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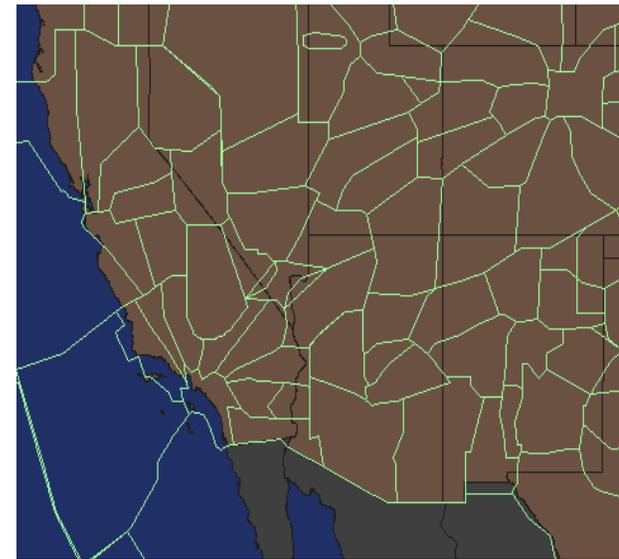
Standard Flow Abstractions as Mechanisms for Reducing ATC Complexity

Jonathan Histon

May 11, 2004

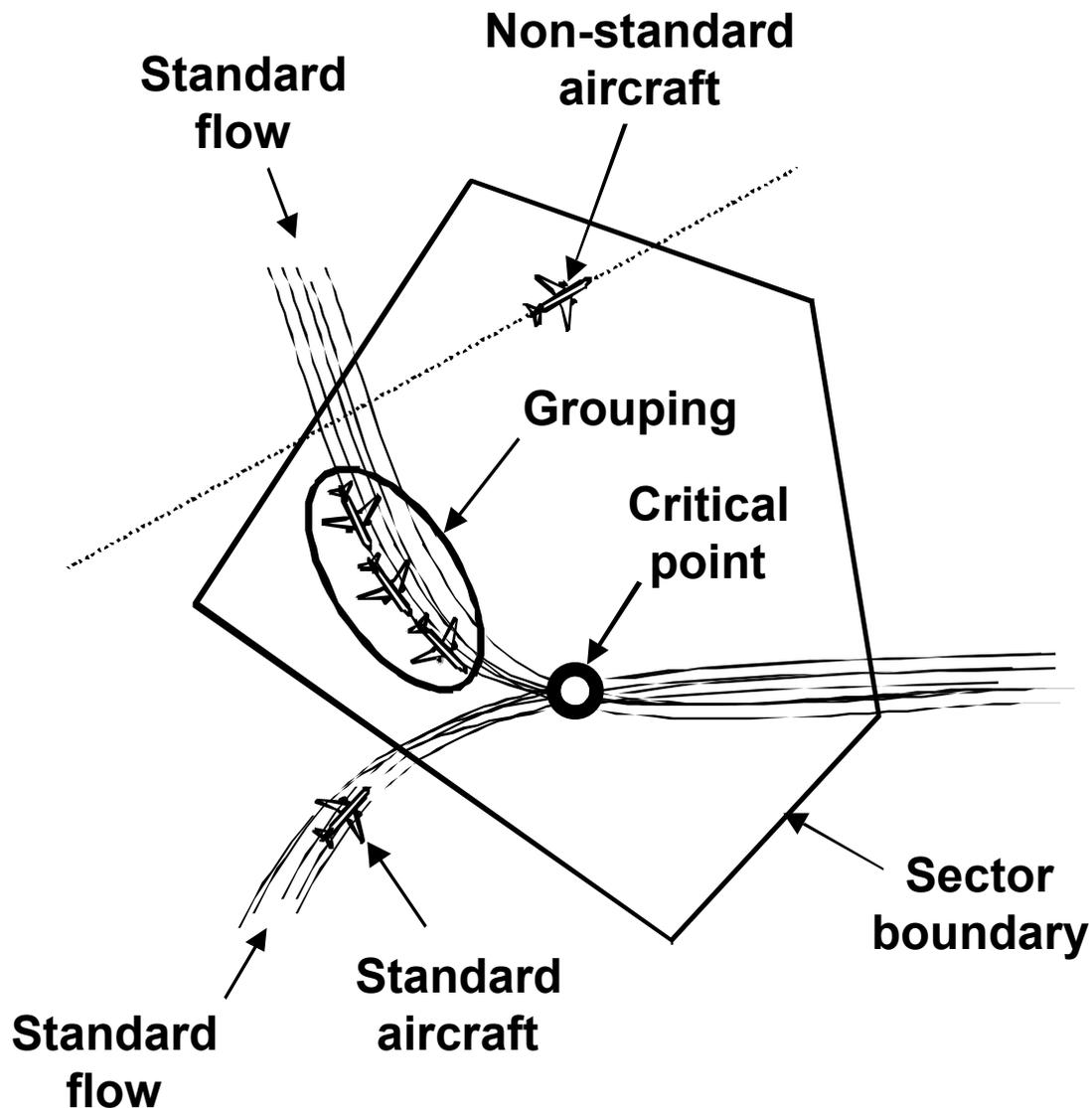
Introduction

- **Research goal: Improve our understanding of complexity in the ATC domain.**
- **Complexity represents a limiting factor in ATC operations:**
 - Limit sector and system capacity to prevent controller “overload.”
- **ATC environment is extremely structured:**
 - Standardized procedures
 - Division of airspace into sectors
 - ATC preferred routes
- **Structure is believed to be an important influence on cognitive complexity.**
 - Not considered in current metrics.
- **Research Question:**
 - What is the relationship between this structure and cognitive complexity?

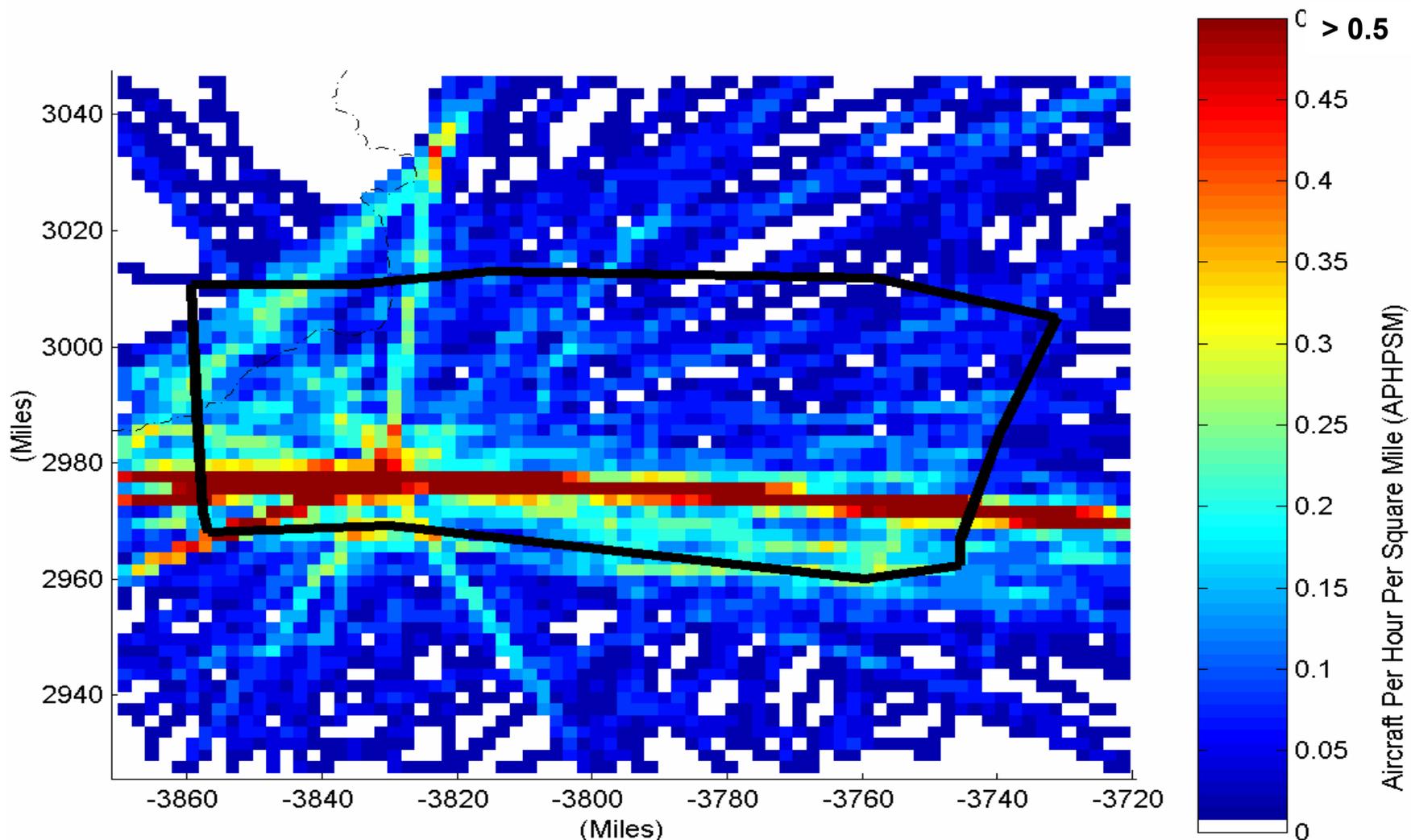


Previous Work: Structure-Based Abstractions

- **Standard Flows**
 - Aircraft classified into standard and non-standard classes based on relationship to established flow patterns.
- **Groupings**
 - Common, shared property, property can define non-interacting groups of aircraft
 - E.g. non-interacting flight levels
- **Critical Points**
 - Sector “Hot Spots”
 - Reduce problem from 4D to 1D “time-of-arrival”.

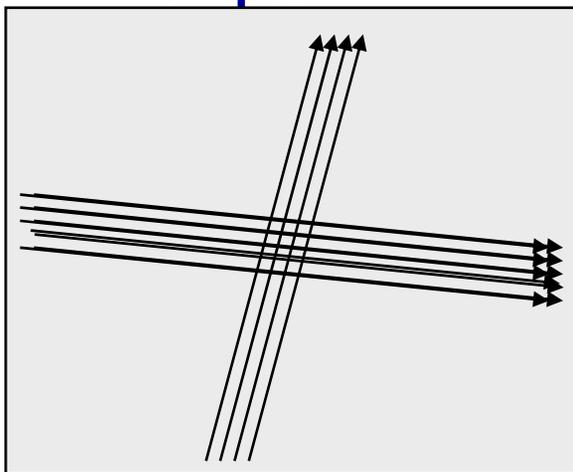


Example Basis for Standard Flow Abstraction



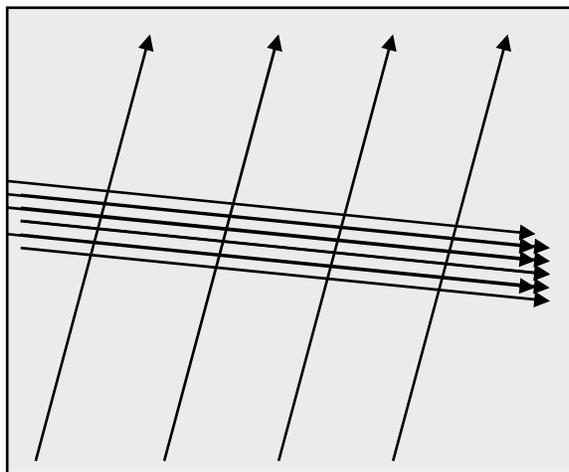
Mechanisms of Structure

- Hypothesis: structure-based abstractions reduce cognitive / situation complexity through reducing “order” of problem space
- Where “order” is a measure of the dimensionality of the problem
- Example:



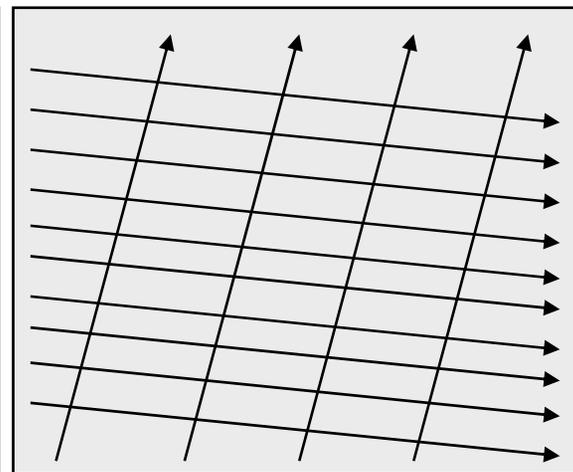
*1 D Problem Space
(T)*

“Point” Scenario



*2 D Problem Space
(X, T)*

“Line” Scenario

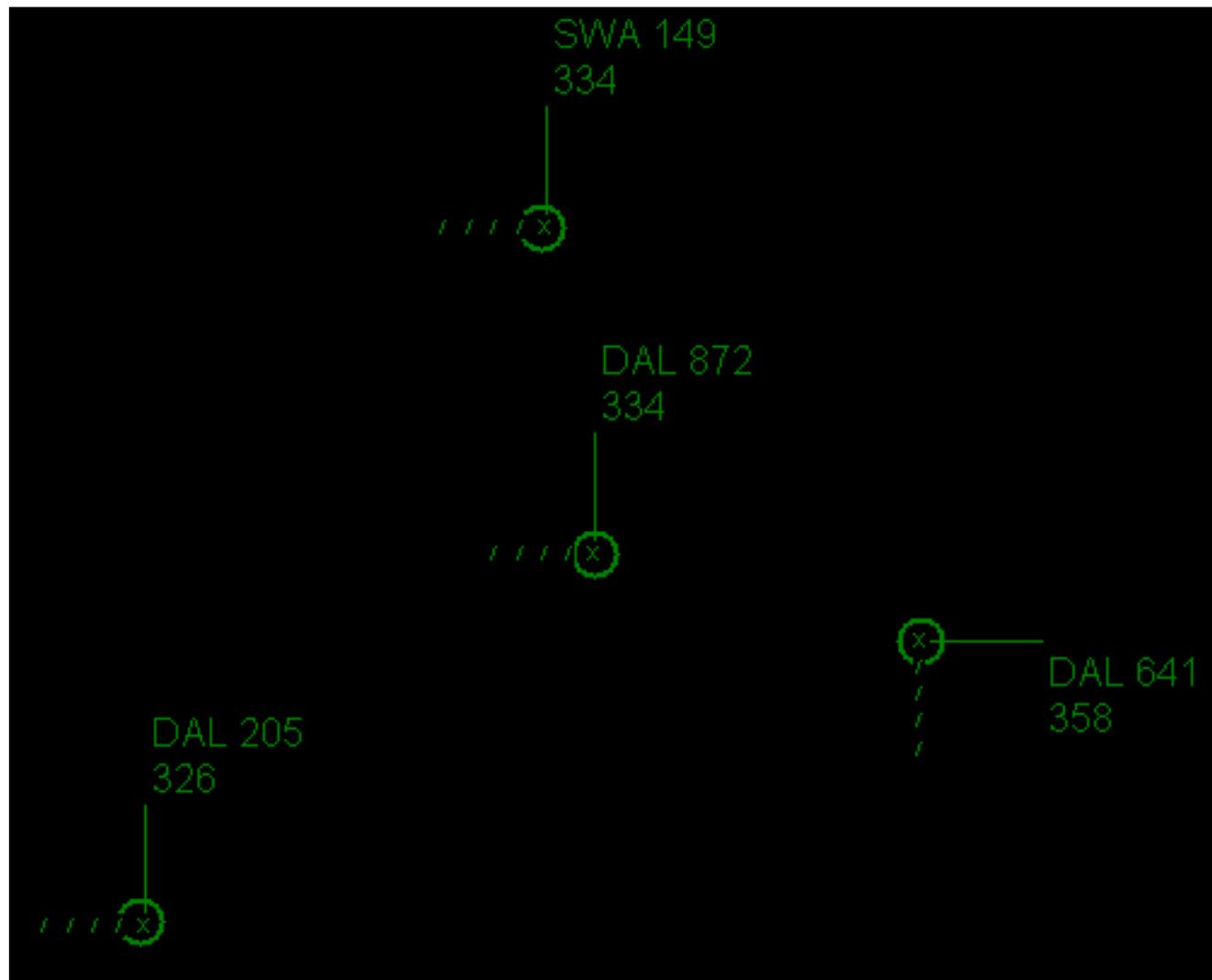


*3 D Problem Space
(X, Y, T)*

“Area” Scenario

Experiment Task

- Observe ~ 4 minutes of traffic flow through “sector”
- Monitor for potential conflicts
- When suspect conflict, pause simulation and identify aircraft involved



Experiment Design

- **Independent Variable**

- 3 Levels of “problem dimensionality”
 - “Area”
 - “Line”
 - “Point”

- **Dependent Variables**

- Time-to-Conflict when detected
- Detection accuracy
- Subjective questionnaires

- **Within Subjects design**

- 6 conflicts (trials) per level of independent variable
- Scenario for each level of independent variable
 - All conflicts for each level occurred within the scenario
- Order of scenarios counterbalanced

Conflict:	Point	Line	Area
C1			
C2			
C3			
C4			
C5			
C6			



Equivalency of Levels of Independent Variable

- **In order to evaluate hypothesis, scenarios should be as similar as possible**
- **Scenario design established general similarity:**
 - Same aircraft rate (~ 6.5 aircraft / minute / flow)
 - Same range of # of aircraft on screen (6-12 aircraft)
 - Similar range of # of aircraft on screen when conflict occurred
 - o Point: 9 +/- 1
 - o Area: 9 +/- 2
 - o Line: 9 +/- 2

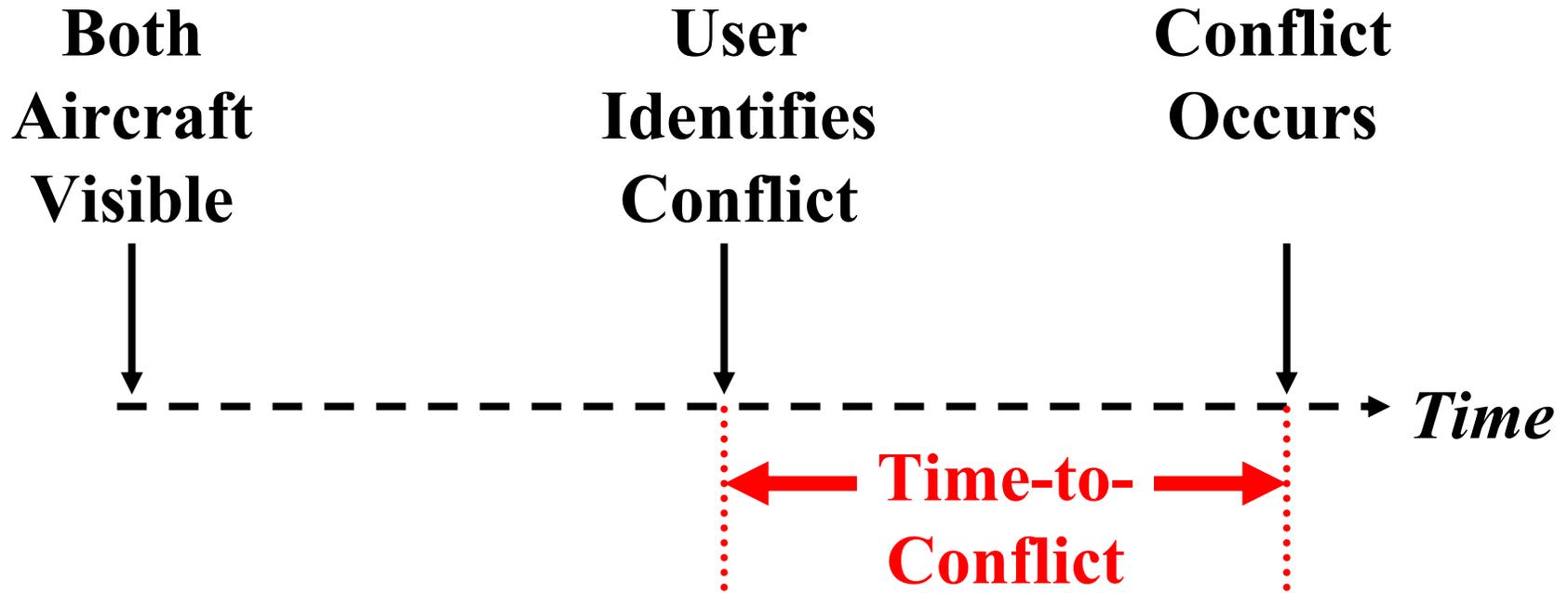


19 Participants

- **Predominantly students**
 - 2 Air Traffic Control Trainees from France
- **Predominantly male (80%)**
- **Age ranged from 23 – 42**
- **Few participants regularly play computer games (27%)**
 - Most never played ATC simulations (71%)



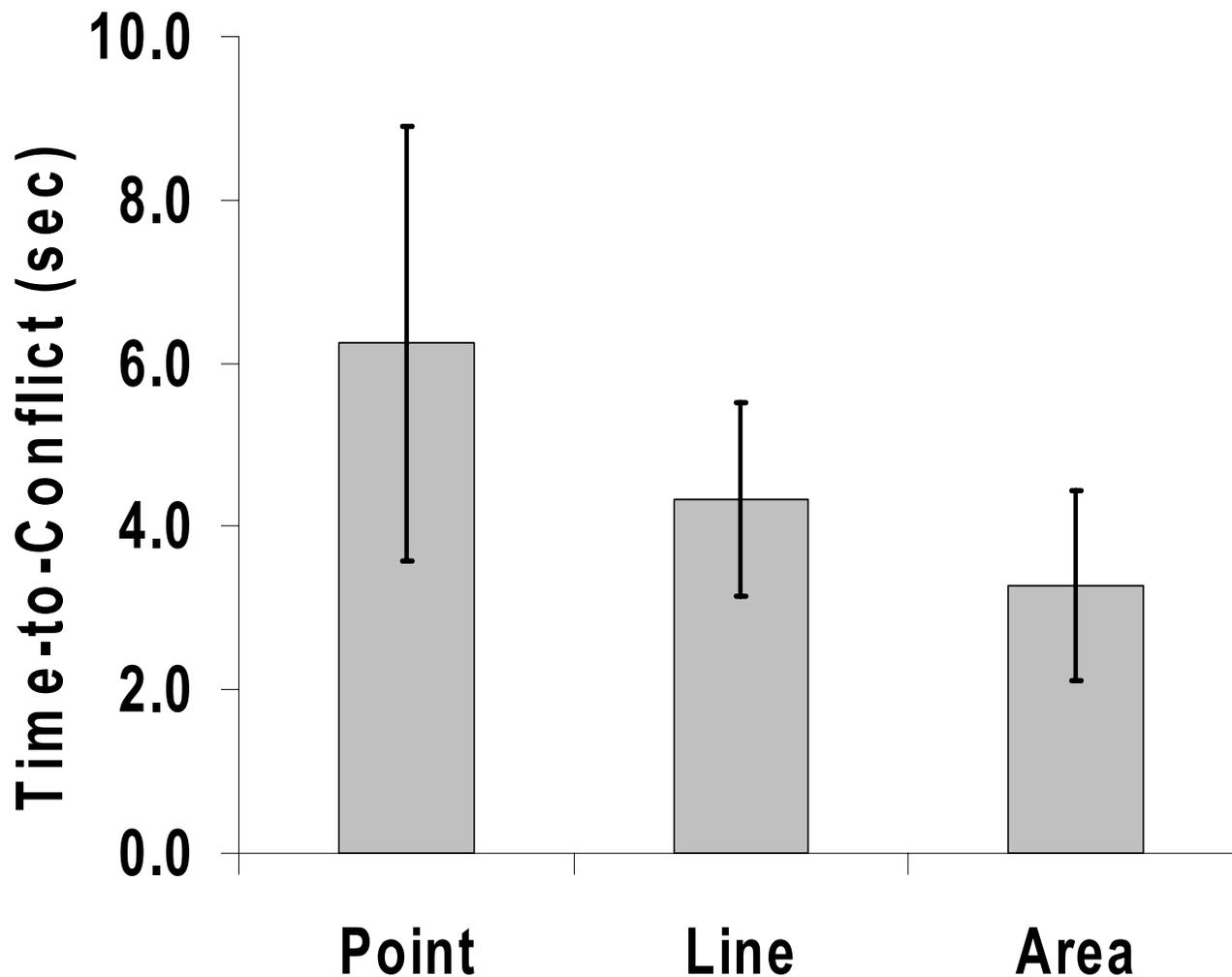
Primary Dependent Variable: Time-to-Conflict





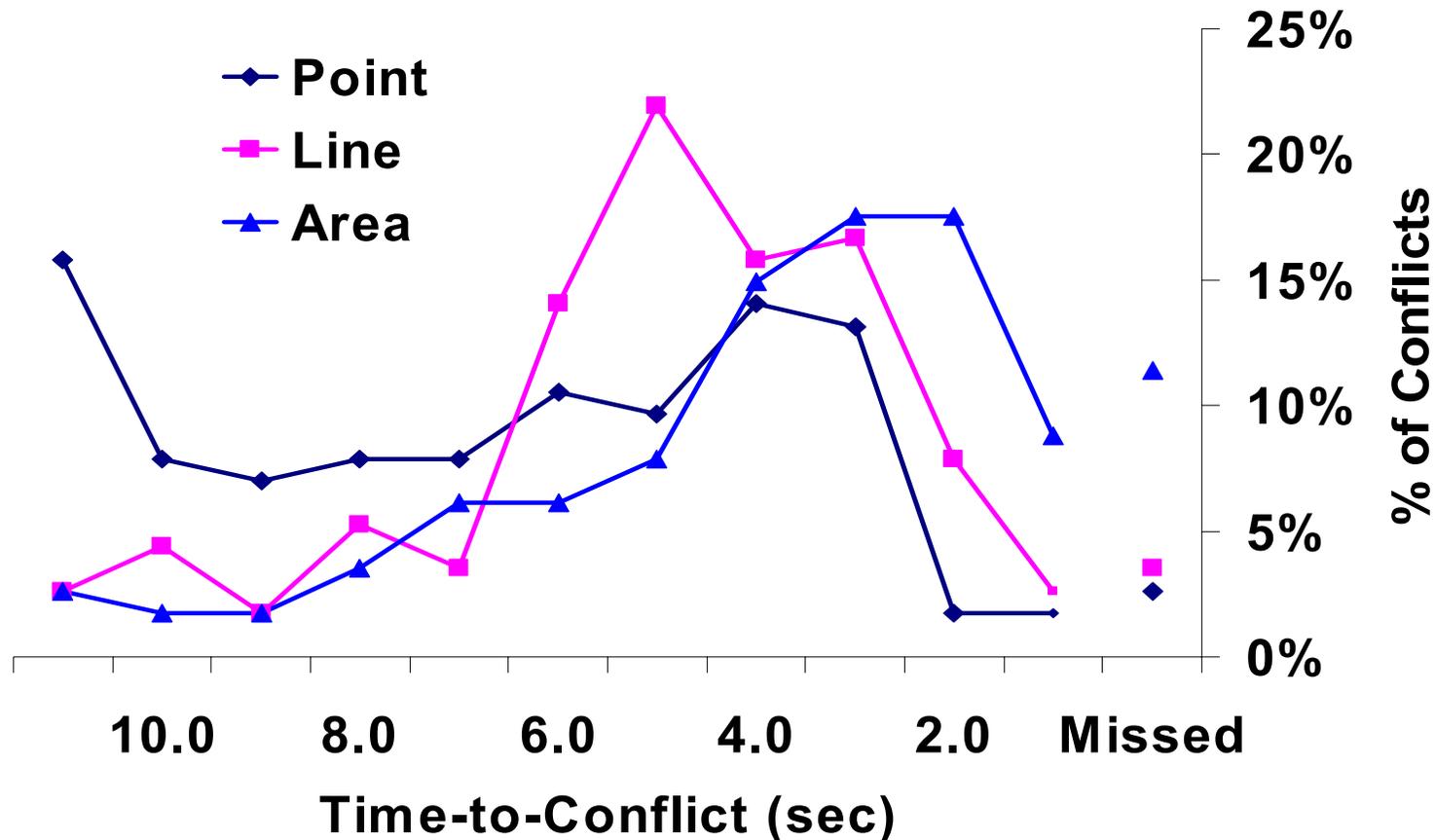
Conflicts are Identified Earlier in “Point” and “Line” Scenarios

- Computed average Time-to-conflict per scenario for each subject
- ANOVA is significant at $p < 0.00002$
- Follow-up two-tailed t-tests indicate all differences statistically significant at $p < 0.002$



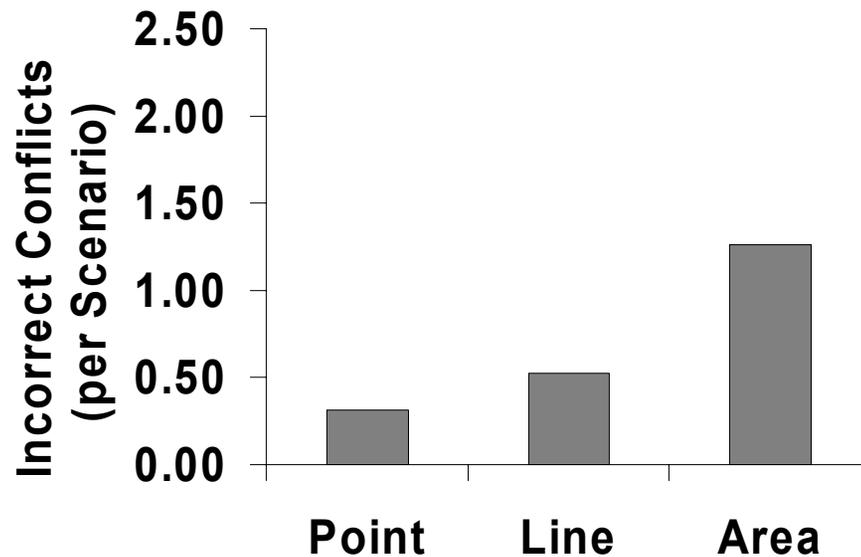
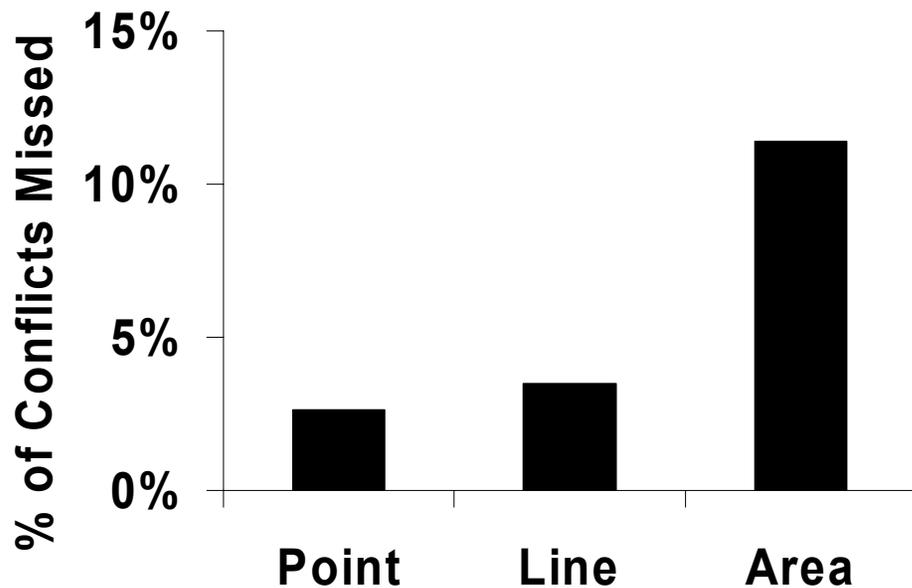
Time-to-Conflict Distributions

- Peak in “Line” condition clearly earlier than for “Area”
- “Point” condition much flatter
 - Sharp drop indicative of attention capture?



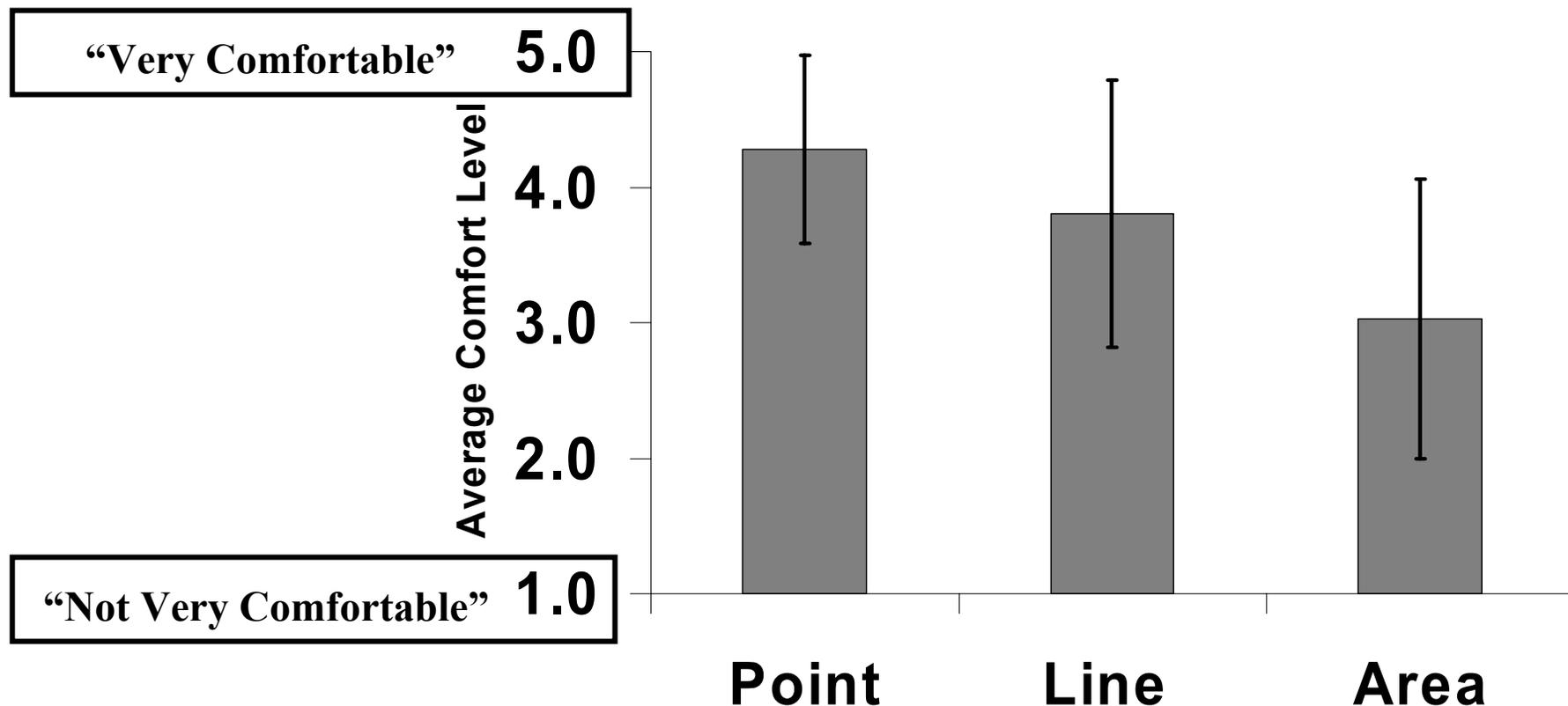
More Errors Occurred in “Area” Scenario

- Missed detections occurred primarily in the “Area” Scenario
- Incorrect identifications occurred primarily in the “Area” Scenario



Subjects are Least Comfortable Identifying Conflicts in “Area” Scenario

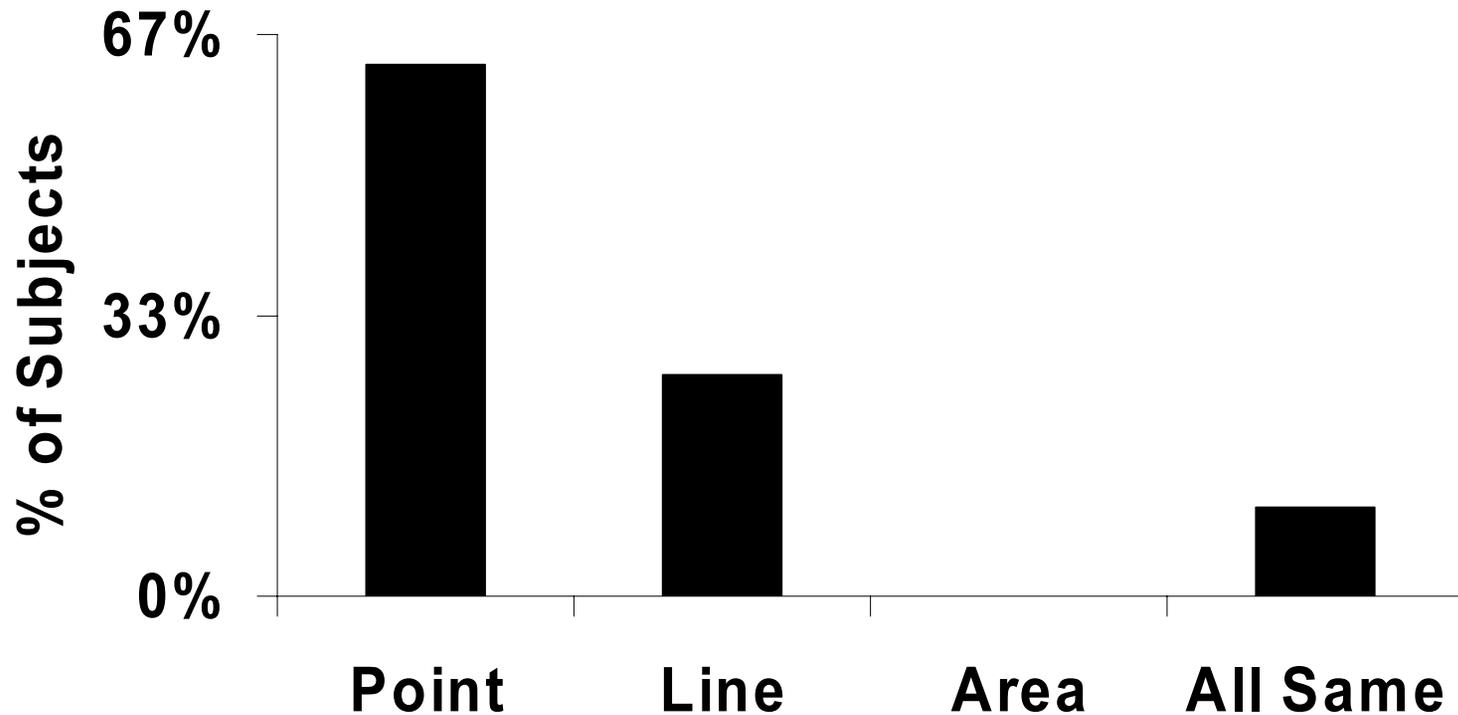
Did you feel you were able to comfortably identify all conflicts in the scenario?





Most Subjects Identified Point Scenario as Easiest

Which scenario did you find it easiest to identify conflicts in?





Subject Comments

- **“Think aloud” protocol**
 - Pair-wise comparisons
 - Grouping / Standard flow indicators
 - o “gap”, “between them”, “through here”
- **What made the hardest scenario difficult?**
 - “Lack of predetermined routes ... Lack of intersection points between possible routes”
 - “Multiple horizontal streams - gives multiple intersection venues. Hard to memorize them and monitor them continuously”
- **What made the easiest scenario easier?**
 - “The intersecting stream structure made it simpler to do.
 - ...Simultaneous near collisions were not possible, so I could pay more attention to the aircraft with near-term possible conflicts.”

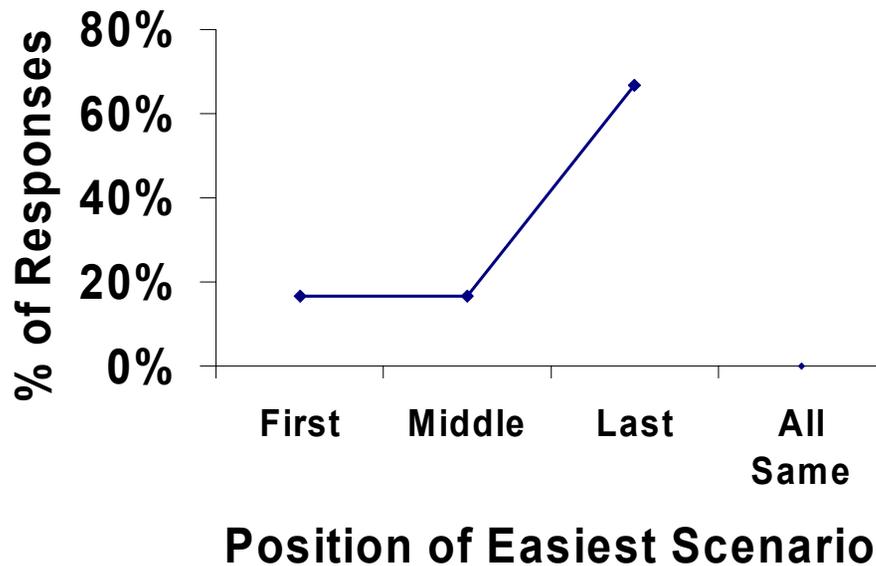


Two Issues Probed Further

- Possible Learning Effect Due to Design of Training
- Characteristics of Individual Conflicts

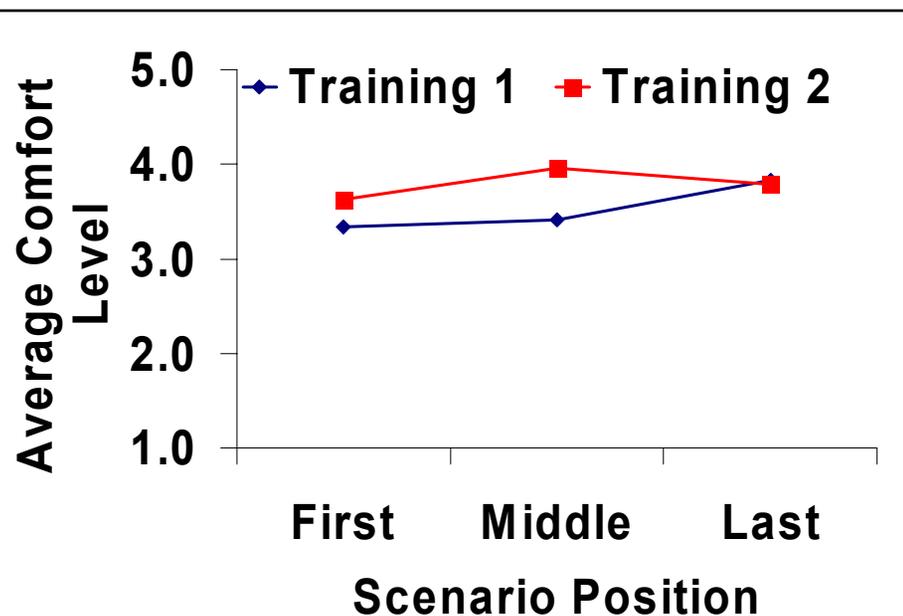
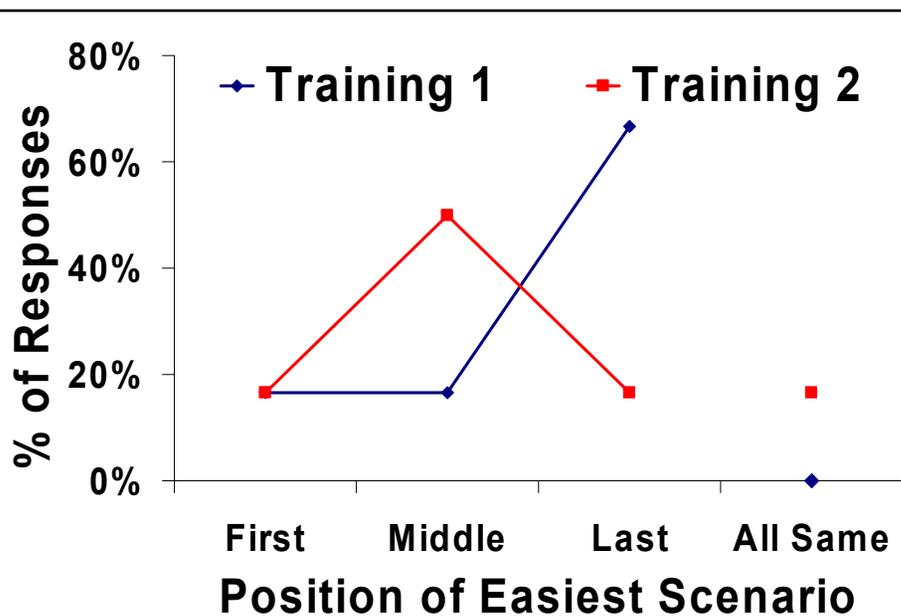
Training Issue

- Previous results encompass entire population of subjects
- Initial group of 6 showed some possible learning effects:
 - Easiest scenario usually identified as “last” scenario
 - Average comfort level slightly higher in last scenario
 - User comments *strongly* suggesting easiest scenario was easier because of experience



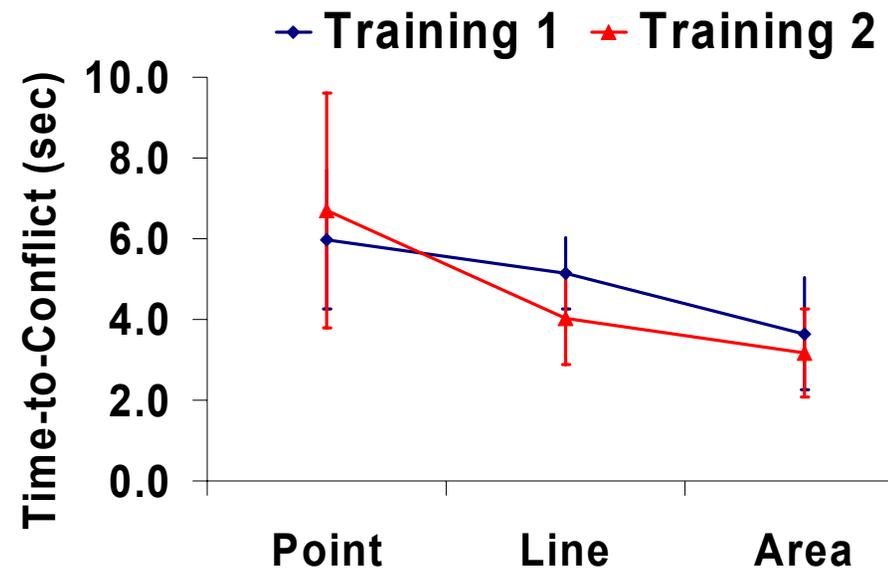
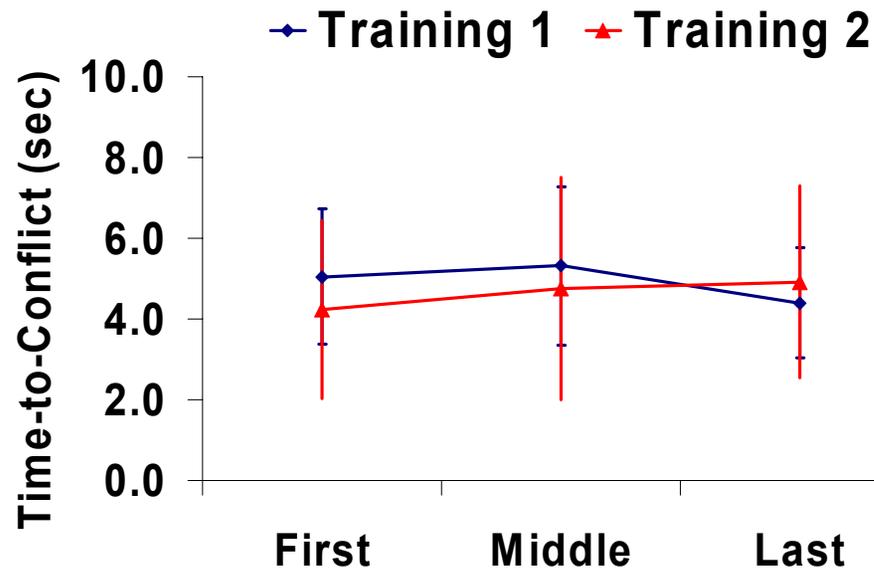
Modifications to Training

- Created new training scenarios:
 - Subjects trained on 14 conflicts (increase from 4)
 - Subjects completed 2 complete practice scenarios (increase from 0)
 - Exposed subjects to all conditions (vs. only point condition)
- New training appears to have changed *perceived* training effect:



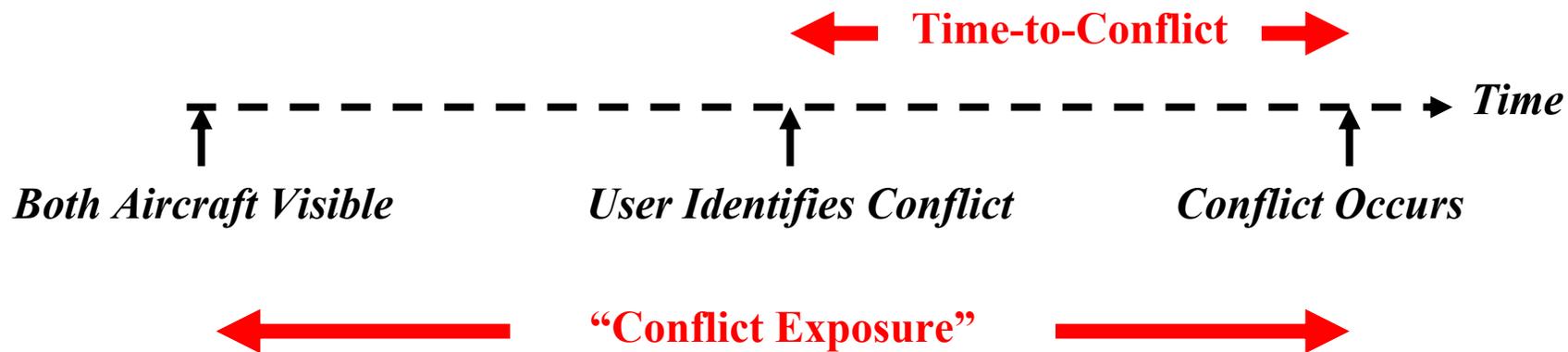
Effect on Performance

- Little change on Time-to-Conflict performance:
- Exposure to Line and Area in training appears to have decreased performance

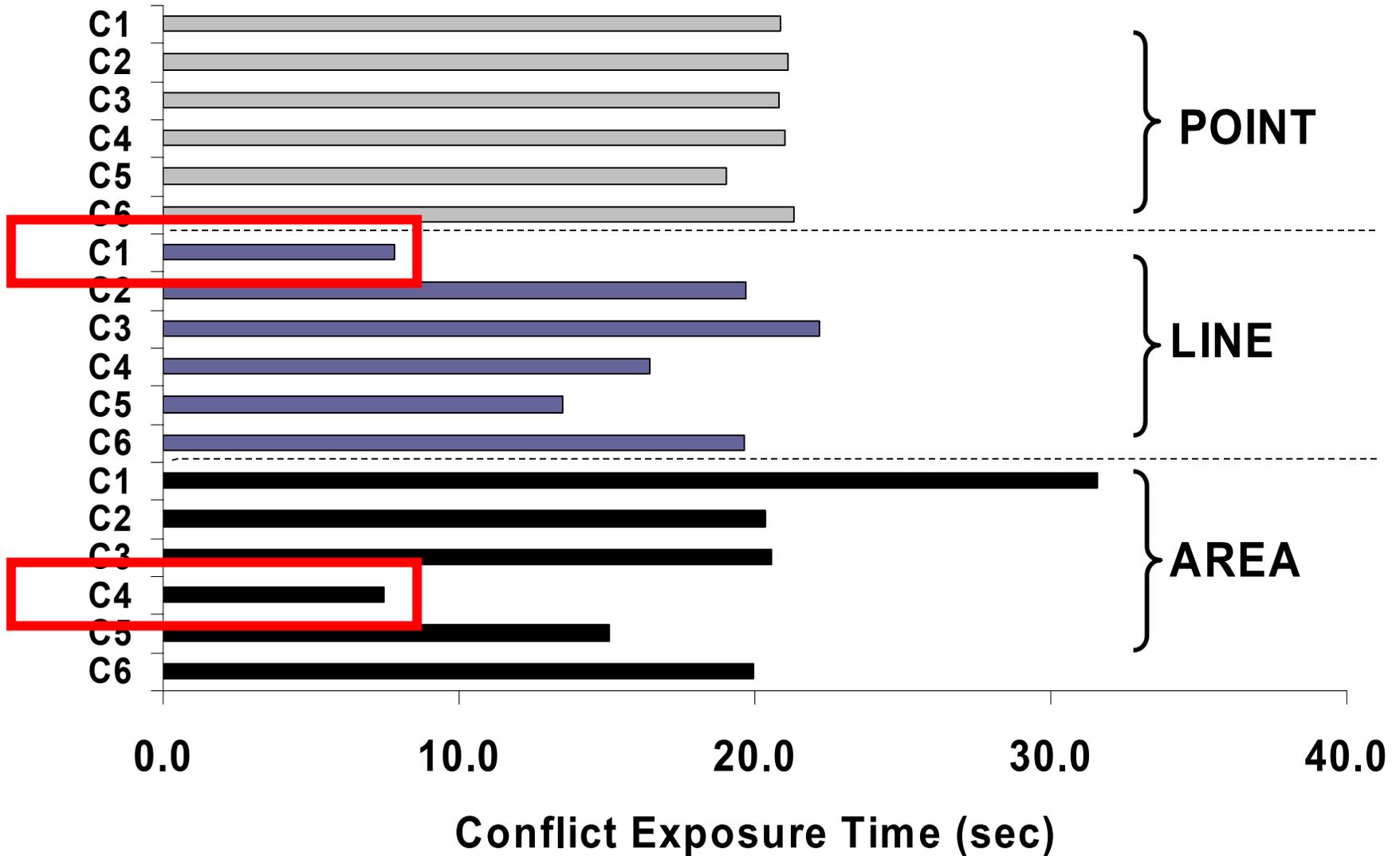




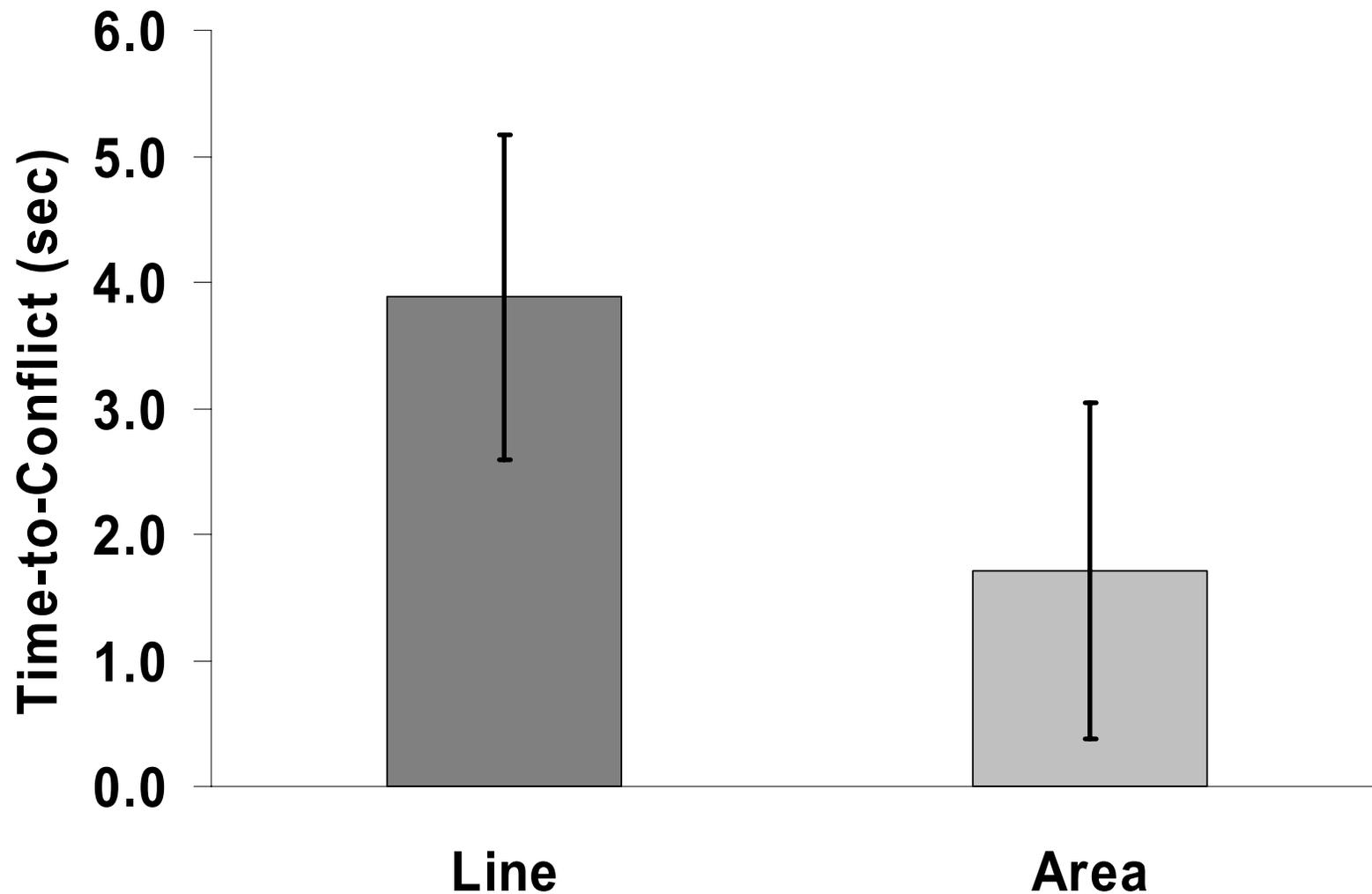
Characteristics of Conflicts: Conflict Exposure Time



Conflict Exposure Times

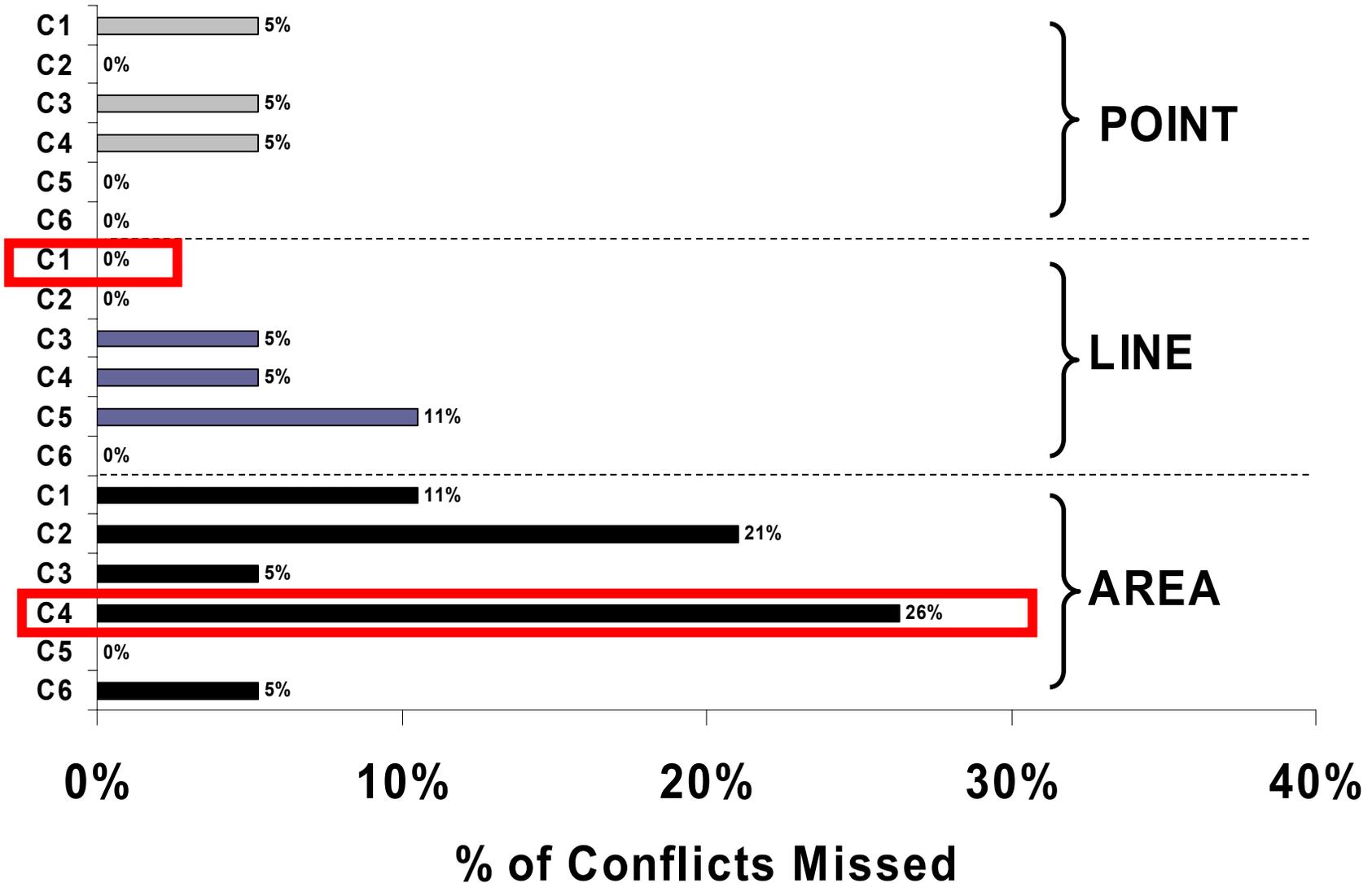


Comparison of “Quick” Conflicts (< 7 sec)





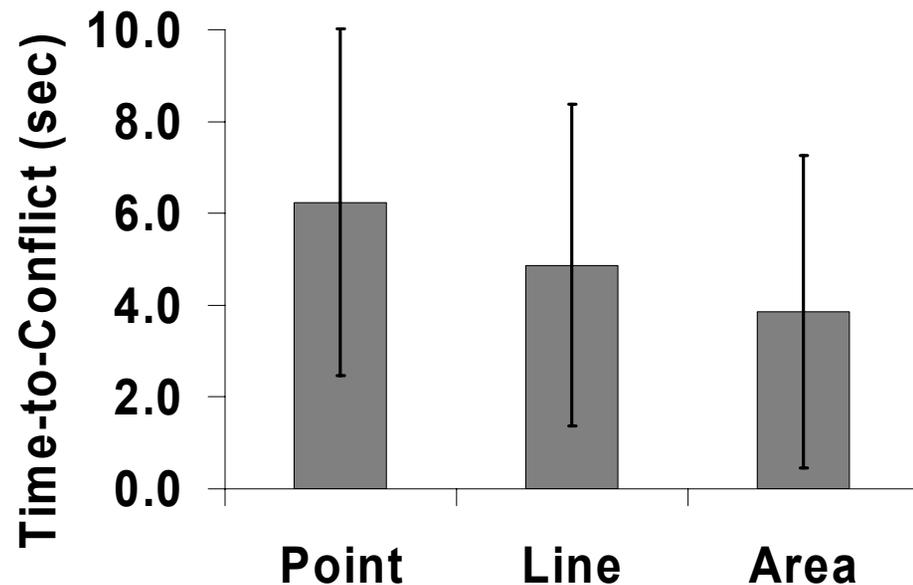
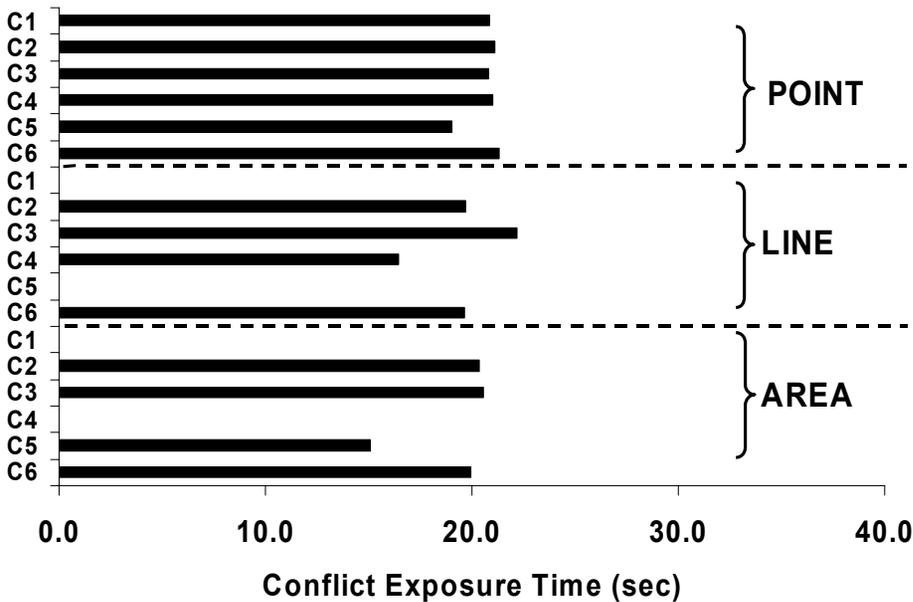
Differences Between “Quick” Line and “Area” Reflected in Error Data



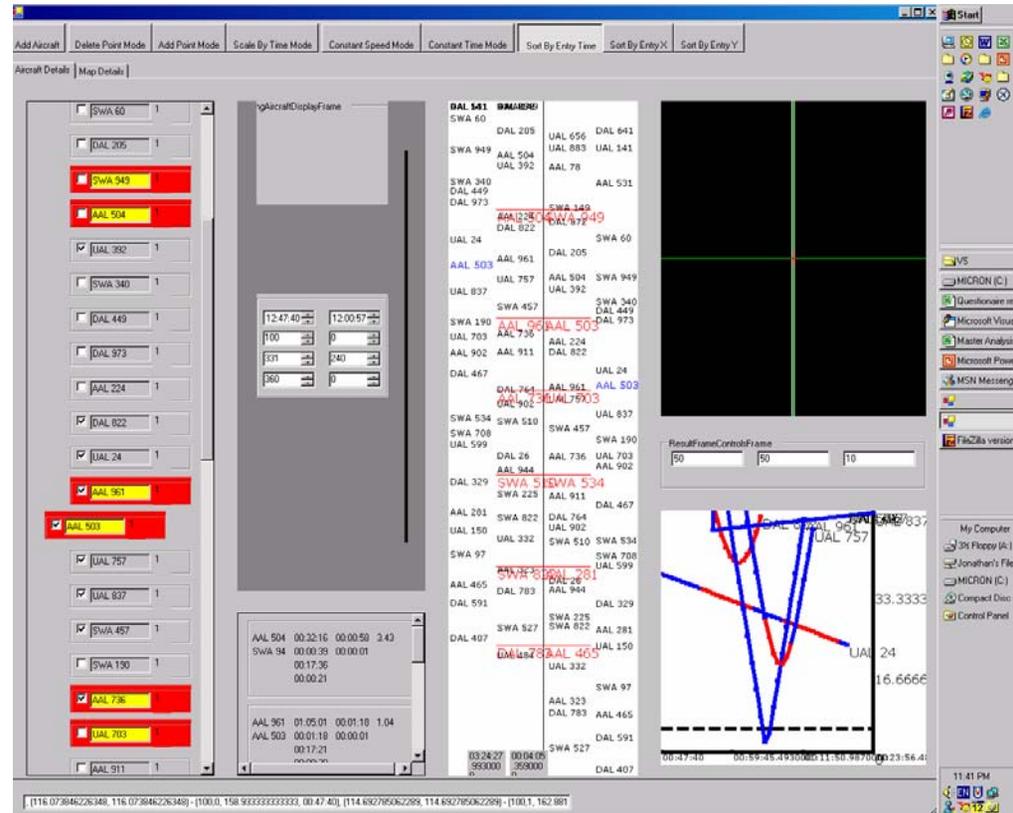
Variance of Conflict Exposure Time Does Not Change Fundamental Result

- Selected only those conflicts with Conflict Exposure Times of 20 +/- 5 sec

- ANOVA still significant at $p < 0.005$



- **Display design issues:**
 - Overlapping data tags
 - Effect of choice of separation standard
- **Experiment design issues:**
 - Importance of pilot testing through statistical analysis
 - Scenario design is difficult!
- **Establishing “equivalency” of scenarios provides insight into characterizing complexity**
 - Categorizing aircraft based on point of closest approach





Summary

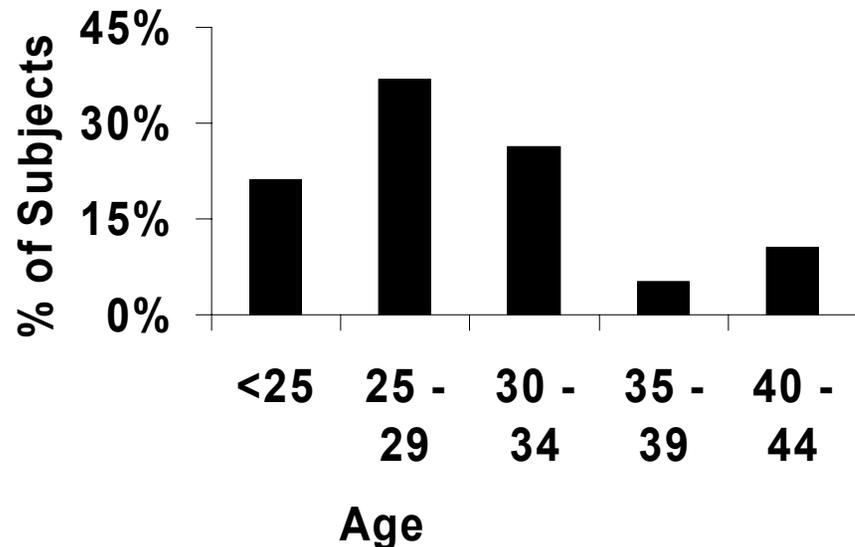
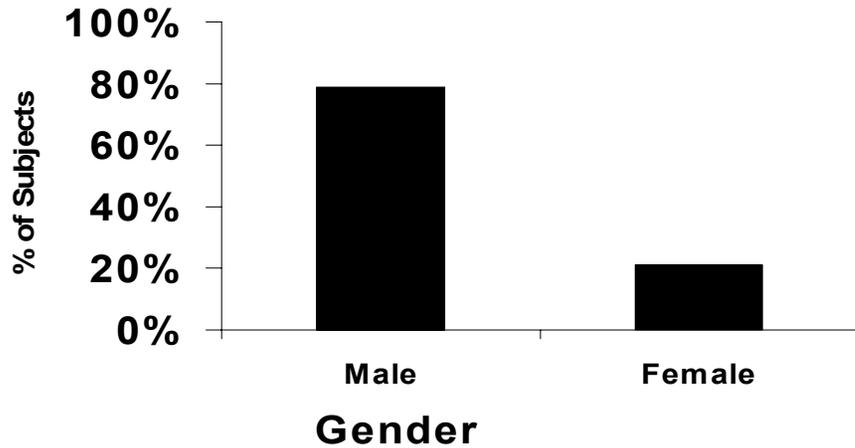
- **Results support hypothesis that problem spaces of fewer dimensions reduce complexity**
 - Performance
 - Subjective assessments
 - User comments
- **Identified and addressed potential learning effect**



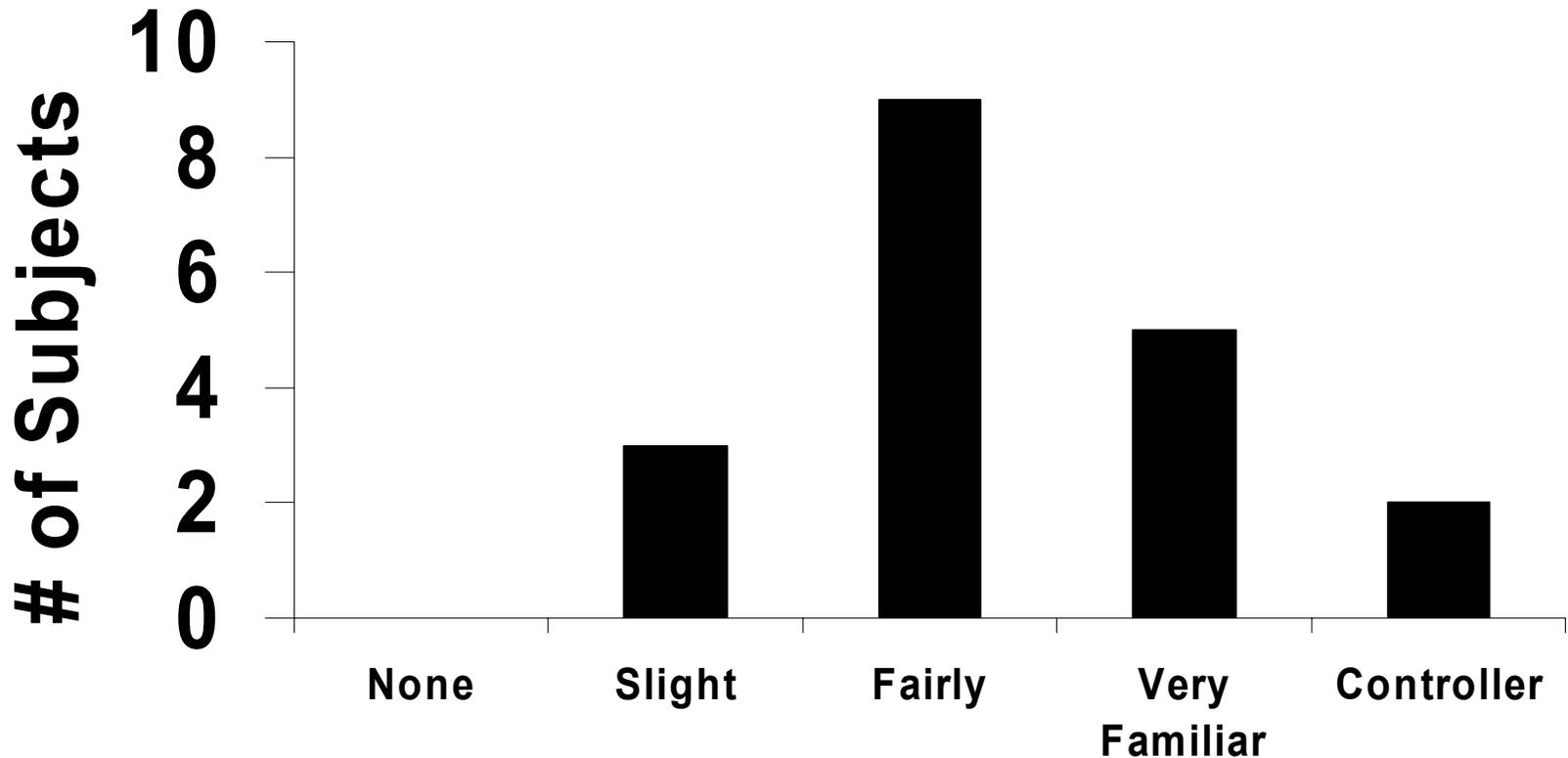
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Backup Slides

15 Participants



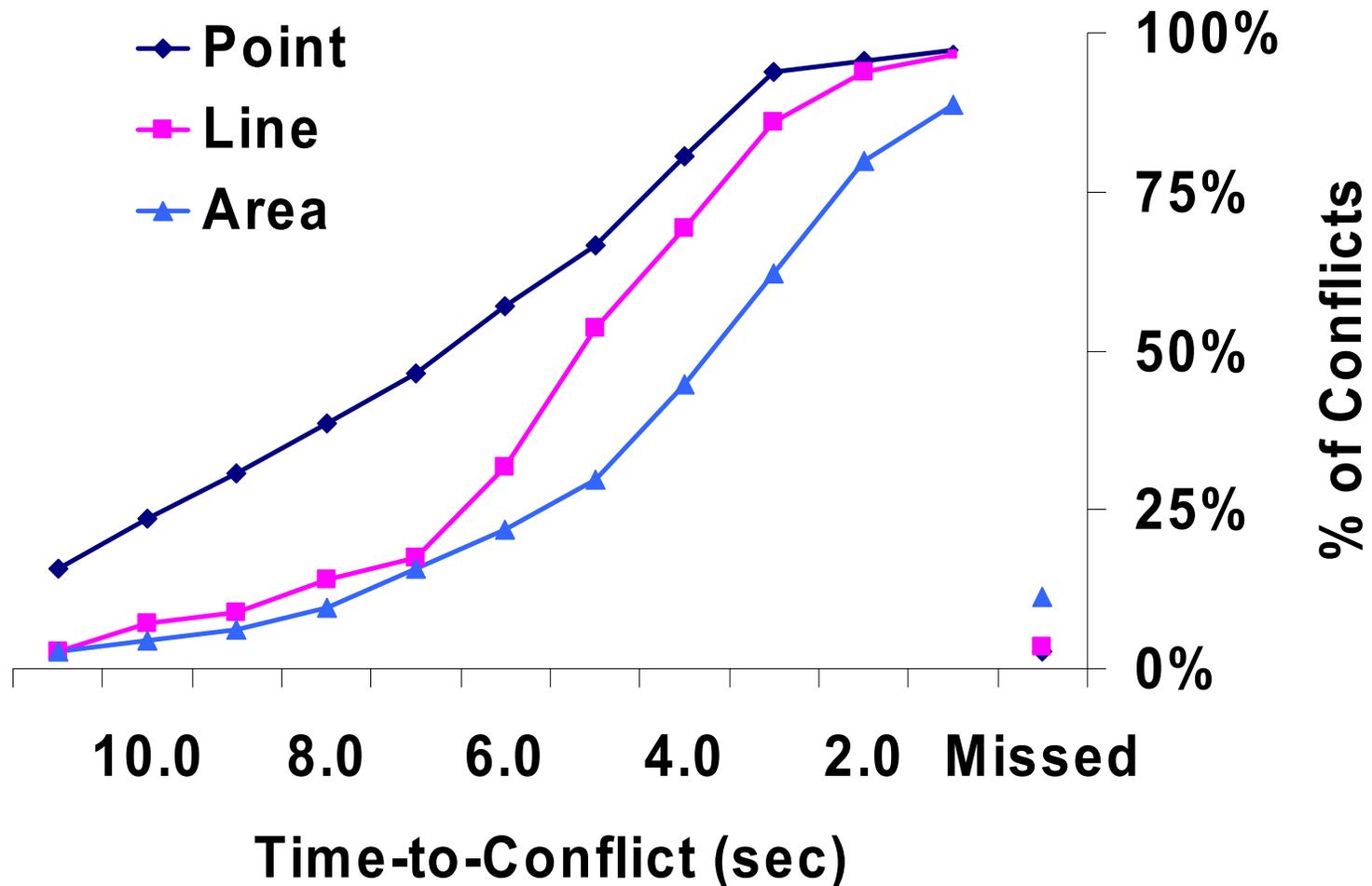
ATC Experience?



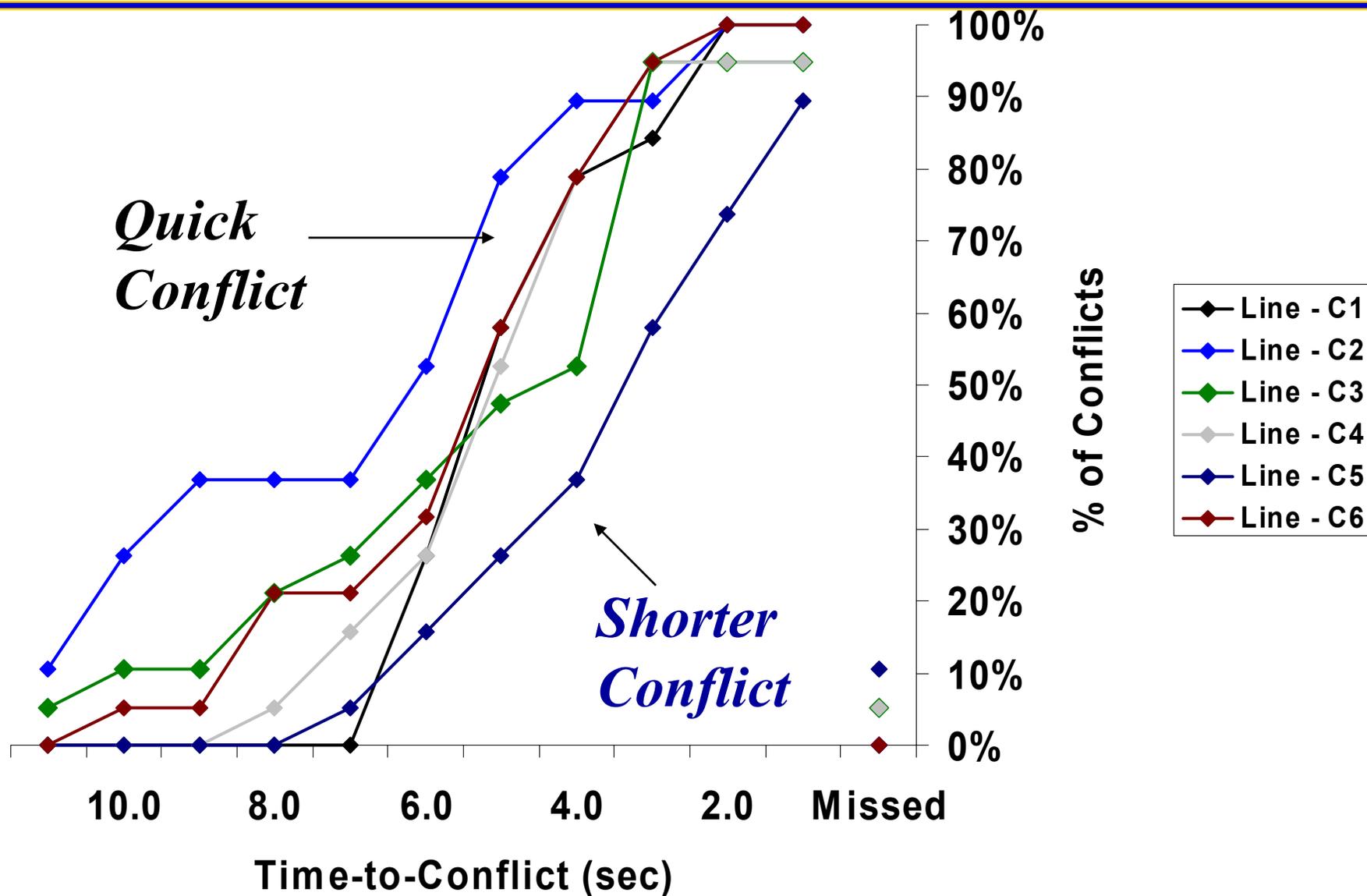
How Familiar with ATC Concepts and Typical Operating Procedures Are You?

Differences Clearer in Cumulative Distributions

- How many conflicts were identified by “at least” this much time prior to the conflict?

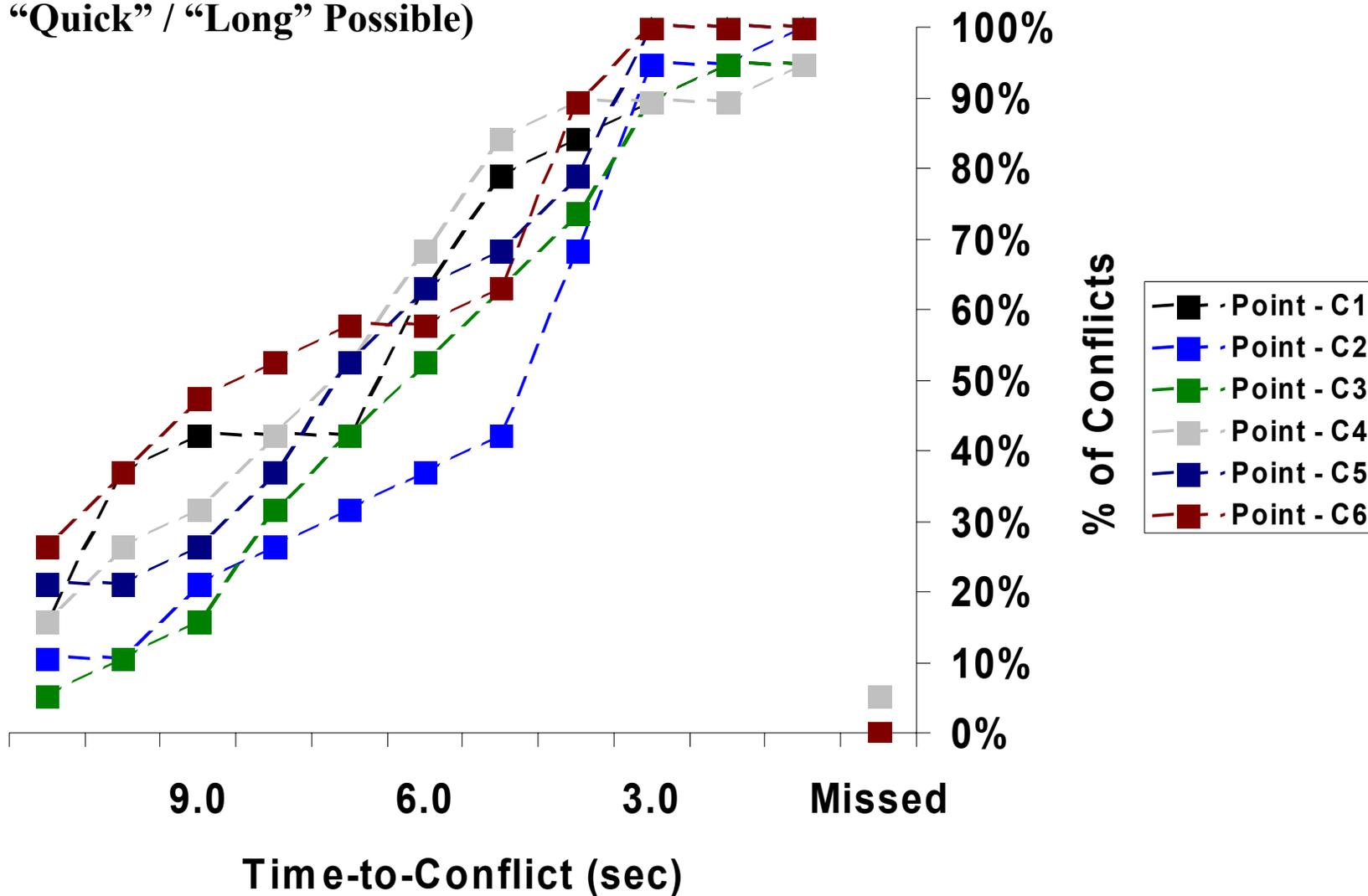


In Line, Quick Conflict is Unremarkable

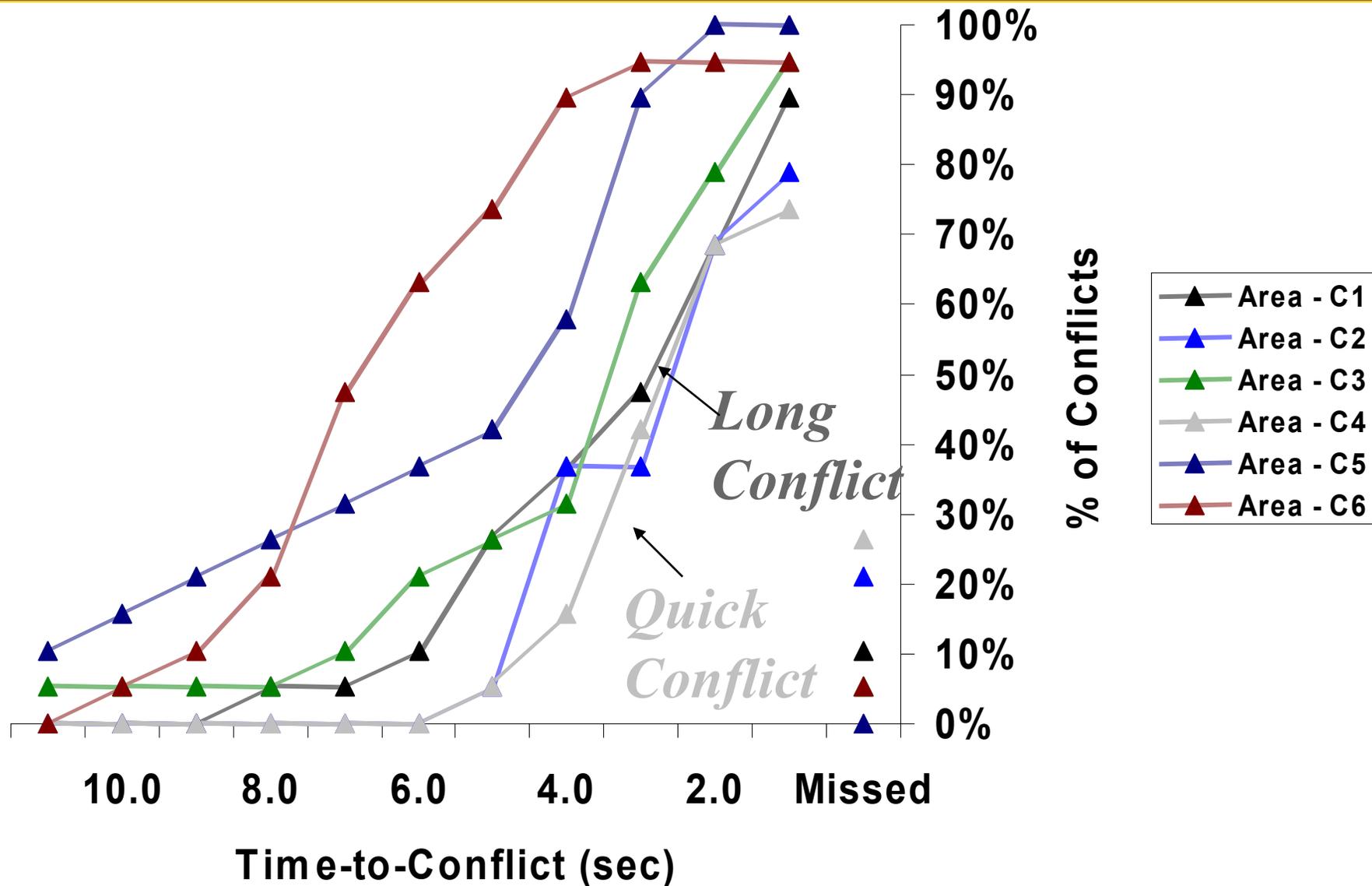


“Point” Conflicts Very Consistent

(No “Quick” / “Long” Possible)

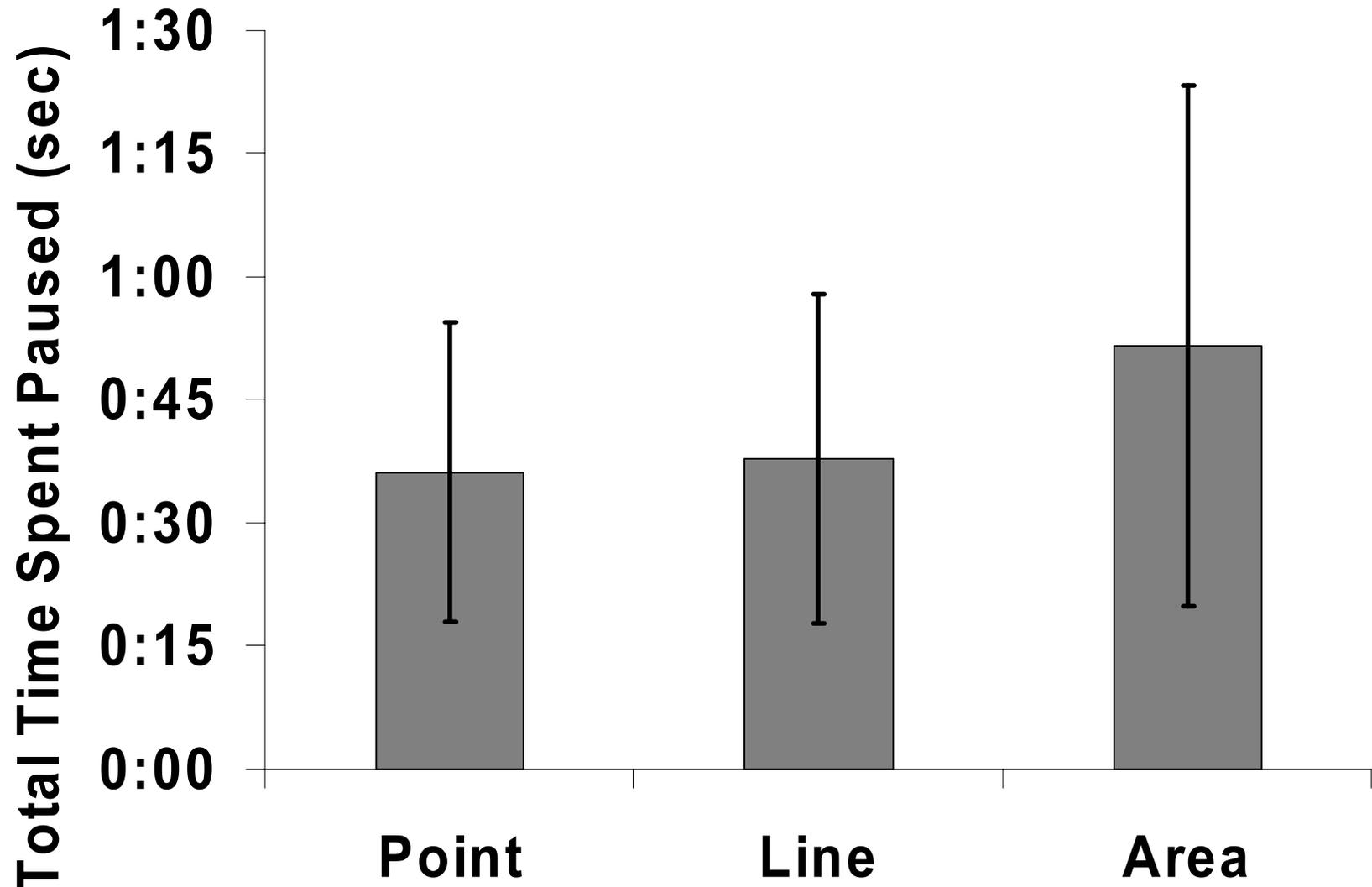


In "Area", Both Quick and Long Conflicts Were Among Worst Performance



Total Time “Paused” Indicates Less Confidence in Selections in “Area” Scenario

Not Statistically Significant at $p < 0.10$



Time-to-Conflict Data was Inconclusive

