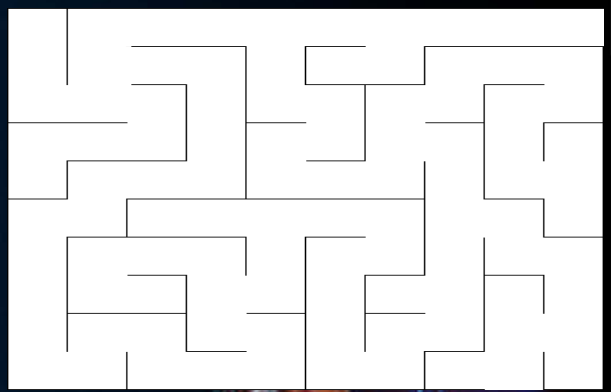
Current Objective

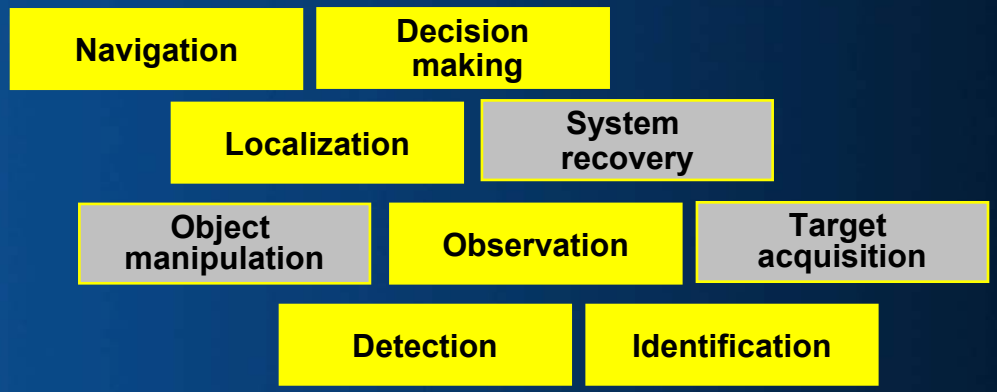
- Look into specific aspects of the model
  - Assess effects of robot control requirements (and the addition of automation) on operator performance and SA in UV control task
    - Compare serial manual control with parallel manual control
    - Compare manual control with automated control modes
  - Investigate any relationships between response measures

Experimental Tasks

- Navigation of two robotic systems through maze
  - Two 6x6 maze environments with familiar landmarks
  - Designed for equal difficulty and two successful paths from start to finish







SA technologies
Situation Awareness

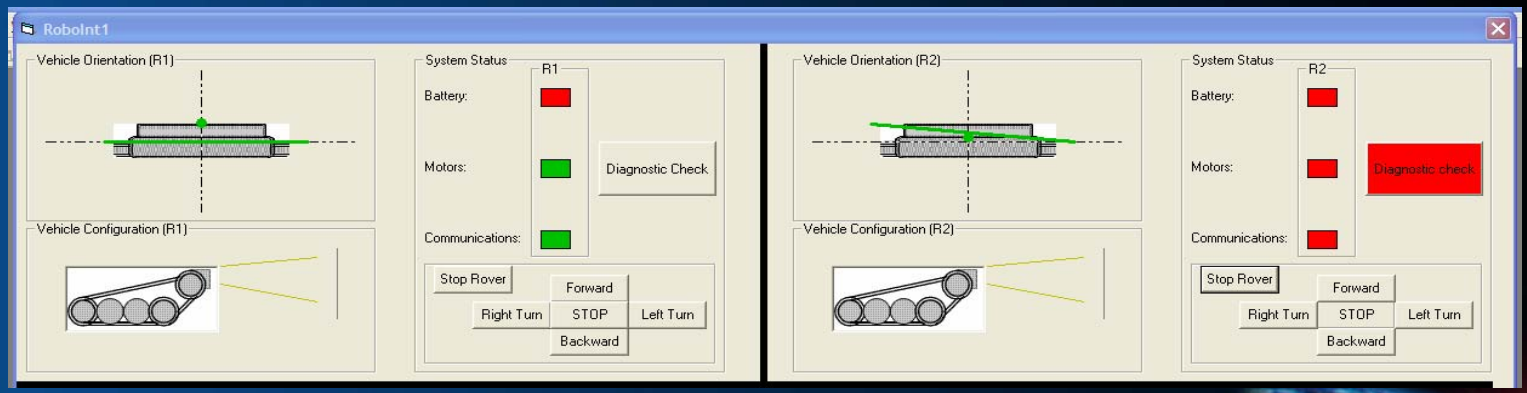
Experimental Tasks

- Hand-held controller for manual rover control
  - Double joystick controller for two independently controlled track
  - Secured to workstation surface for dual control condition
- Verbal commands for automated condition requiring operator intervention
  - Go forward
  - Turn left
  - Turn right
  - Go back
- Viewed environments through two video monitors

SA technologies
Situation Awareness

Experimental Tasks

- Monitoring robot system status
  - Simulated interface with battery, motors, and communications status
  - Subjects instructed to monitor system status and respond to diagnostic failures
    - Two-dimensional objects representing “lights” on interface displays that indicate system functioning
      - Normal functioning – green square
      - Poor functioning – red square
    - Decision making on overall system status required.



SA technologies
Situation Awareness

Independent Variable

- Robot control mode
  - Four types
    - Manual serial control
      - Control robots in serial, with complete attention dedicated to one at a time
    - Parallel manual control
      - Control robots at the same time, switching attentions as needed for parallel control
    - Parallel automated control with rules
      - Control one robot and monitor the control of the other under autonomy with pre-defined execution rules
    - Parallel automated control with decision points
      - Control one robot and monitor the control of the other under semi-autonomy requiring operator intervention at pre-defined decision points

Rover Navigational Rules

- Go straight or forward (if possible)
- Go right (if cannot go forward)
- Go left (if cannot go right)
- At dead-end automatically return to last intersection and go in opposite direction

SA technologies
Situation Awareness

Dependent Variables

- Performance
  - Measured in minutes for time-to-task completion
  - Measured in hit-to-signal ratio for diagnostic failures for monitoring performance
- Situation awareness
  - Measured with Situation Awareness Global Assessment Technique (SAGAT) (Endsley, 1988)
  - Measured on three levels)
    - Perception – Level 1 SA
    - Comprehension – Level 2 SA
    - Projection – Level 3 SA
  - Measure of awareness of current and future status of robotics task based on responses to SA queries.
- Workload
  - Measured using NASA-Task Load Index (TLX) (Hart and Staveland, 1988)
  - Rating scale from low to high
  - Six workload components (mental, physical, temporal, performance, frustration, and effort)

Example SA queries

What is the current battery status?

What is the overall status of Rover 1?

What should your next control action be?

What was the direction of your last turn?

How long have you been in the maze?

SA technologies
Situation Awareness

Experimental Design

- A between-subjects design with control mode as the control variable used.
- Subjects randomly assigned to groups.
- Repeated measures of performance, SA, and workload.

	Robot Control Condition			
	SERIAL	***PARMAN***	***PARRULES***	***PAROPDEC***
Participant	1-4 Trial 1 Trial 2	5-8 Trial 1 Trial 2	9-12 Trial 1 Trial 2	13-16 Trial 1 Trial 2

Participants and Equipment

- 16 participants, age 17 and 18
  - 9 males, 7 females
  - 20/20 or corrected to normal vision
  - Average video game usage = 4.4 hours / week
  - Experience with personal computers and mouse controllers and remote control toys
- Experimental equipment
  - Two miniature rovers equipped with wireless cameras
  - Hand-held control device
  - Two video monitors (9 inch)
  - VCRs, digital video recorder
  - Two laptop computers (one for rover interface, one for SA testing and spatial abilities)

Statistical Analysis

- General Linear Model (GLM)
  - Proc GLM with control mode coded as between-subjects variable.
  - MANOVA
    - Investigate overall control mode effect on family of response measures.
  - ANOVAs
    - F-tests in individual measures incorporated mean square error for participant to account for individual differences in control groups.
    - α = 0.05 significance level.
  - Duncan's Multiple Range (MR) tests
    - Post-hoc means analysis procedure.
    - Controls for comparisonwise error rate.
    - α = 0.05 significance level.

Hypotheses

- Participants in serial condition will have better SA and will navigate the maze faster
- Participants will have better SA for maze components of manually controlled robot
- Participants in parallel manual control condition will have poorest SA due to cognitive demand and will require more time to navigate the maze
- Participants with rule-based automation will navigate the maze faster than those with operator controlled automation
- For queries focusing on navigation (rather than status), SA expected to be higher for rover under manual control when under the parallel automated conditions

Results

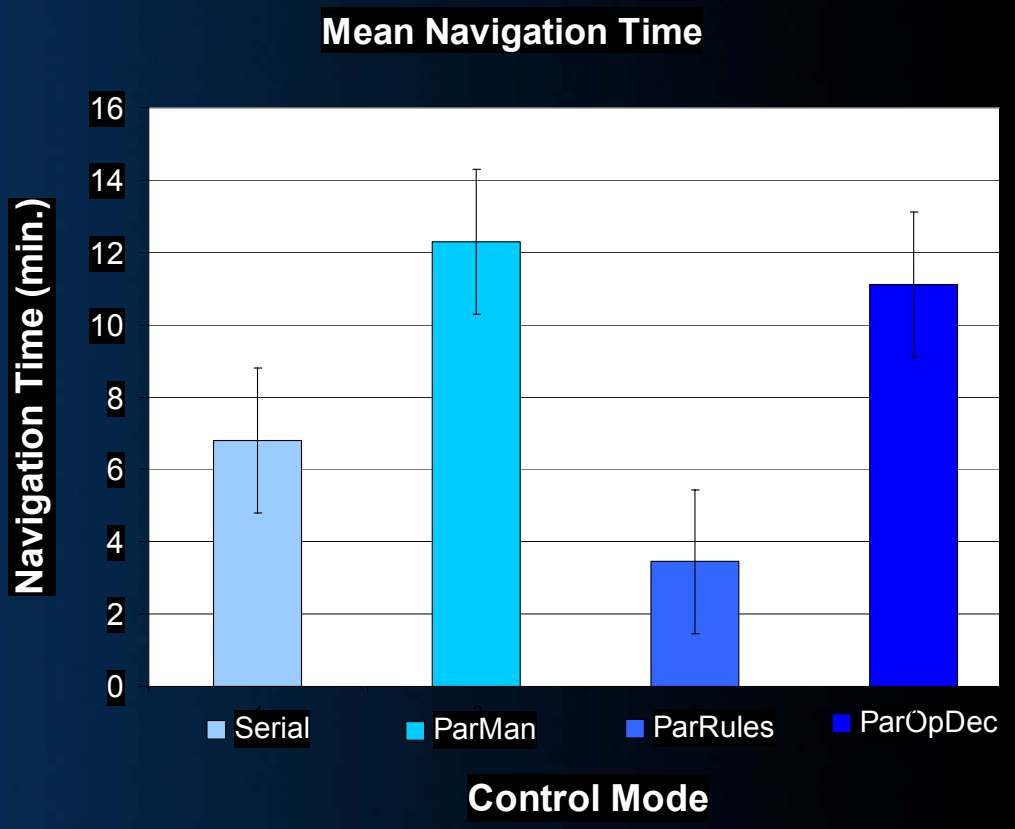
- MANOVA
  - No significant effect of Control Mode on family of responses. $F_{(3,12)} = 5.45$, $p > 0.05$.
  - Potentially due to high insignificance for some variables.

Results

- ANOVAS
  - No significant effect ($p>0.05$) of Control Mode on overall SA.
    - Average performance for subjects relatively low (53%), ranging from 51%% to 60%.
    - High workload may have resulted in limited cognitive resources for acquiring SA.
    - Small sample size may have resulted in lack of significant effect.
      - Note: though statistically insignificant, highest average overall SA occurred for the SERIAL group (60%). All others approx 51%.

Results

- Navigation Performance
  - Significant effect of Control Mode on Navigation Time ($p<0.05$).
  - Duncan's test revealed significant difference ($p<0.05$) in average performance between groups.
    - ParRules (3.448 min) sig different from
      - ParMan (12.306 min)
      - ParOpDec (11.108 min).
    - Serial (6.806 min)

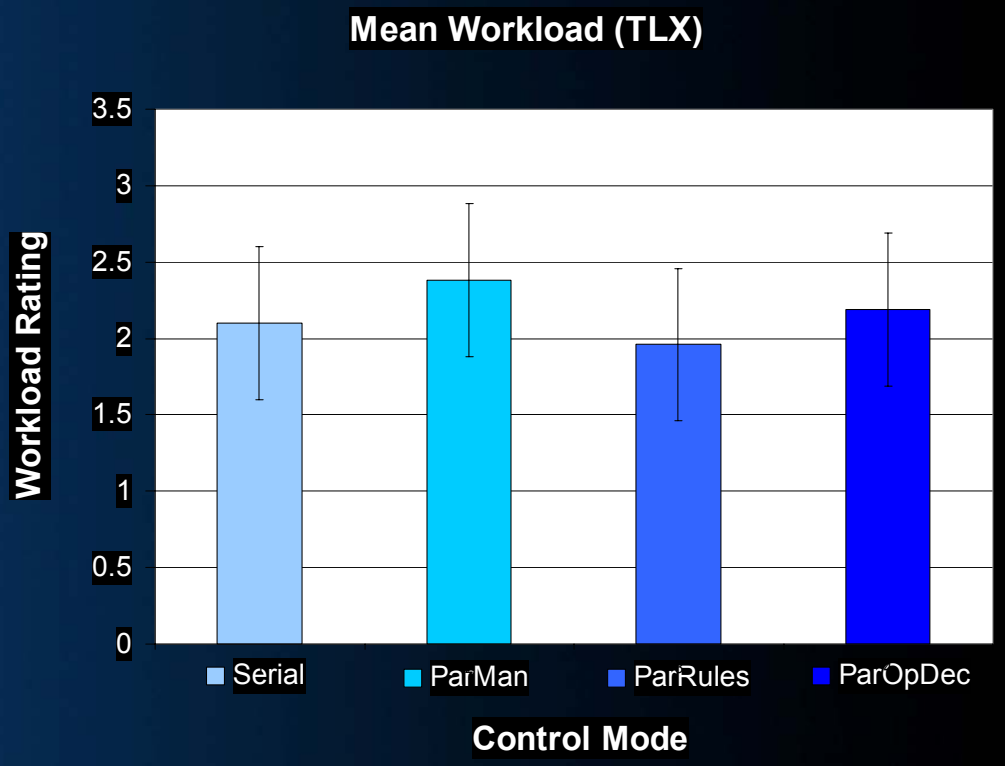


Did participants under rule based automation perhaps adopt the navigation strategy of the automation?

SA technologies
Situation Awareness

Results

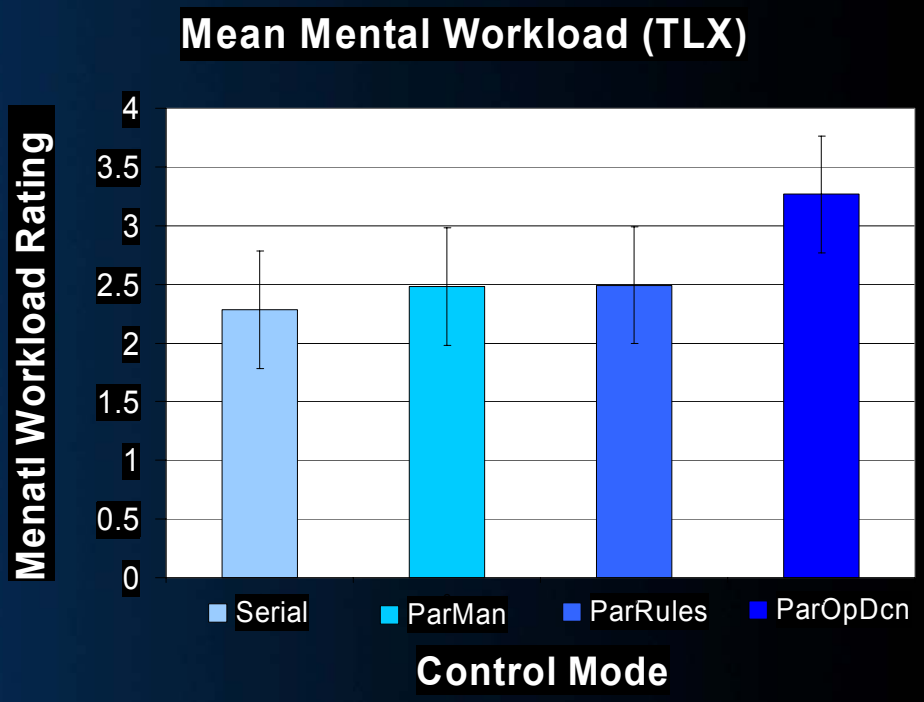
- Workload (Overall)
  - Significant effect of Control Mode on Workload, TLX ($p<0.05$).
  - Duncan's test revealed significant difference ($p<0.05$) in average workload between groups.
    - ParRules scores (1.96) sig different from
      - ParMan (2.83)
      - ParOpDec (2.19).
    - Serial (2.09)



SA technologies
Situation Awareness

Results

- Mental Workload
  - Significant effect of Control Mode on mental demand ratings ($p<0.05$).
  - Duncan's test revealed significant difference ($p<0.05$) in average mental demand ratings between groups.
    - ParOpDec scores (3.27) sig different from all others
      - Serial (2.28)
      - ParMan (2.48)
      - ParRules (2.49)



Significant effects for Physical Demand, Effort, and Frustration.

- Physical demand rating higher for manual control modes as compared to automated control.
- Effort ratings highest for parallel conditions with ParMan significantly different from all others.
- Frustration higher for parallel conditions.

SA technologies
Situation Awareness

Results

- Individual SA Queries (control mode effects)
  - What should your next action be based upon the current overall status of Rover (1 or 2)?
    - Significant difference between groups ($p<0.05$)
      - Highest SA recorded for Serial group (80%), which was significantly different from the ParRules group (49%).
        - » Though insignificant for individual level 1 SA queries on status, Serial group provided highest percentage of correct responses to questions on individual system status.
        - » ParRules essentially full automation which may have led to decrease in attention to status data and negative effect on comprehension of overall rover status for decision making.

	Battery,	Motors,	Comms
Serial	**81%,**	**78%,**	**81%**
ParMan	**63%,**	**74%,**	**66%**
ParRules	**63%,**	**66%,**	**74%**
ParOpDec	**67%,**	**65%,**	**69%**

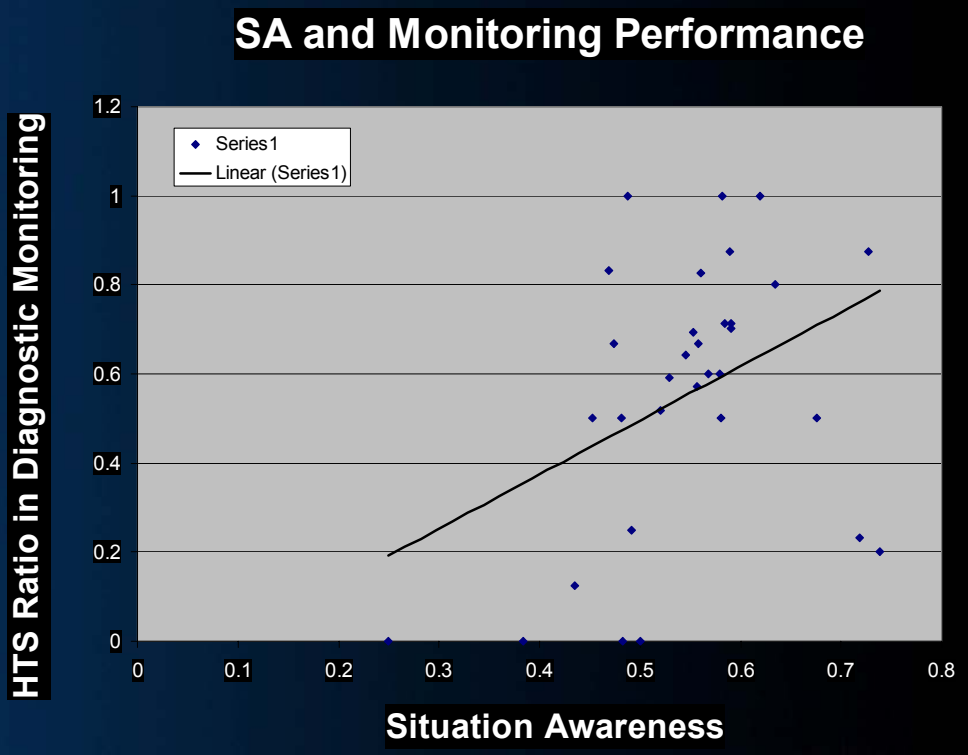
SA technologies
Situation Awareness

Results

- Individual SA Queries (group automation effects)
  - What is the current overall status for Rover (1 or 2)?
  - What should your next action be based upon the current overall status of Rover (1 or 2)?
    - Significant difference between subjects in manual control vs automation ($p<0.05$)
      - Manual control produced higher SA as compared to automated control.
        - » Overall status (manual = 62%, automation = 43%)
        - » Action based on status (manual = 75%, automation = 57%)
      - Automation may have led to lack of attention allocation to rovers under automation, leading to lower SA scores under automated conditions.
- Individual SA queries (operator performance across queries)
  - As expected, significant differences in performance on SA queries ($p<0.05$)
    - Highest SA results on status questions and awareness of rover in current dead end
      - 70-82%
    - Lowest SA observed for queries on rover orientation/direction, number of dead ends, total time in maze, and pitch and roll of rover
      - 23-32%

Results

- Correlation analysis (Pearson)
  - SA and Monitoring Performance
    - Positive correlation
    - r =0.3948, p<0.05
    - As monitoring performance for diagnostic checks increases, SA increases.
      - Suggests attention allocation to status displays as part of interface, caused increase in percent correct responses to SA queries (e.g., on status questions)



Limitation of Results

- Participant population consisted of naïve, high-school participants rather than experienced operators.
  - Level of task involvement may be different for real operators.
  - Performance and response to measures may be different for real operators.
- Simulated tasks and environment, rather than actual teleoperation task.
  - Potentially affects level of involvement.
- Results may be specific to this task and environment.