

Acquisition and Retention of Team UAV Coordination Skill.

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21-23 May 2007

CERI's Human Factors of UAVs
Workshop

Chandler, AZ





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Overview of Talk

- **Team Coordination and UAS Control**
- **Team Cognition & Coordination**
- **Experiment 1: Retention of Team Coordination**
- **Experiment 2: Training Team Coordination**
- **Conclusions**

Team Coordination and UAS Control

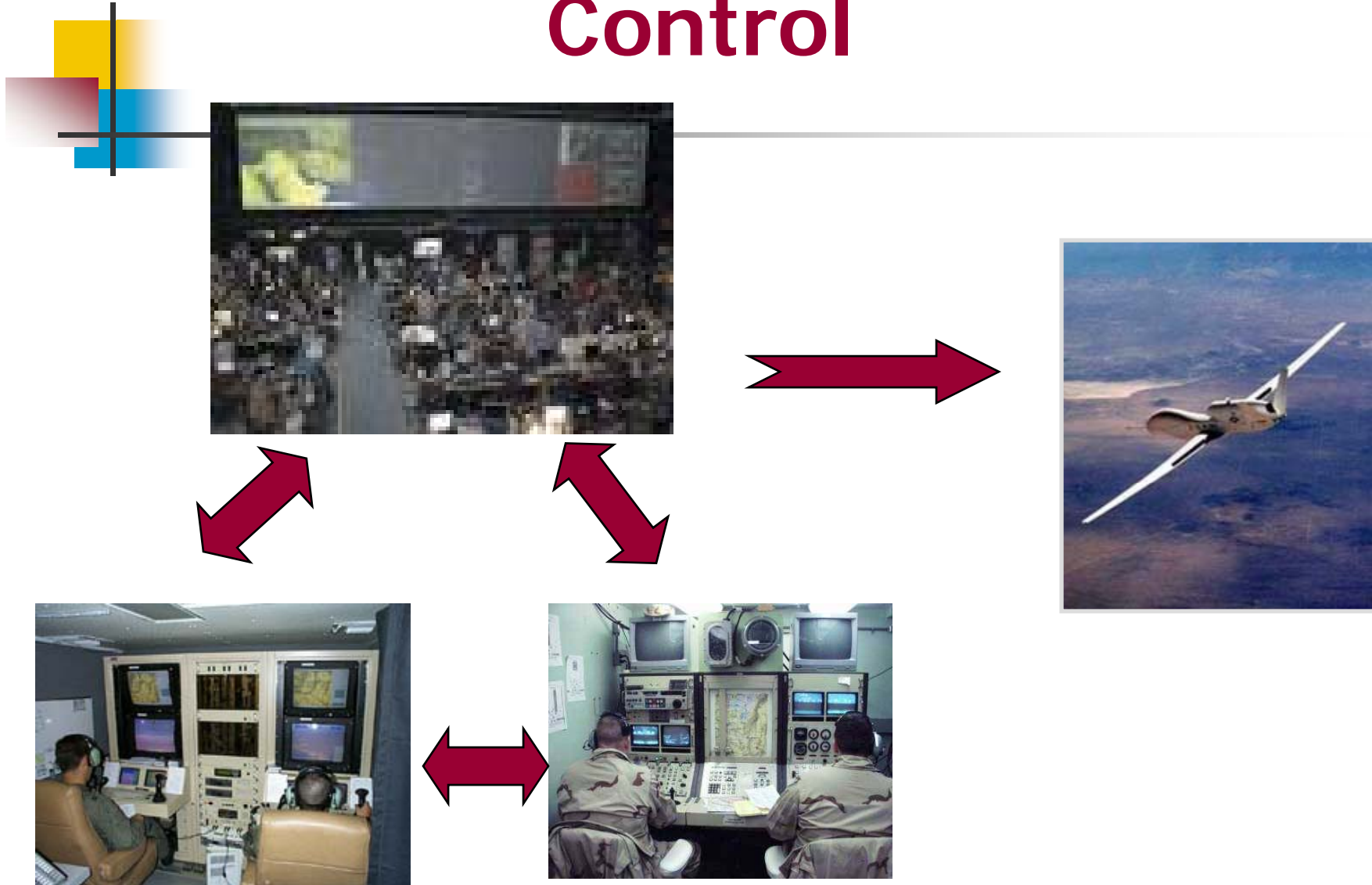


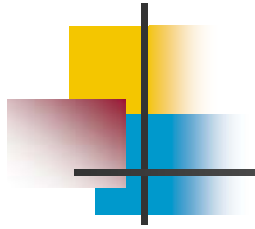
2 Operators: 1 UAV

Team Coordination and UAS Control



Team Coordination and UAS Control





TEAM COGNITION AND COORDINATION

Team Cognition in Practice



Interdependent groups of individuals who plan, decide, perceive, design, solve problems, and act as an integrated unit.



**What is team cognition?
How can we measure it?
How can we improve it?**

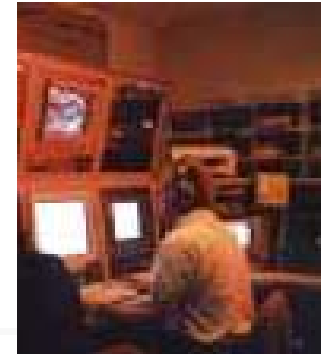
Our Context: Uninhabited Air Vehicle Synthetic Task Environment (CERTT Laboratory)



In our UAV STE three operators must coordinate over headsets in order to maneuver their UAV to take pictures of ground targets

CERTT UAV Teams

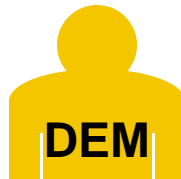
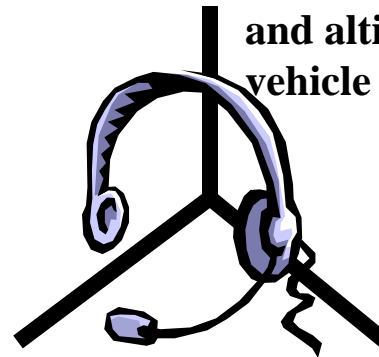
Critical Features: Heterogeneous,
Interdependent



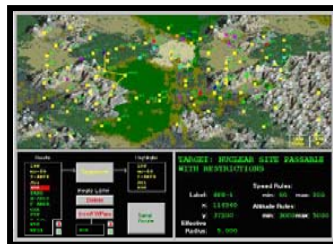
Controls UAV airspeed, heading, and altitude and monitors air vehicle systems

Common Display

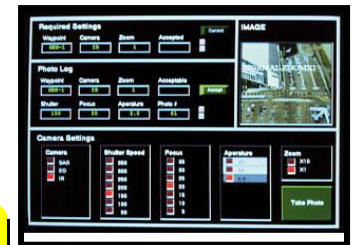
Current/Next Target
Heading
Altitude
Airspeed



Plans route from target to target under constraints



Controls camera settings, takes photos, and monitors camera systems





Team Cognition

- Cognitive activity at the team level (planning, decision making, perceiving, situation assessment)
- Relevant to C2 performance and other cognitive team tasks
- Training and technological interventions can facilitate

Team Cognition

Team Level Perception, Attention, Thinking, and Action

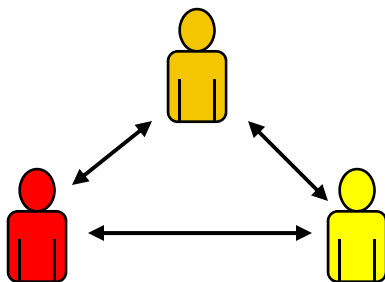
A Inside the Head View



Team cognition as *collective cognition*

- Measure individuals and aggregate
- Increasing similarity or convergence over time is associated with better performance or implicit coordination
- Assumptions of homogeneity

B Interactionist View



Team cognition as *holistic cognition*

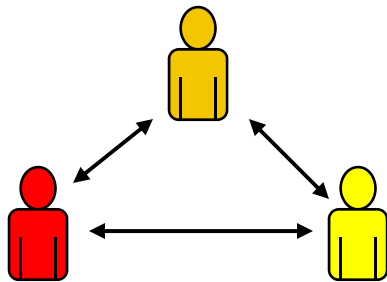
- It is more than the sum of the cognition of individual team members
- It emerges (Gestalt - like) from the interplay of the individual cognition of each team member or cognitive entity

Team Cognition

Team Level Perception, Attention, Thinking, and Action

B

Interactionist View



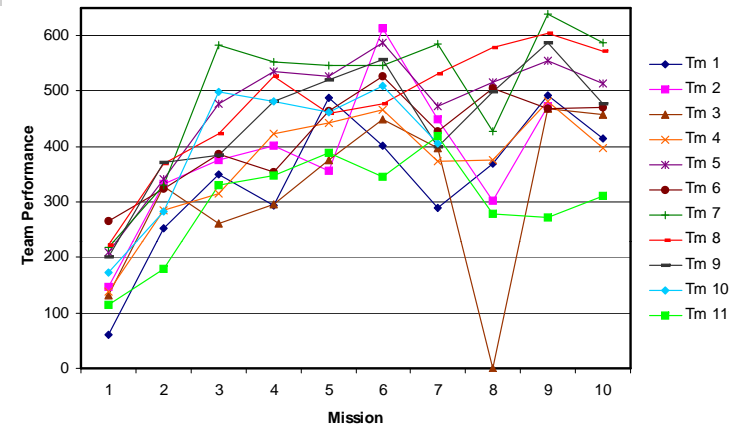
Team
cognition
as *holistic
cognition*

- Team cognition is in the *interactions among team members*
- Communication, coordination, push-and-pull of info. is team-level cognitive processing
- Focused on team process (vs. team member knowledge)
- Team cognition (or team mind) is observable in the team's interactions

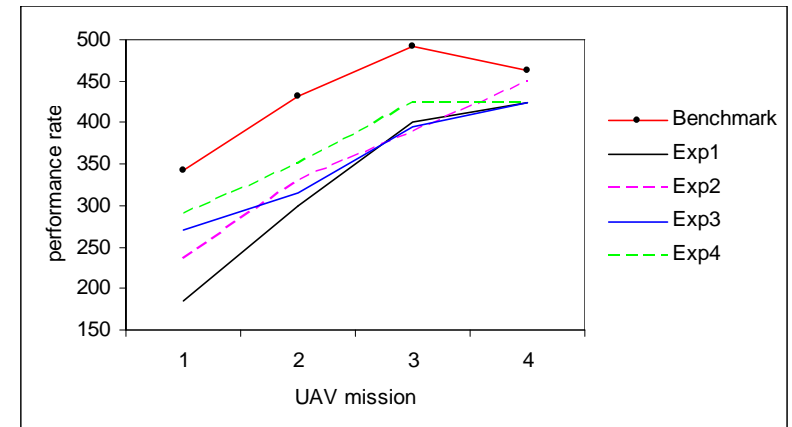
Results That Support Holistic Team Cognition

- Performance and process change with team-level experience and periods of nonuse
- Knowledge is relatively stable after training
- Manipulations (dispersion, knowledge sharing, cross training) affect knowledge, but not performance
- Other factors (team familiarity, video game experience) correlate with performance, but not knowledge.

Acquisition of Team Skill



Team of internet video gamers exceed typical performance levels on UAV task





Disclaimer



- We are NOT saying that there is nothing worthwhile inside the heads of individuals....
- But we ARE saying that *in our studies* the interactions among individuals provide more predictive power (are more relevant to *team performance*) than individual cognition



Implications of Holistic or Interactionist View

■ Measures & Metrics

- Focus on process over knowledge
- Process-based measures e.g., team SA, coordination

■ Theories and Models

- Inspired by ecological psychology
- Dynamical systems models

■ Interventions

- Process vs. knowledge oriented

Team Coordination in Command-and-Control

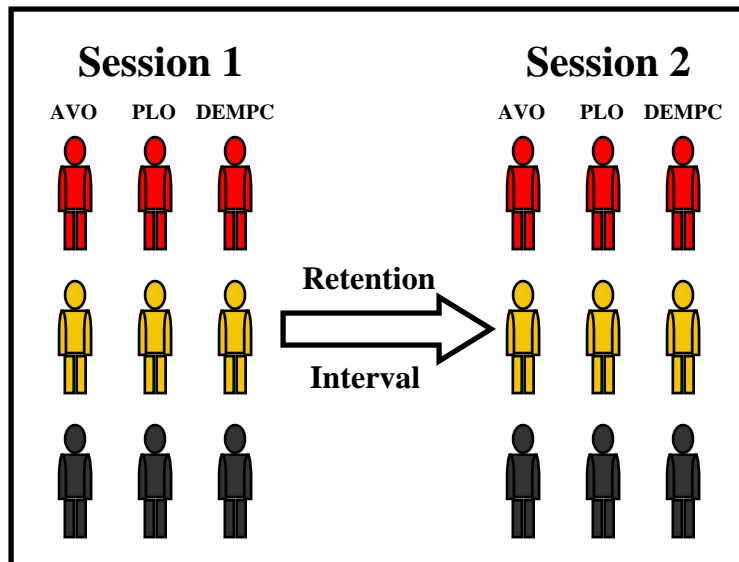
- **Coordination**, a team-level cognitive process, is a type of team cognition
- **Team coordination** is the timely and adaptive exchange of information among team members/cognitive entities
- In the command-and control context, **team coordination** means getting the right information to the right person and the right time
- Observations in our lab and of C2 problems in general have identified **team coordination** as central to team performance

Exp. 1 Method: Experimental Design

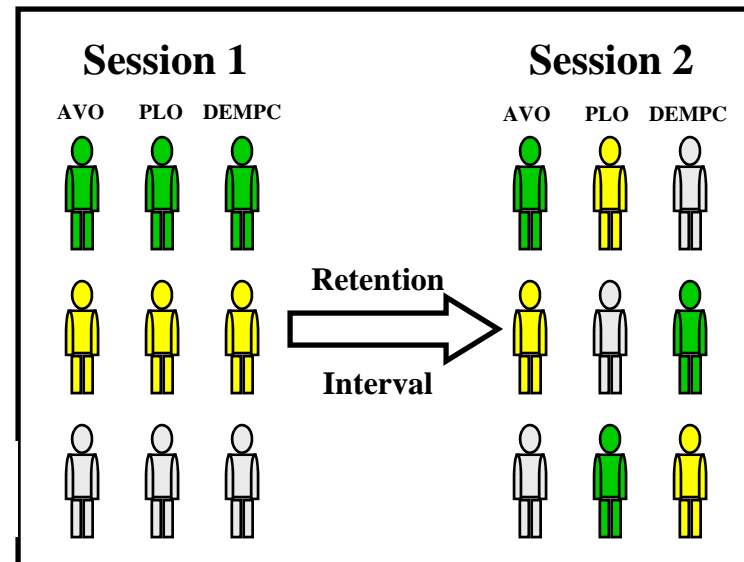
- 117 males(92) & females(25) divided into 39 3-person (unfamiliar) Session 2 teams
- Two between subjects conditions (retention interval and familiarity) randomly assigned with scheduling constraints
- Participants randomly assigned to one of three roles
- Session 1: 5 40-min missions
- Session 2: 3 40-min missions

		Retention Interval	
		3-5 weeks	10-13 weeks
Composition	Same	10 Teams	9 Teams
	Mixed	10 Teams	10 Teams


Same Condition



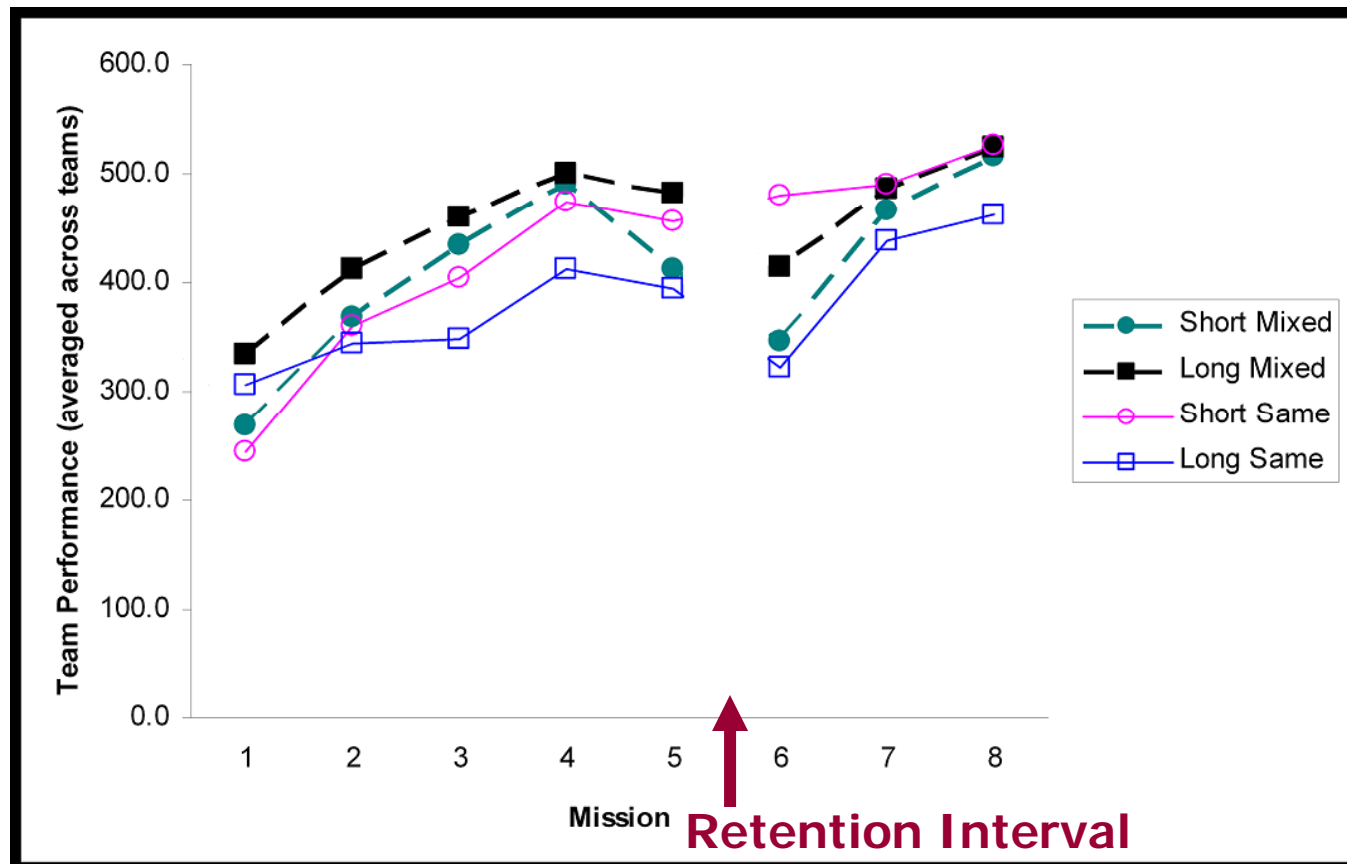
Mixed Condition



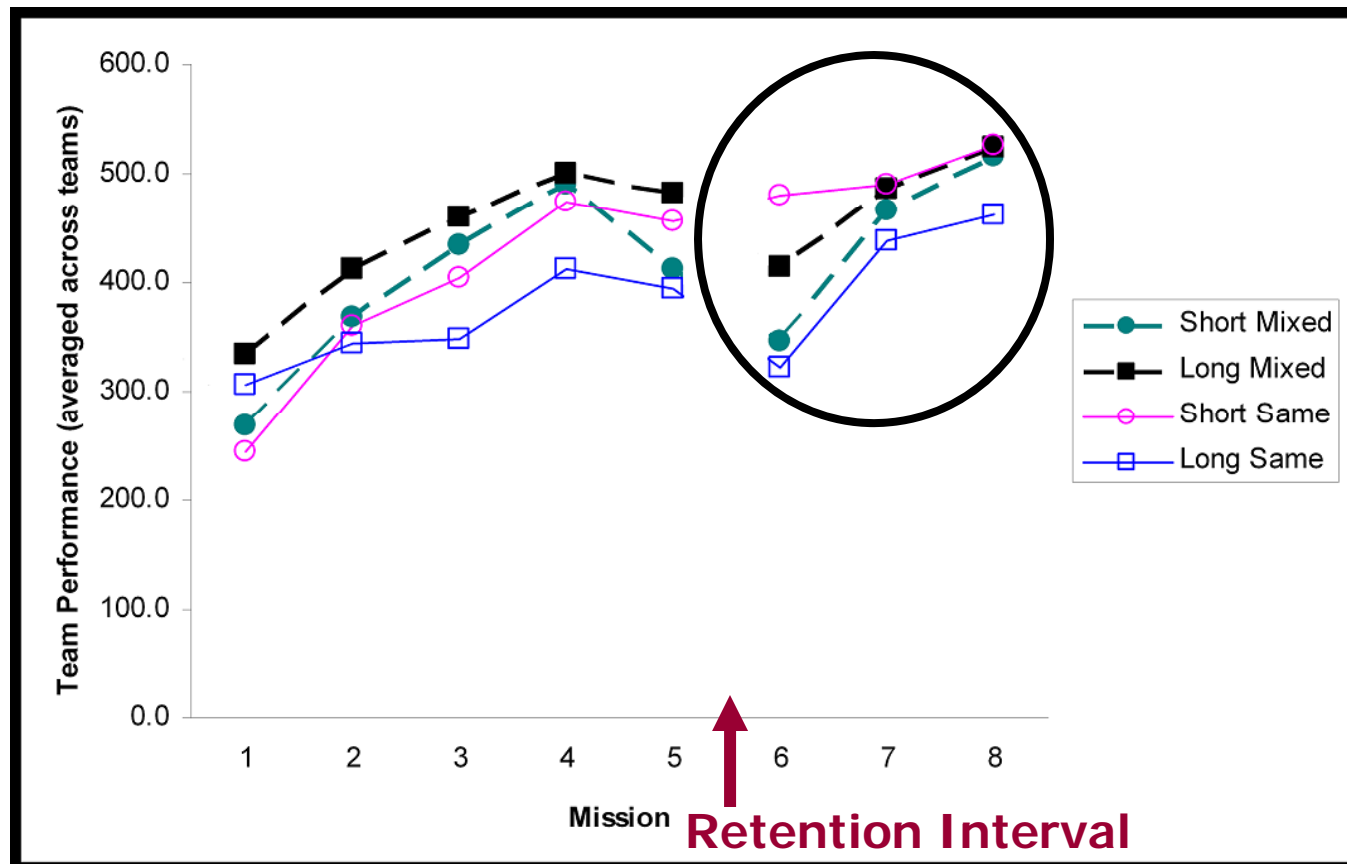
Exp. 1 Hypotheses

- 
- **H1:** Teams in the Long retention-interval condition will demonstrate performance and cognitive (knowledge, process, coordination, SA) deficits compared to teams in the Short retention-interval condition.
 - **H2:** Mixed teams will demonstrate performance and cognitive deficits compared to teams in the Same condition.
 - **H3:** Retention interval and familiarity should interact, whereby the deleterious effects of unfamiliar team members are more severe at the short retention interval compared to the long one (team member familiarity will decline with time)

Exp. 1 Results: Team Performance

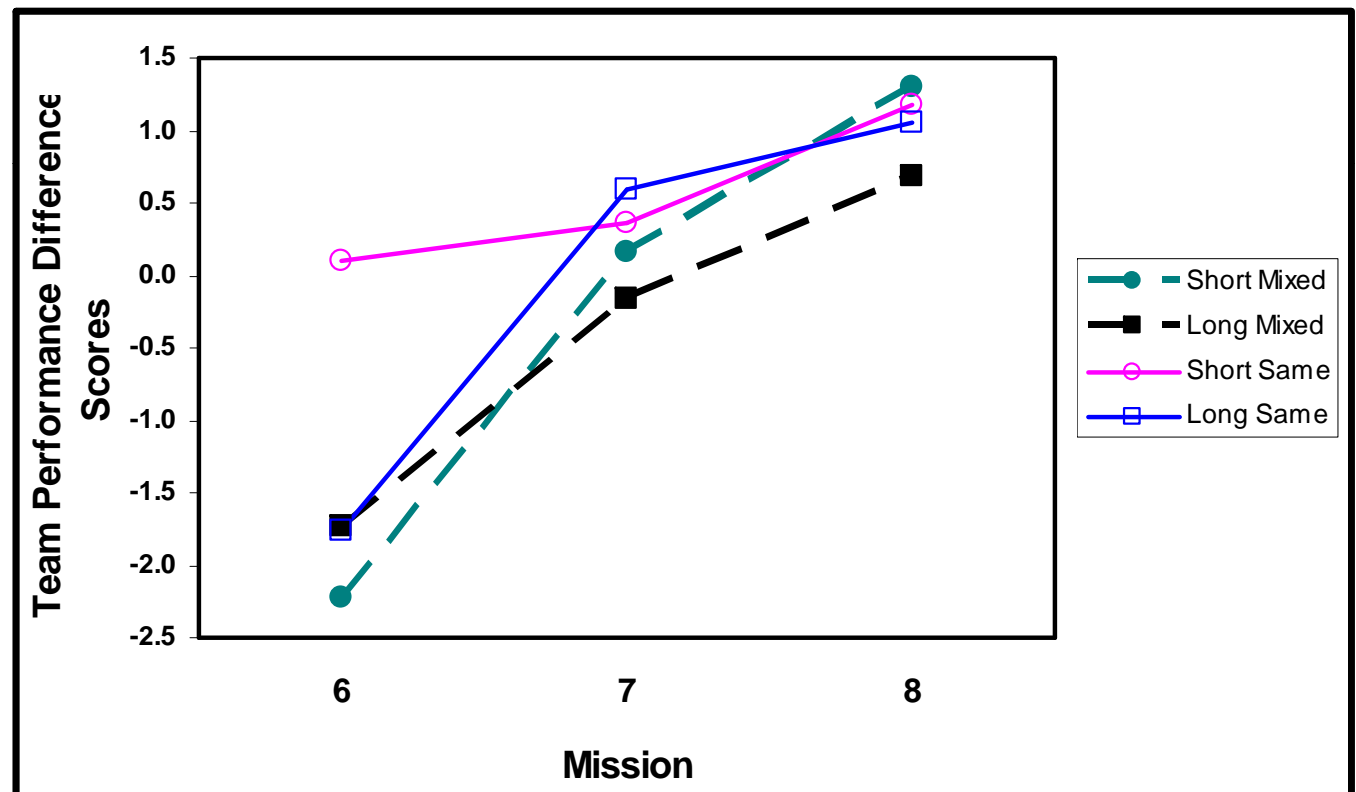


Exp. 1 Results: Team Performance



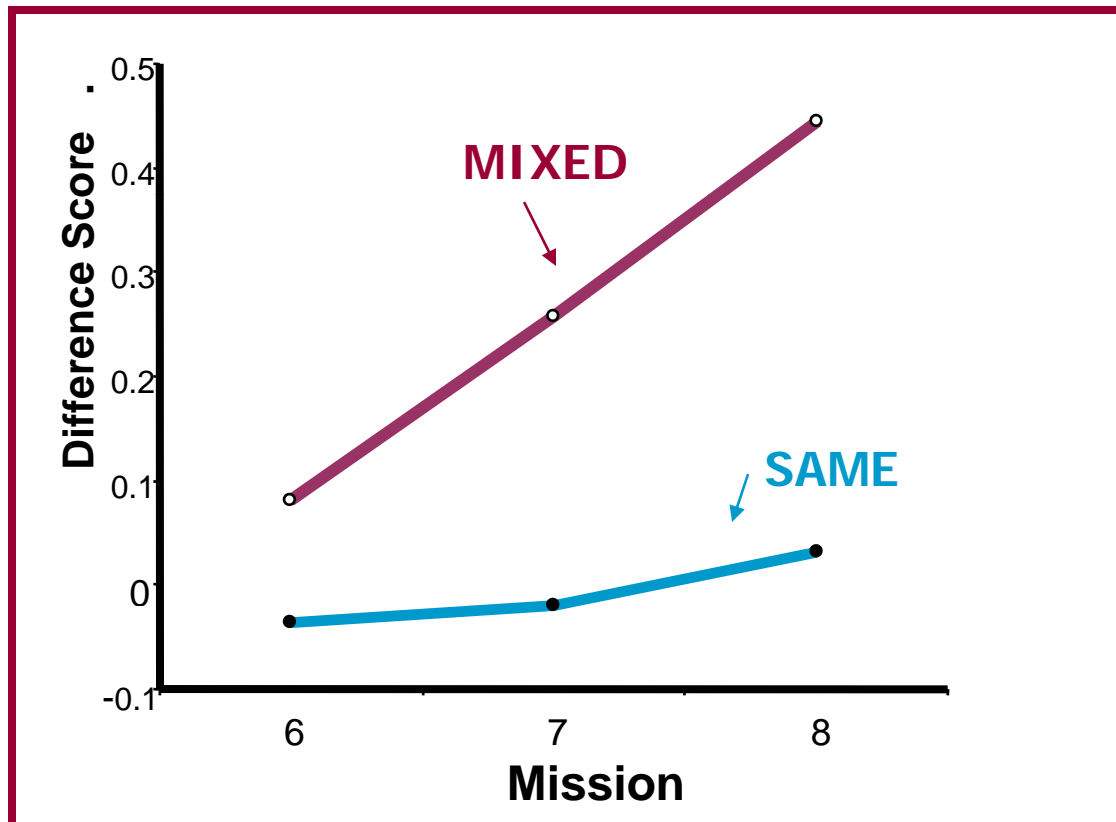
Exp. 1 Results: No Team Performance Decrement for Short –Same Teams

- No decrement for short-same teams (H1)
- Mixed teams show significant decrement after break (H2)
- No improvement for short-same teams



Exp. 1 Results: Team Process

Mixed teams show improved process after the break.



■ Mission x Familiarity effect

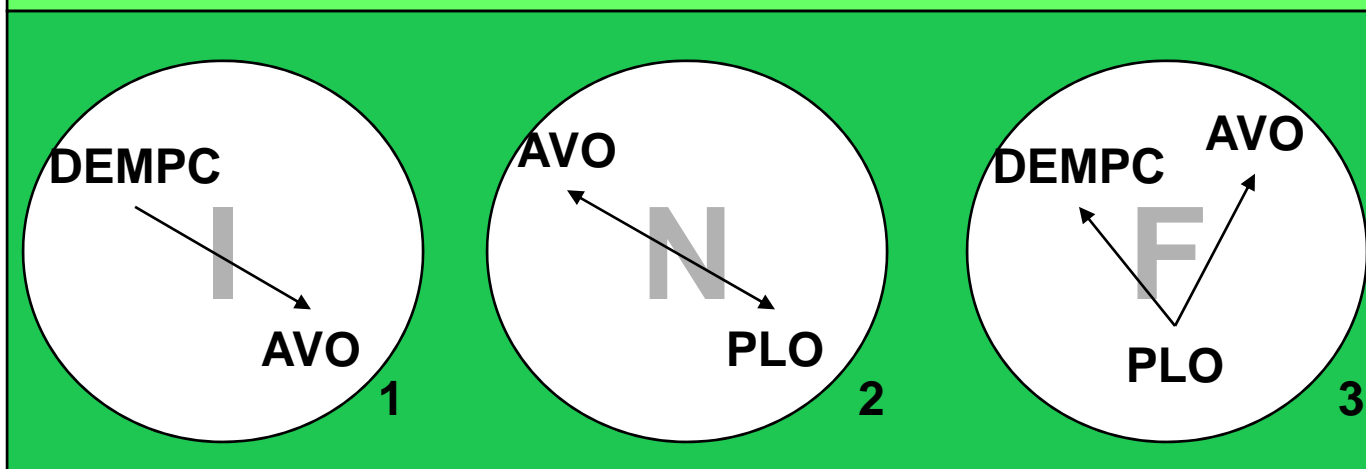
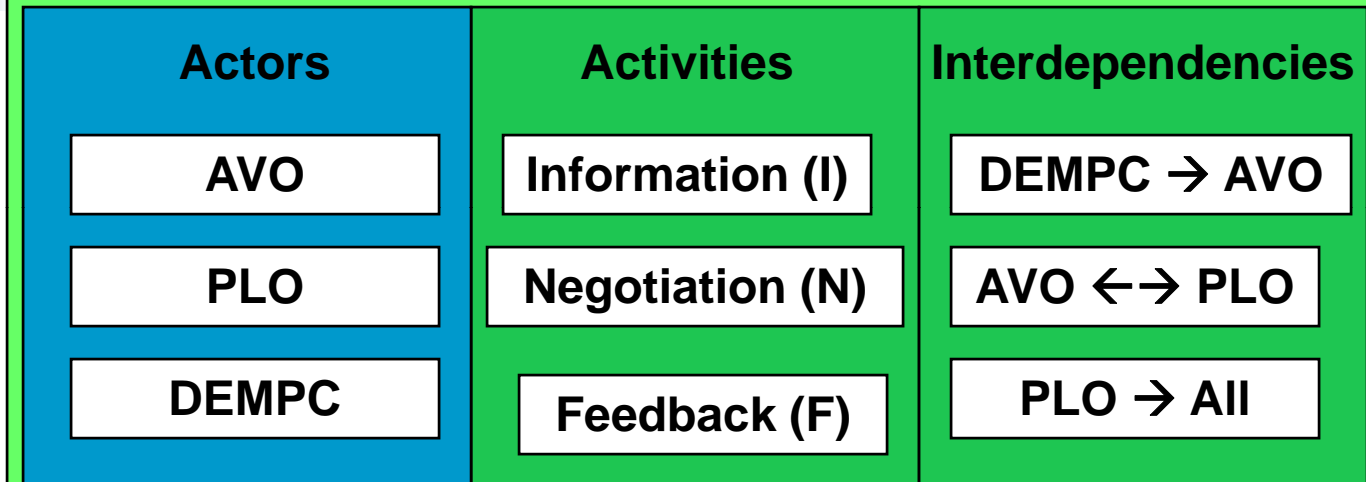
- Same teams showed no process change after the interval
- Mixed teams did not show a decrement and in fact, improved across missions



MEASURING & MODELING TEAM COORDINATION

Target Procedure

Goal: Take picture of a ground target



Recording Time Stamps of the Target Procedure

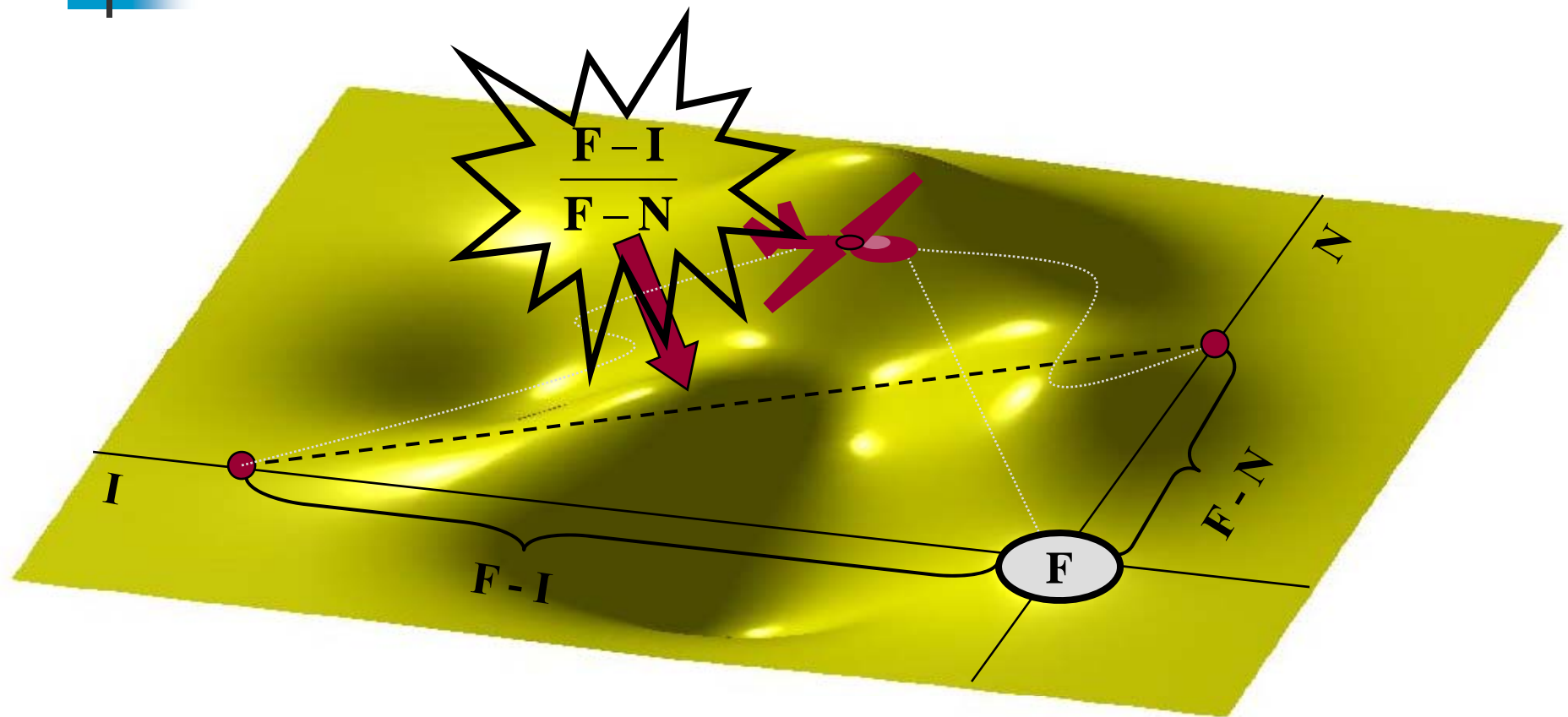
UAV task elements

CONF

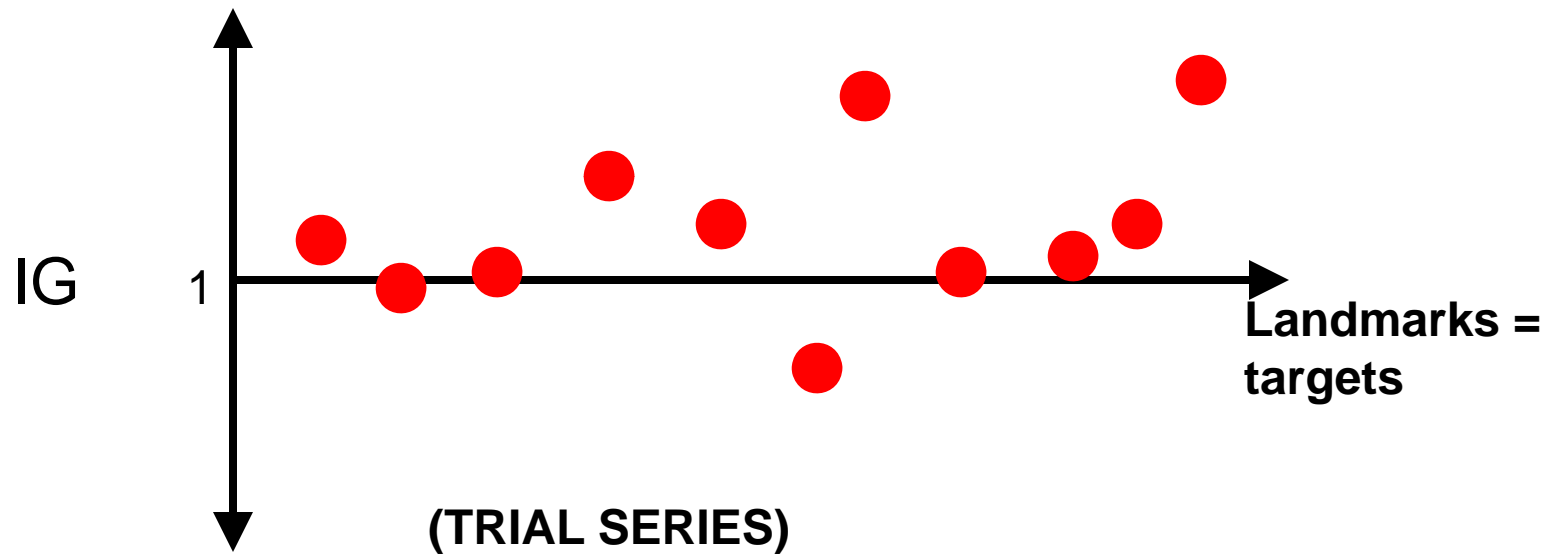
		TH AREA											
		YES	ASPER			ESSER			NO	IMP	RE-PASS		
			A	P	D	E	S	S	P	D			
1.	AVO was told restrictions	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2.	AVO was told radius	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3.	AVO was told it is target	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4.	PLO was told radius	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5.	PLO was told it is target	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6.	PLO/AVO coordinate altitude	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7.	PLO/AVO coordinate airspeed	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8.	AVO was told good pic	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

COMMENTS PROCESS ?

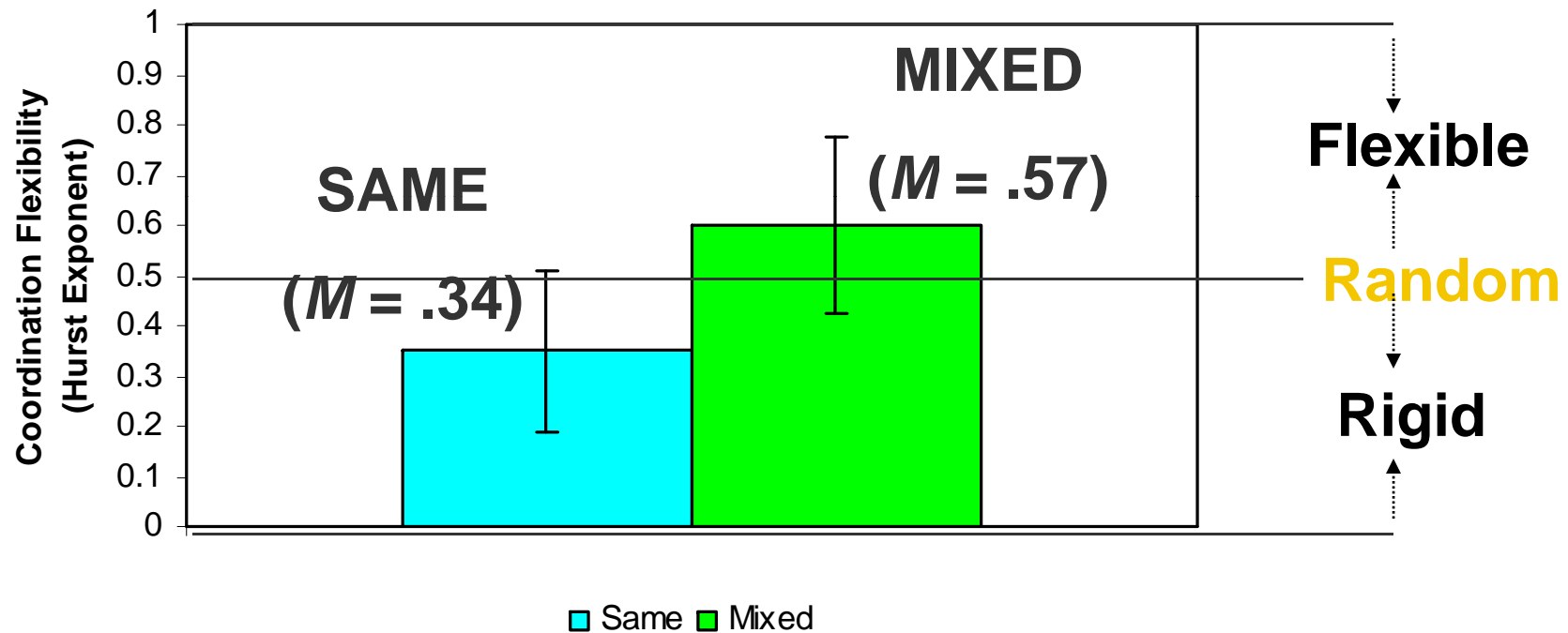
Intrinsic Geometry (IG) Metric of Coordination



Landmarks + Intrinsic Geometry = Trial Series



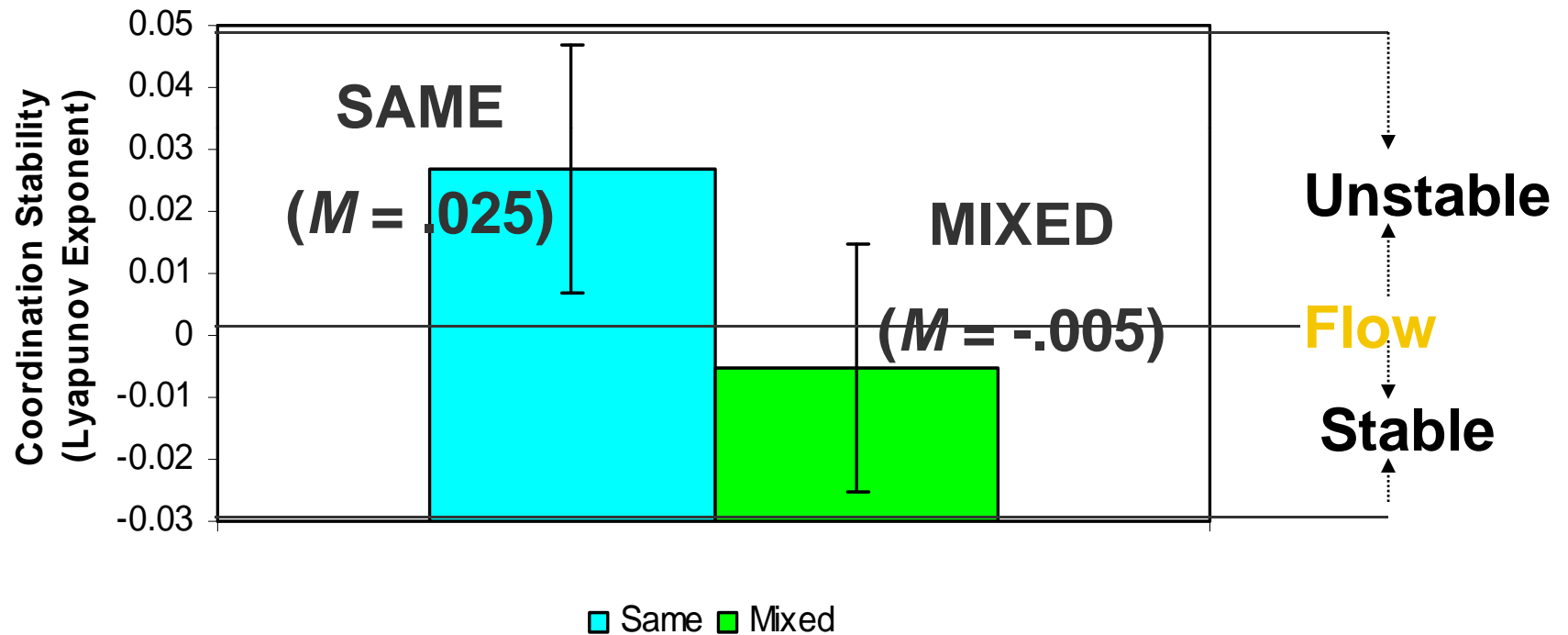
Mixed Teams are More Flexible/ More Exploratory



Coordination Flexibility was correlated with post-retention
performance decrement

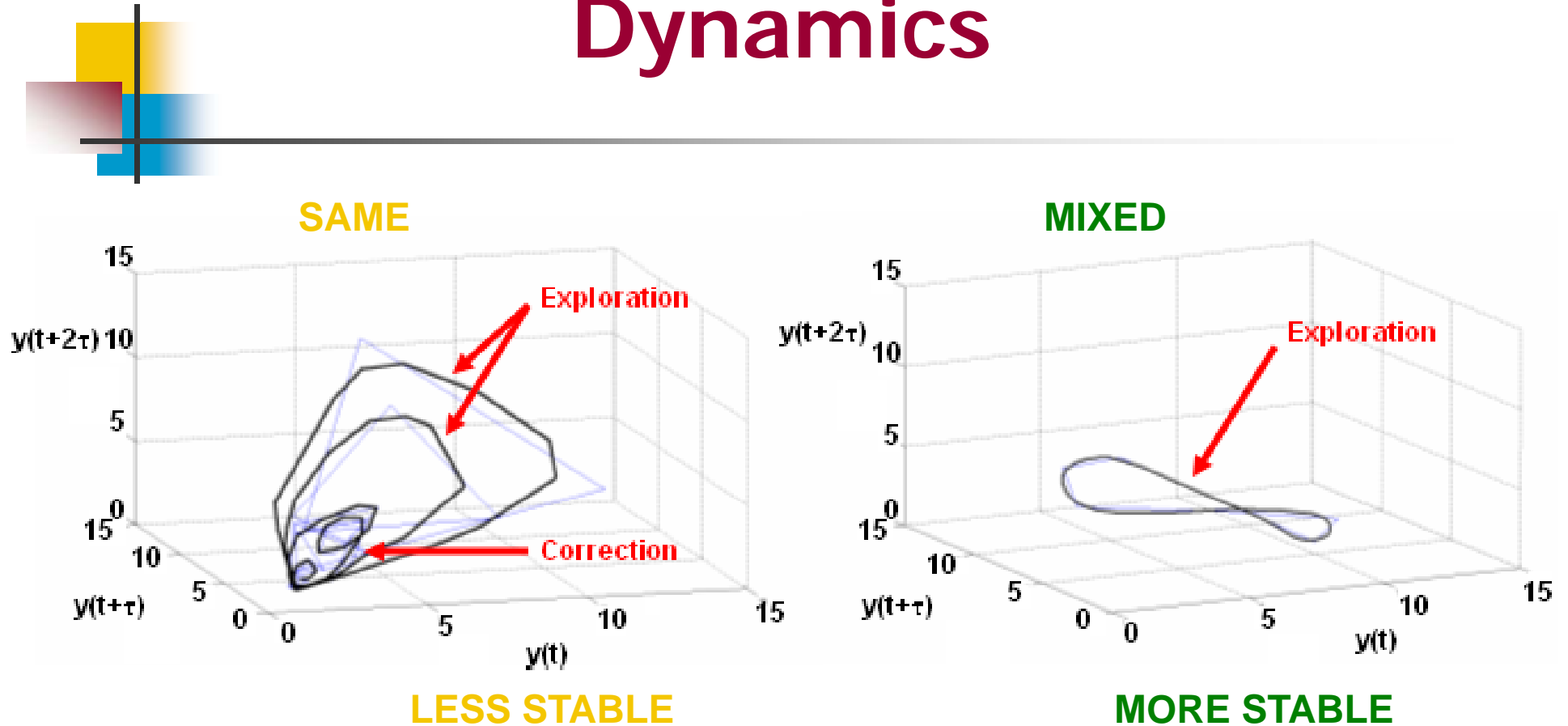
$$(r(30) = -.39, p < .03)$$

Mixed Teams are More Stable To Perturbation



Coordination Stability was correlated with post-retention number of **Team SA roadblocks** overcome ($\rho(36) = -.36, p < .03$)

Summary of Experiment 1 Dynamics





Experiment 1 Findings

- Long retention intervals and changes in team composition result in short-lived team performance decrements
- However these same factors (especially changes in team composition) result in more adaptive (flexible, stable) teams in terms of coordination

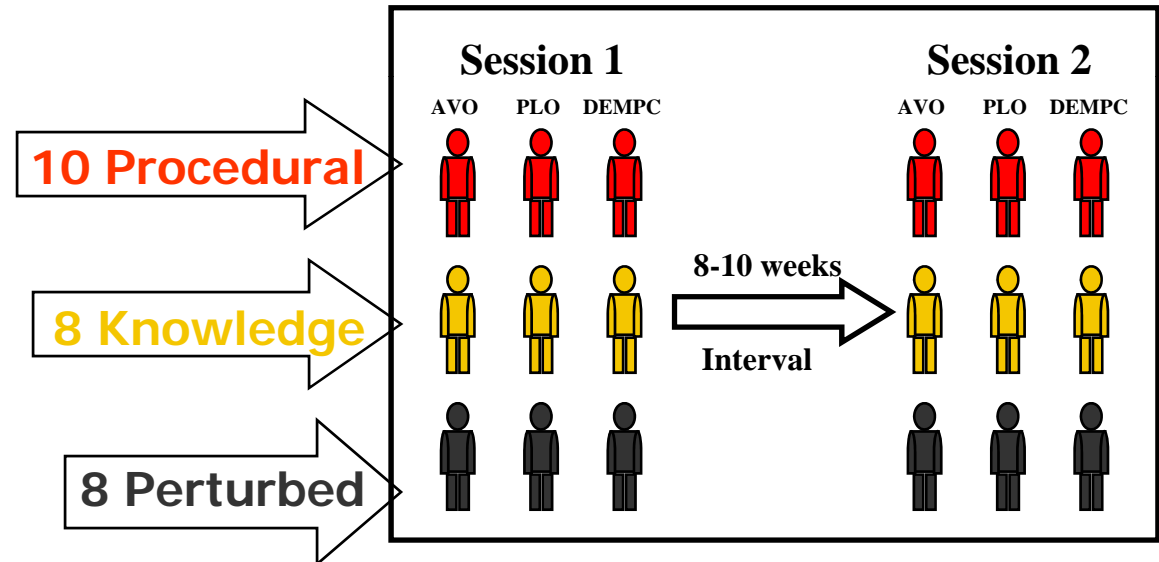
Experiment 2 Research Question

Can we devise a training protocol that mimics the dynamics of Mixed teams to produce adaptive team coordination?

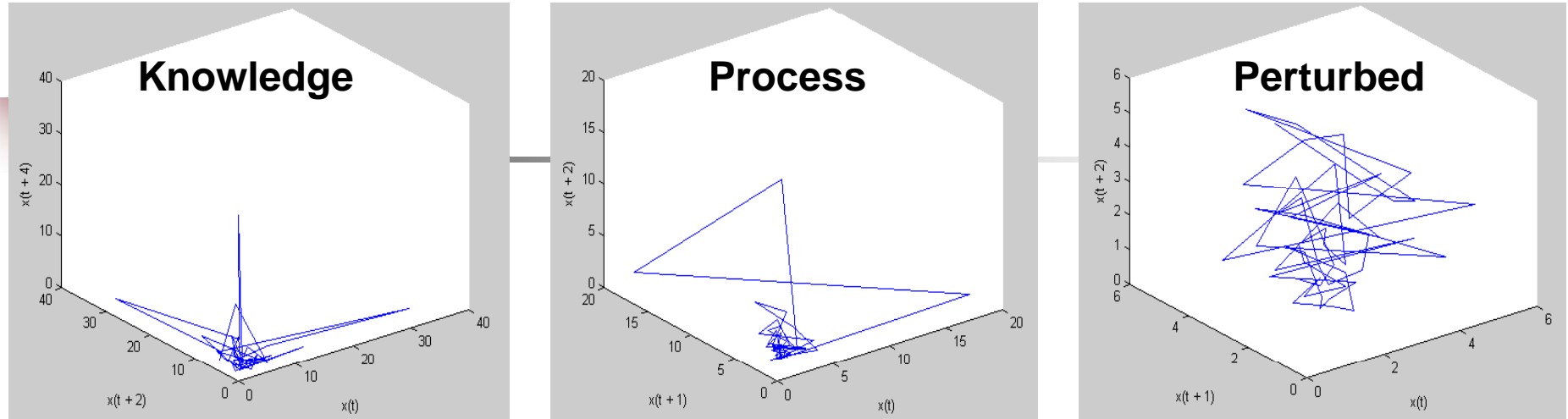
- Procedural: Procedural Training – rigid, prescriptive $I \rightarrow N \rightarrow F$
- Cross-Trained: Shared Mental Models – cross train team members
- Perturbation: constrain possible interactions to force new patterns

Experiment 2 Design

- 26 3-person (unfamiliar) teams completed all 9 missions (six additional teams did not)
- Three training interventions (between subjects condition)
- Nine missions (within subjects) with an 8-10 week interval separating the 5th and 6th missions
- Teams randomly assigned to condition with constraints and participants randomly assigned to one of three roles



Experiment 2 Dynamics Results



Correlations between coordination stability (Lyap.) and team performance in response to team situation awareness roadblocks

Overcome Roadblock Perturbation:

Session 1 $r(24) = -.40, p < .05$

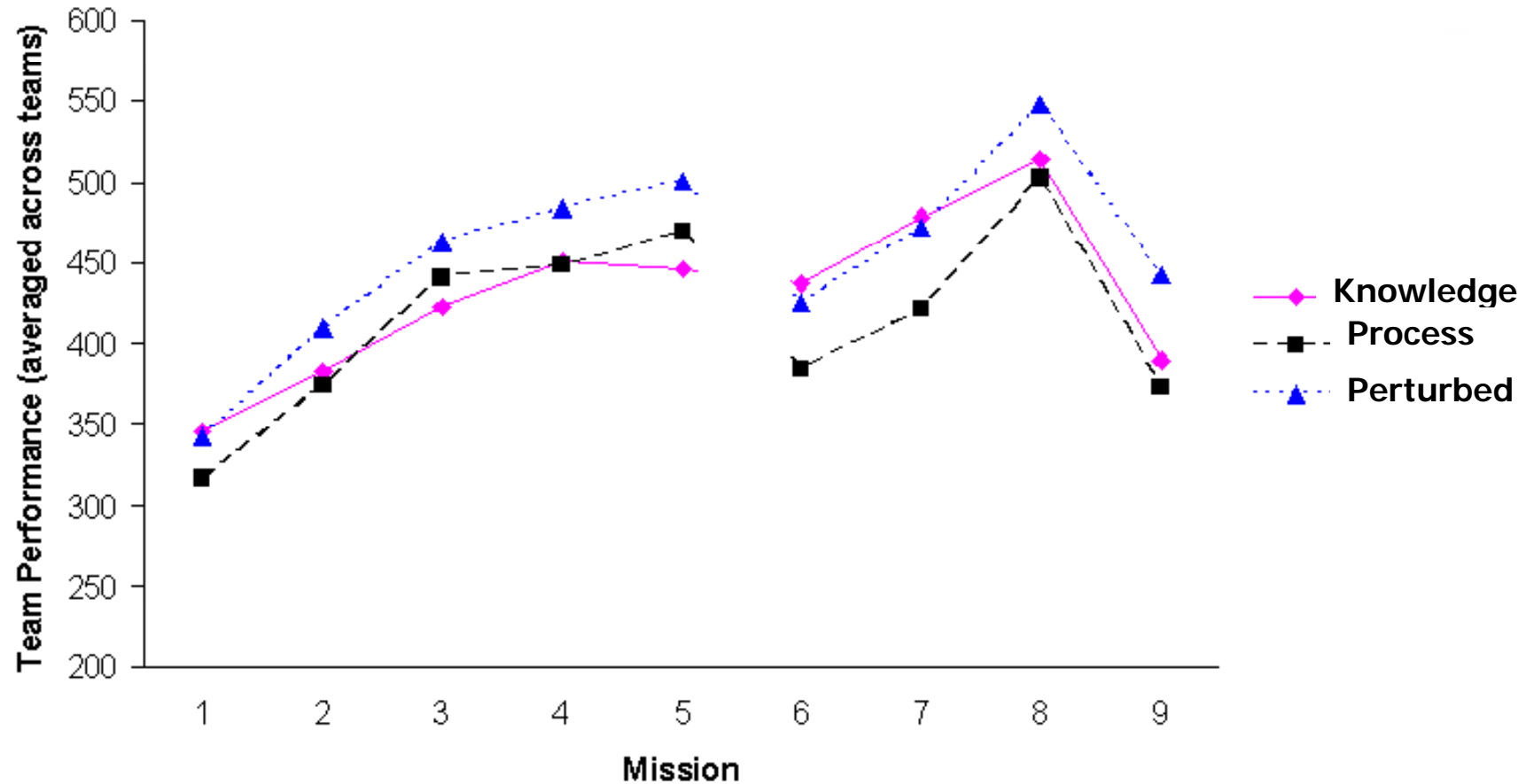
Session 2 $r(24) = -.38, p < .06$

Relaxation Time to Perturbation:

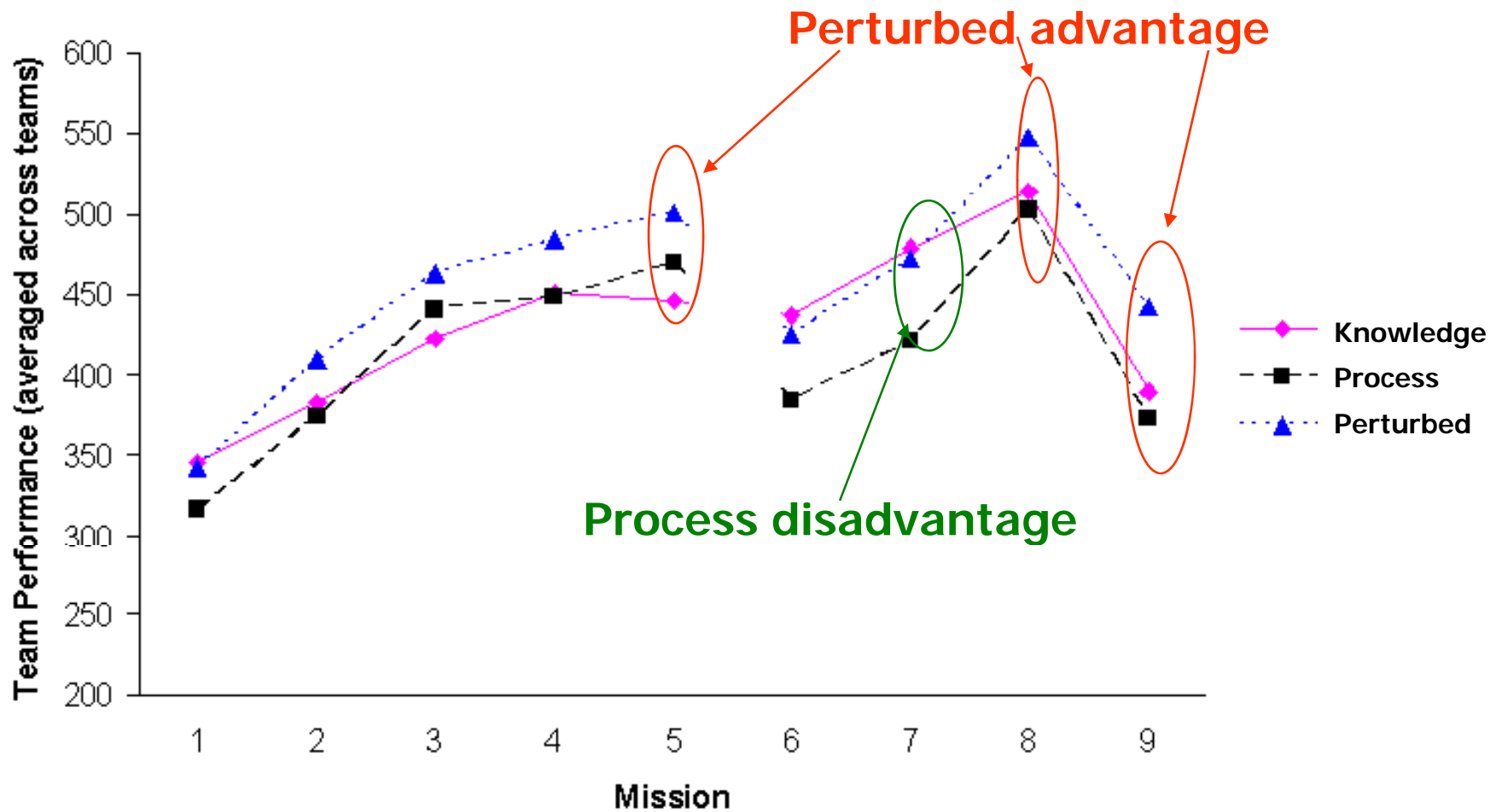
Session 1 $r(24) = .26, p < .10$

Session 2 $r(24) = .41, p < .05$

Experiment 2 Results: Team Performance



Experiment 2 Results: Team Performance





CONCLUSIONS

Conclusions



■ Theoretical

- Process view of team cognition
- Focus on interactions over knowledge
- Ecological, Gibsonian

■ Empirical

- Importance of team process over knowledge
- Short term dips due to long retention and team mixing, but adaptive in long term
- Suggests perturbation training for adaptivity



Conclusions

■ Methodological

- Team cognition metrics
- SA, Coordination, Communication
- Facilitates on-line measurement

■ Modeling

- Dynamical Systems → predictions
- Next steps...ACT-R AVO Agent



Thank You!

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Web Sites:

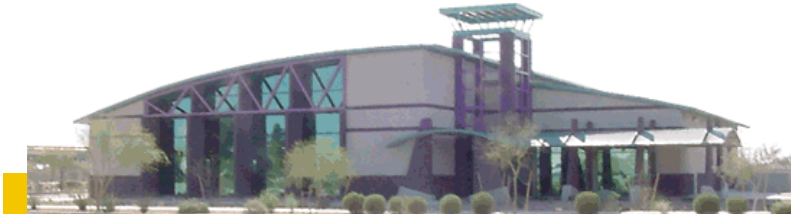
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US 2004 Olympic Basketball Team

"We still have a couple of days, but I don't know where we are," replied USA head coach Larry Brown to a question Wednesday on where his team was in its preparations. "We have good moments and bad, but I've got a pretty good understanding of who needs to play. Now the job is to get an understanding of how we have to play."



US 1980 Olympic Hockey Team



Team Cognition Problems

INCIDENTS

- Vincennes 1989
- Challenger & Columbia
- 9/11 Response 2001
- Friendly Fire Incidents
- Response to Katrina 2005
- Remotely Operated Vehicles mishaps



Team Cognition Problems

CHALLENGES

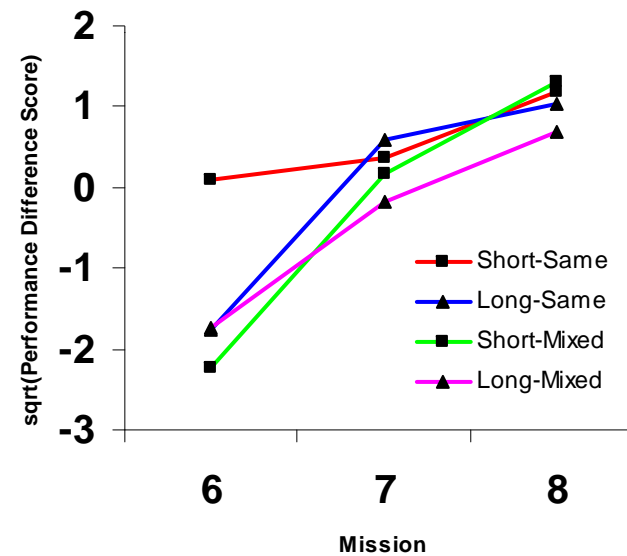
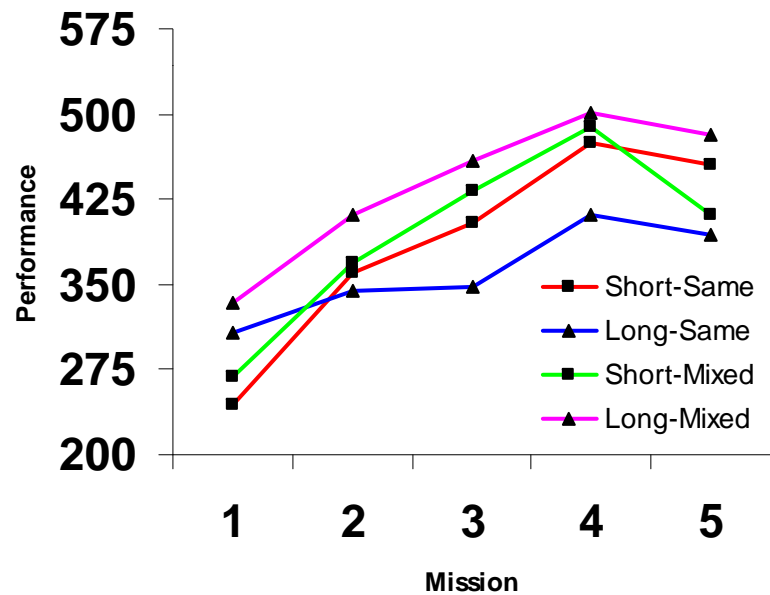
- Automation
- Complex dynamic systems
- Fatigue/experience
- Fast Tempo
- Uncertain information

And...

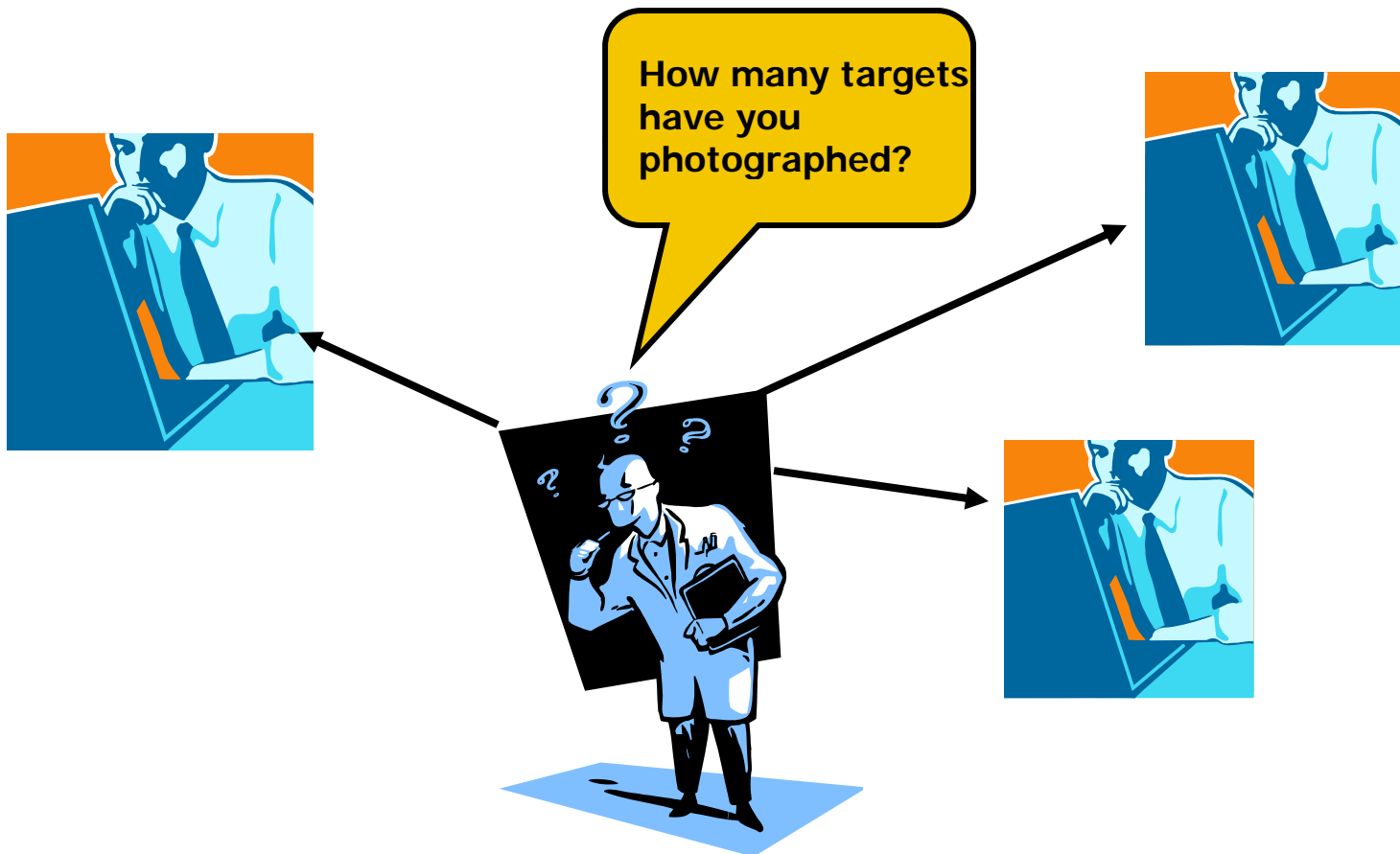
- Distributed teams
- Ad hoc teams
- Interagency coordination
- Communication needs



No Performance Decrement for Short-Same

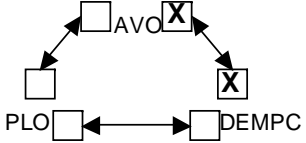
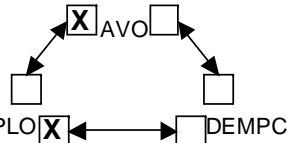
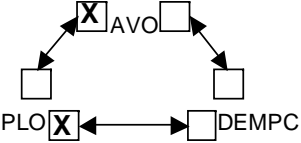
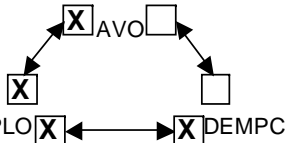


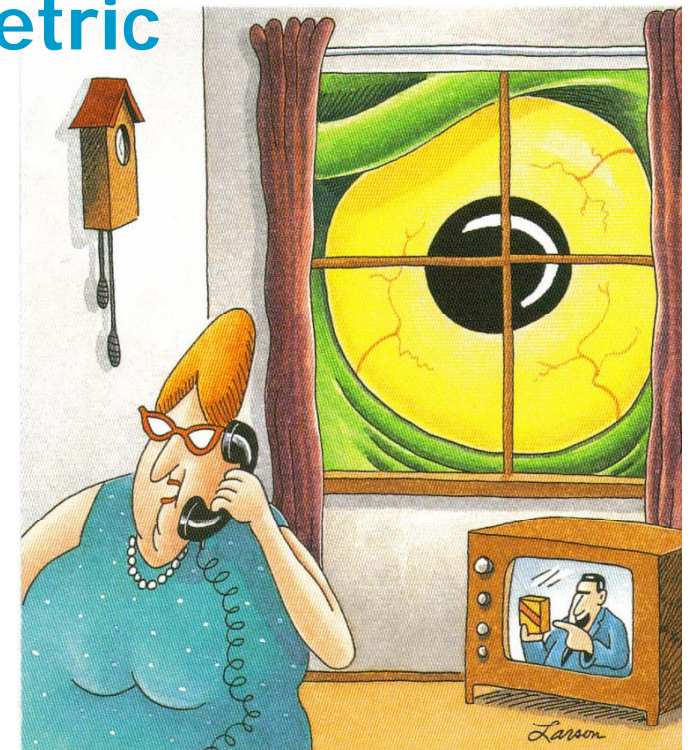
Team Situation Awareness Metric Inside the Head



Measuring Team Situation Awareness

CAST (Coordinated Awareness of the Situation by Team) Metric

<p>Perceived first-hand: <input checked="" type="checkbox"/> AVO <input type="checkbox"/> DEMPC <input type="checkbox"/> PLO</p> <hr/> <p>Coordinated perception: </p> <hr/> <p>Coordinated action: </p> <hr/> <p>Overcome roadblock? <input checked="" type="checkbox"/> YES <input type="checkbox"/> NO</p>	<p>Perceived first-hand: <input checked="" type="checkbox"/> AVO <input checked="" type="checkbox"/> DEMPC <input type="checkbox"/> PLO</p> <hr/> <p>Coordinated perception: </p> <hr/> <p>Coordinated action: </p> <hr/> <p>Overcome roadblock? <input checked="" type="checkbox"/> YES <input type="checkbox"/> NO</p>
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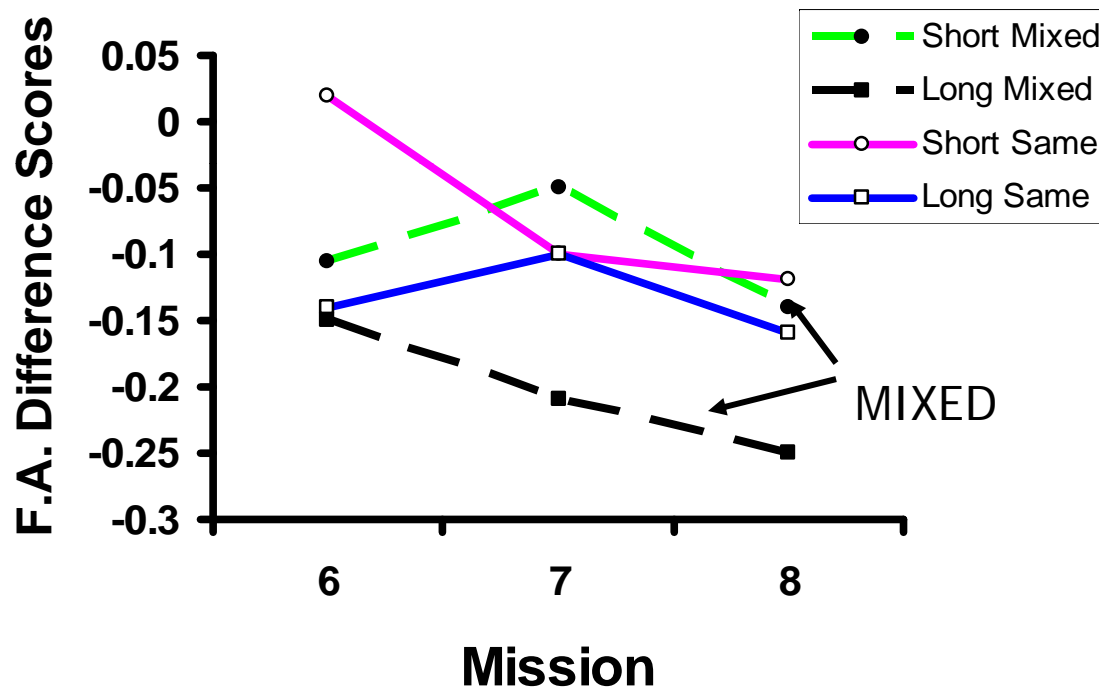
"Hello, Emily. This is Gladys Murphy up the street. Fine, thanks. ... Say, Emily, could you go to your window and describe what's in my front yard?"

Exp. 1 Results: Team Situation Awareness

- Teams responded to CAST roadblocks (1 per mission; change that requires coordinated response)
- Events associated with coordinated perception and action are scored
- Optimal degree to which team members are involved in coordination
- Score based on match between observed coordination and optimal model (hits and false alarms)

SCORING	
Stage 1. Perceive	Stage 2. Act
<p><u>Perceived Only:</u> <input checked="" type="checkbox"/> AVO <input type="checkbox"/> PLO <input checked="" type="checkbox"/> DEMPC</p> <p><u>Coordinated Perception</u></p> <pre>graph BT; PLO1[PLO] --> AVO[AVO]; DEMPC1[DEMPC] --> AVO; PLO1 <--> DEMPC1;</pre>	<pre>graph BT; AVO[AVO] --> PLO[PLO]; AVO --> DEMPC[DEMPC]; PLO <--> DEMPC;</pre>
Notes: <input type="text"/>	Did team overcome roadblock? <input checked="" type="checkbox"/> YES <input type="checkbox"/> NO No Test <input type="checkbox"/>

Exp. 1 Results: Team Situation Awareness



Overall and continued decrease in false alarm rate after the break (reduction in unnecessary interactions)

■ Mission x Composition x Retention Interval effect

■ Most evident for Long-Mixed teams



COMMUNICATION ANALYSIS

Team Communication Metrics

(ONR Sponsor)



- Communication is one form of team coordination
- Real-time, embedded in the task
- Observable; Think aloud “in the wild”
- Rich, multidimensional (amount, flow, speech acts, content)
- Reflects team cognition at the holistic level; for us this *is* team cognition
- Automated methods needed to exploit data richness and accelerate data analysis

Automating Communication Analysis

Communication flow data captured by Comlog tool

- Interval time record of who is talking to whom, when, and for how long (8 Hz)
- Logged automatically by intercom system and Comlog software
- Comlog analyzed by FAUCET methods

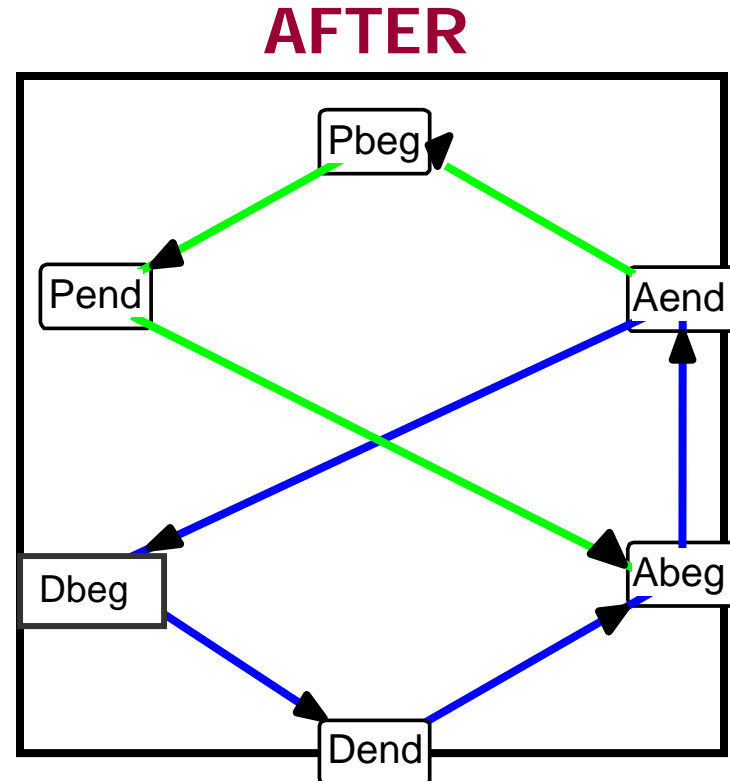
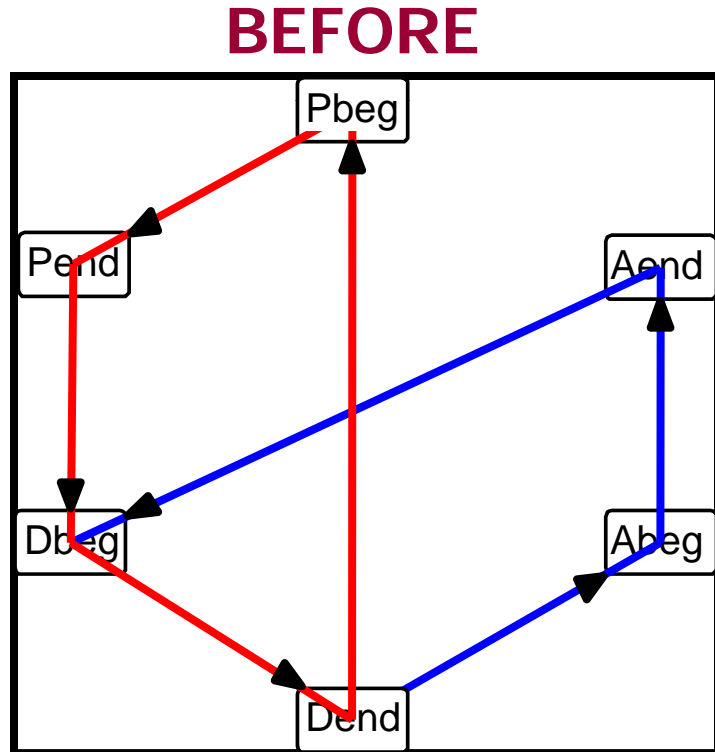


Communication content captured on audio tape

- Discourse on audio tape is manually transcribed
- Transcripts are analyzed using Latent Semantic Analysis (LSA)

ProNet-- Procedural Networks

Specific Patterns: Conflicts





Communication Results

- Distinguish high from low performing UAV teams
 - Co-located vs. distributed
 - Low vs. high workload
- Content coding of macrocognitive processes
 $R^2 = .52$.
- Enron email: unique chains detected surrounding Enron-critical events
- Exploring patterns in chat data
- Use for coordination coding

Summary



- Long retention intervals and mixing cause temporary hiccups in team performance (H1, H2)
- However, there may be long-term benefits to these perturbations of coordination in terms of adaptive, flexible teams (better process, team SA).
- Coordination metric indicates that coordination variability/stability may be most predictive of performance.
- Possible tradeoff between immediate performance and long-term adaptability

Summary



- Model provides a qualitative look at team coordination differences. Same teams achieve self-organization, but not mixed teams.
- Implications for improving team coordination through training interventions
- Coordination metric has general appeal for team assessment (especially if automated through communication analysis)

+





Summary

- Perturbed training resulted in better performance in novel/high workload missions. Process - poorest performance.
- Interesting relationships between flexibility/stability/adaptability
- Adaptive teams may suffer some performance loss along the way, but may be stronger in the end
- Team training can focus on
 - Rigid procedural training (PROCESS) → rigid team
or
 - Presentation of deliberate and varied coordination experiences (PERTURBED) → adaptive team



Coordination Events

- Identified coordination events of good and bad teams
- Developed coordination logger
 - Experimenter–recorded observations of information passing at each waypoint
 - Examples:
 - *AVO was told restrictions*
 - *PLO was told effective radius*
 - *AVO/PLO coordinated target airspeed*
 - Record message present/absent, sender/ receiver repetition, timing
 - 10% of missions were coded by two raters; Weighted Kappa = .675
- Eventually automate using communication metrics