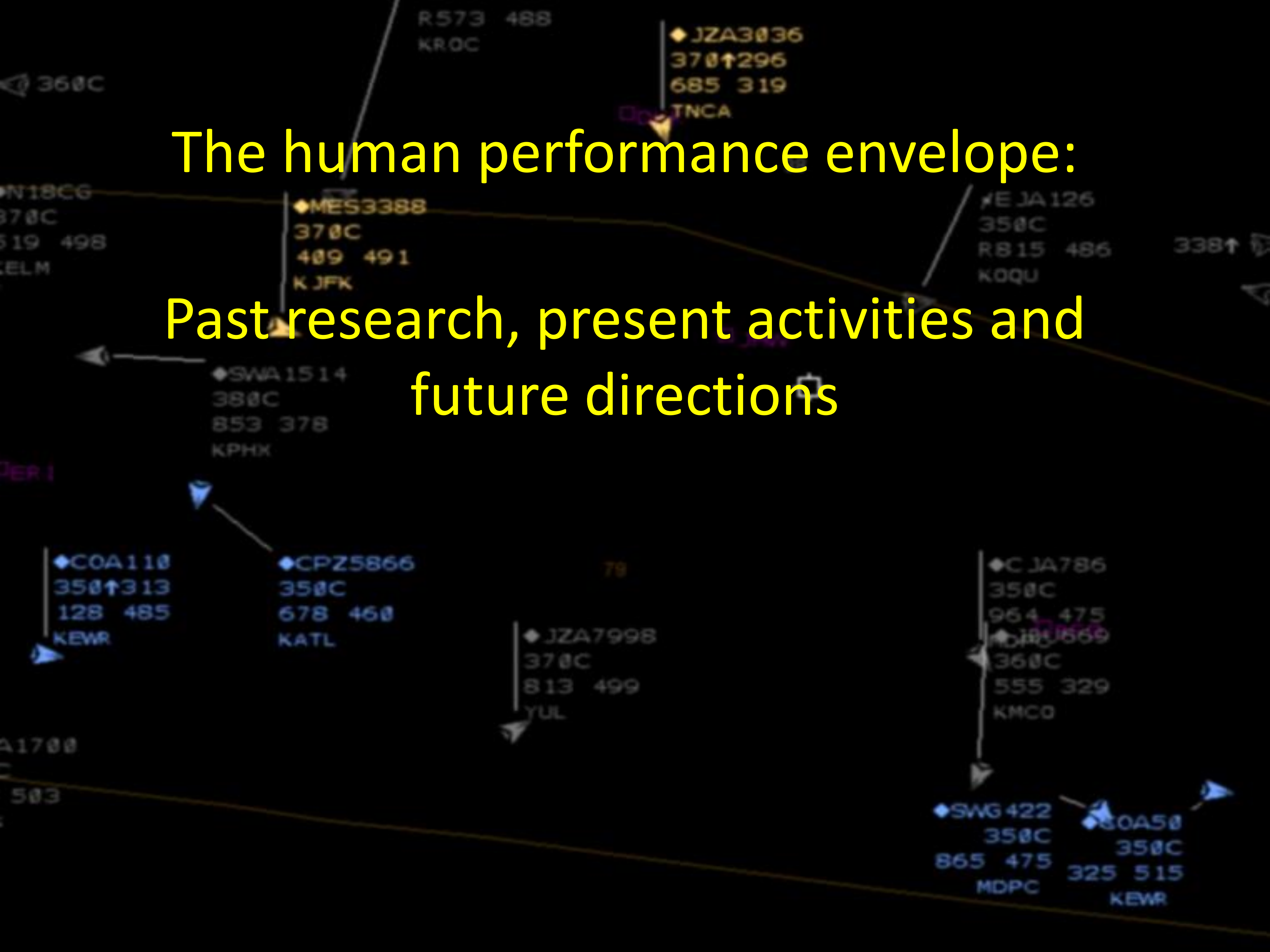
The human performance envelope:

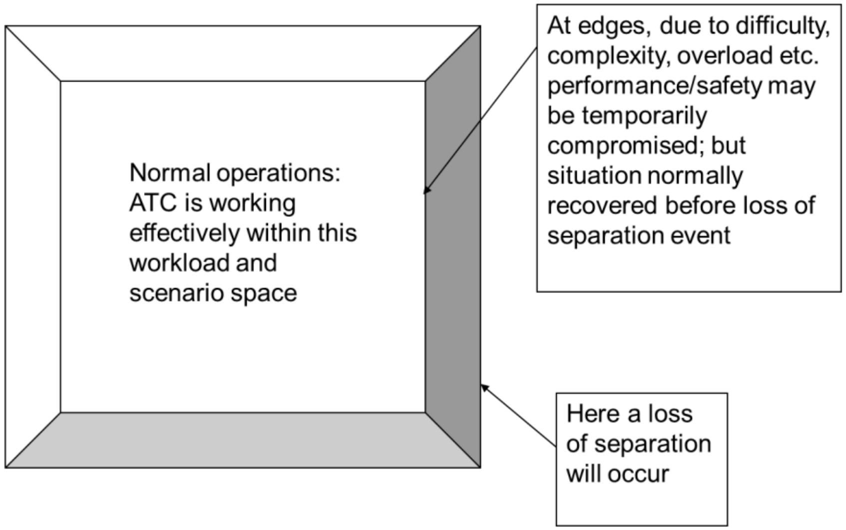
Past research, present activities and future directions

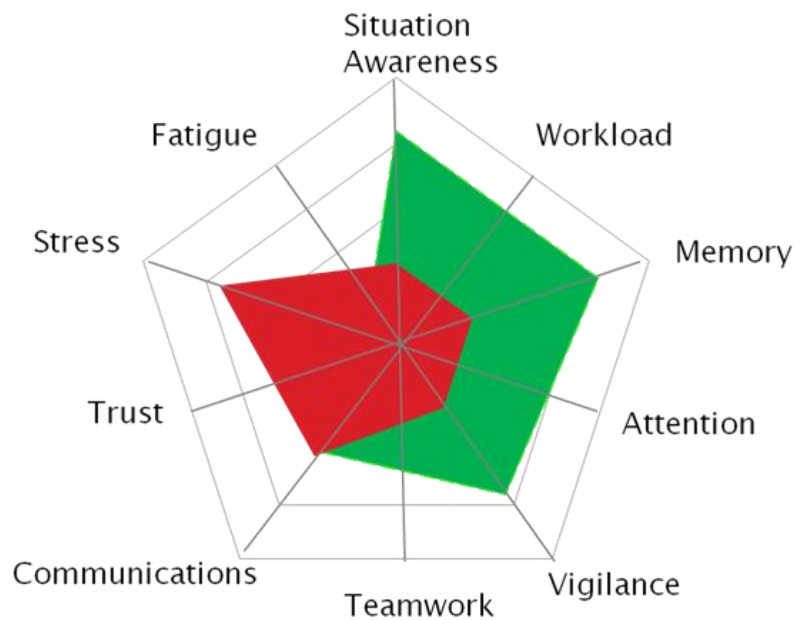


Agenda

- Human performance envelope?
- Past research:
  - Research motivation & overview
  - Initial findings
- Present activities: Confirmation and extension
  - What happens when controllers are working with automation? Overview
- Future directions
- Conclusions
- Applications

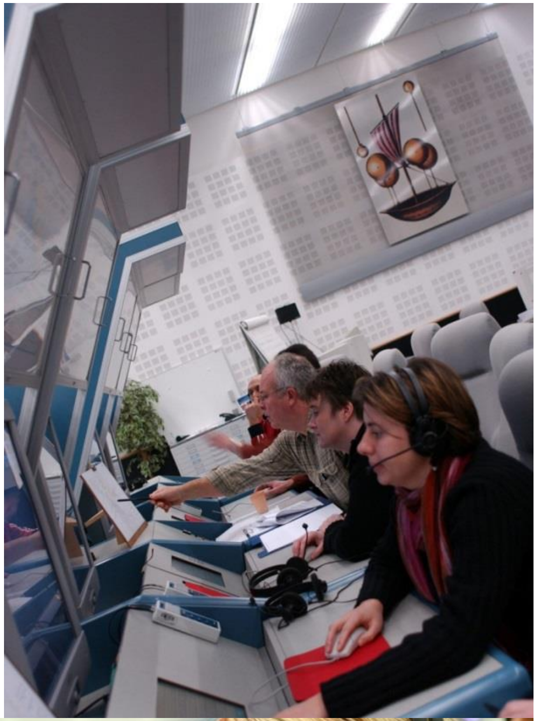
Human performance envelope





Motivation

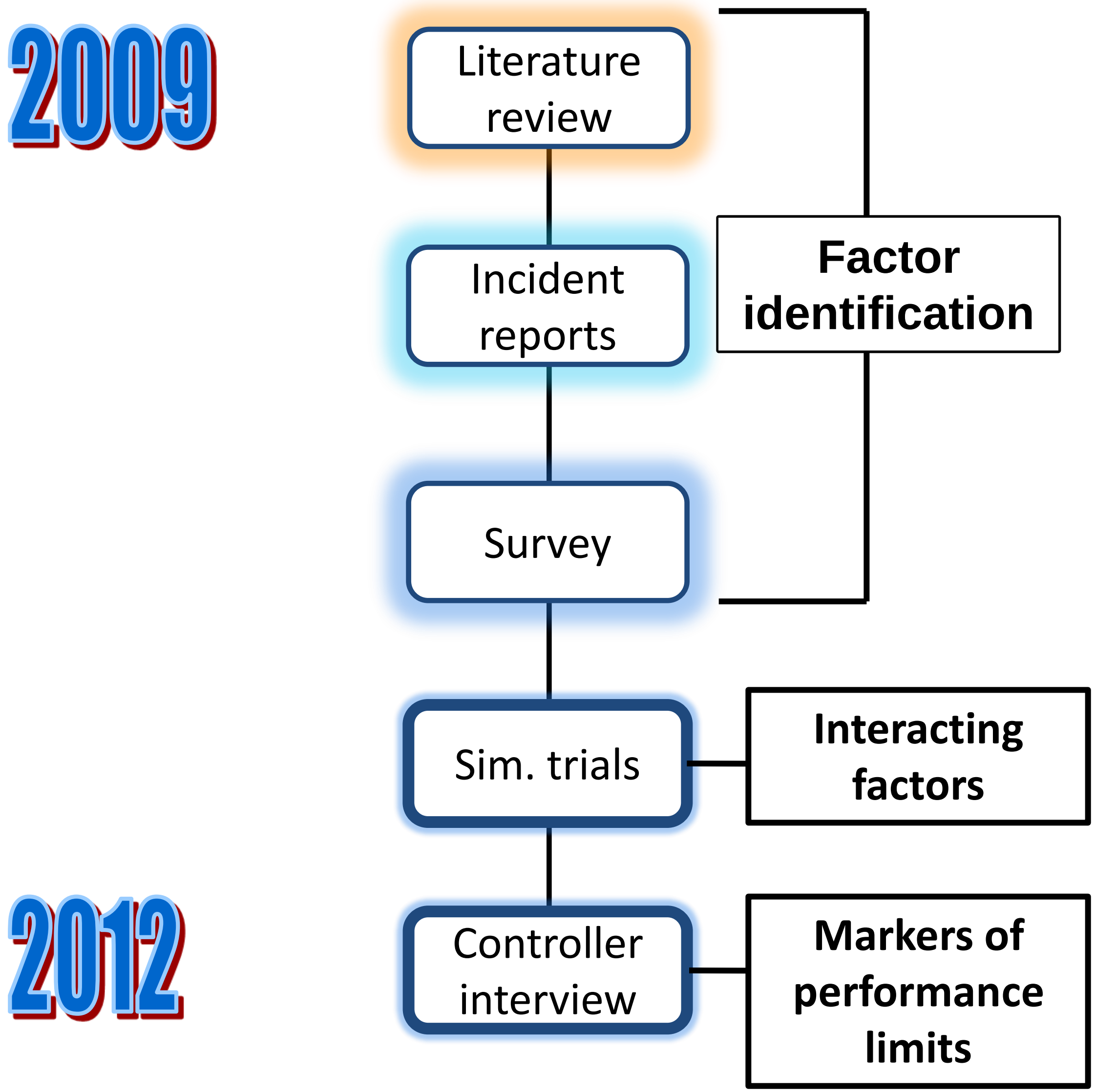
- ATM is an ‘ultra-safe’ industry
- ATM remains highly ‘human-centric’ – real-time operations
- Mitigations defend against incidents, but still occur
- Need to know when controllers are approaching the edges of acceptable performance



Research overview

- Overall Aims
  - Identify factors
  - Identify and verify interactions that threaten performance
  - Develop markers of performance limits or boundaries
- Potential Outcomes
  - Better understanding of ‘difficult’ human performance factors in Air Traffic Control (ATC)
  - Signs and symptoms that performance is threatened

Study approach



Method: ATC exercise

- Design

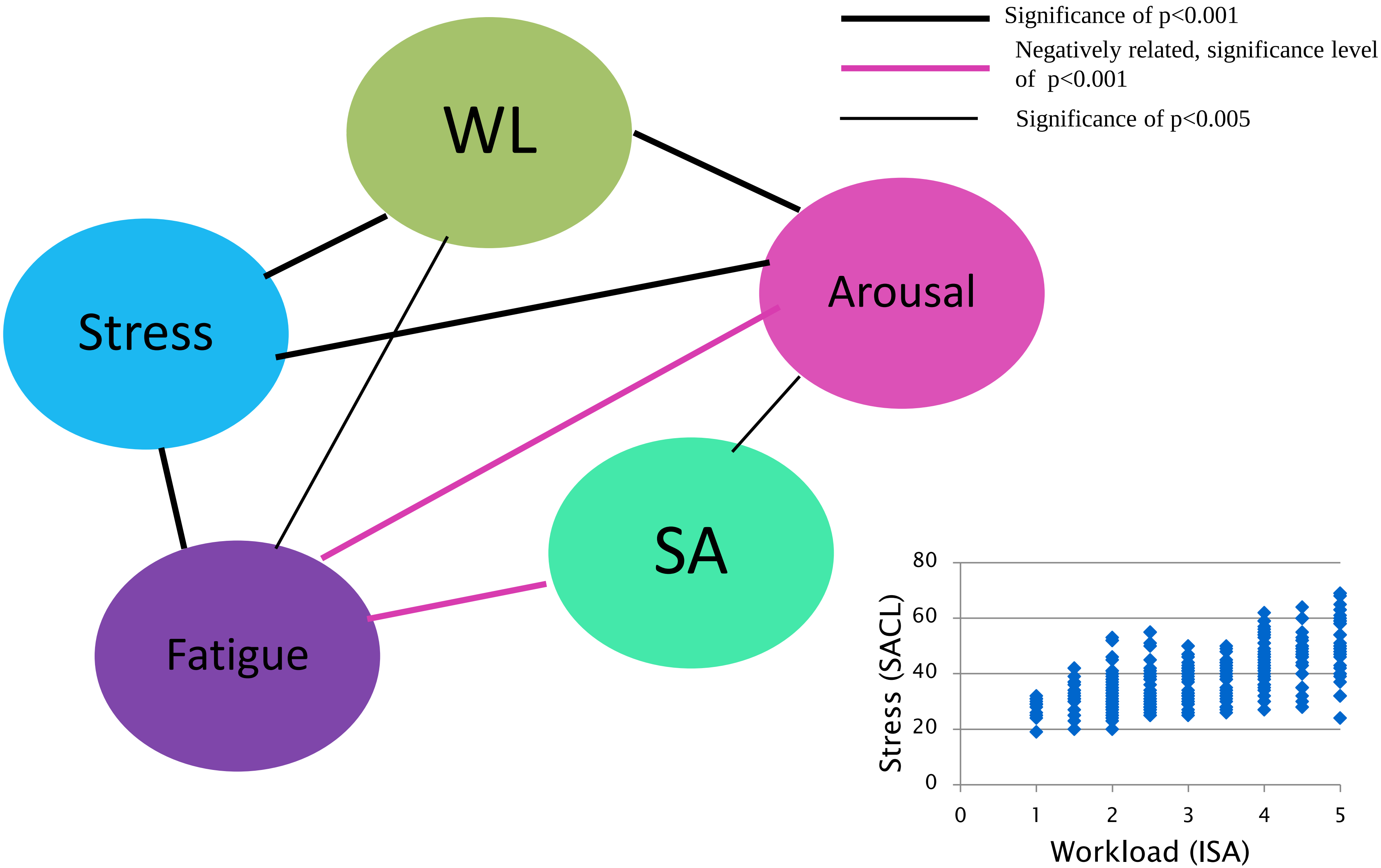
IV: Taskload (low/high) → **Covariates:** Arousal, Fatigue, SA, Stress, Workload → **DV:** (Performance): STCA, route directs, time to respond

- Measures

Covariate	Arousal	Fatigue	SA	Stress	WL
Measure	Stress-Arousal Check List	Visual Analogue	Situation Present Assessment Method	SACL	Instantaneous Self Assessment
Interval (Mins)	20	20	4	20	4

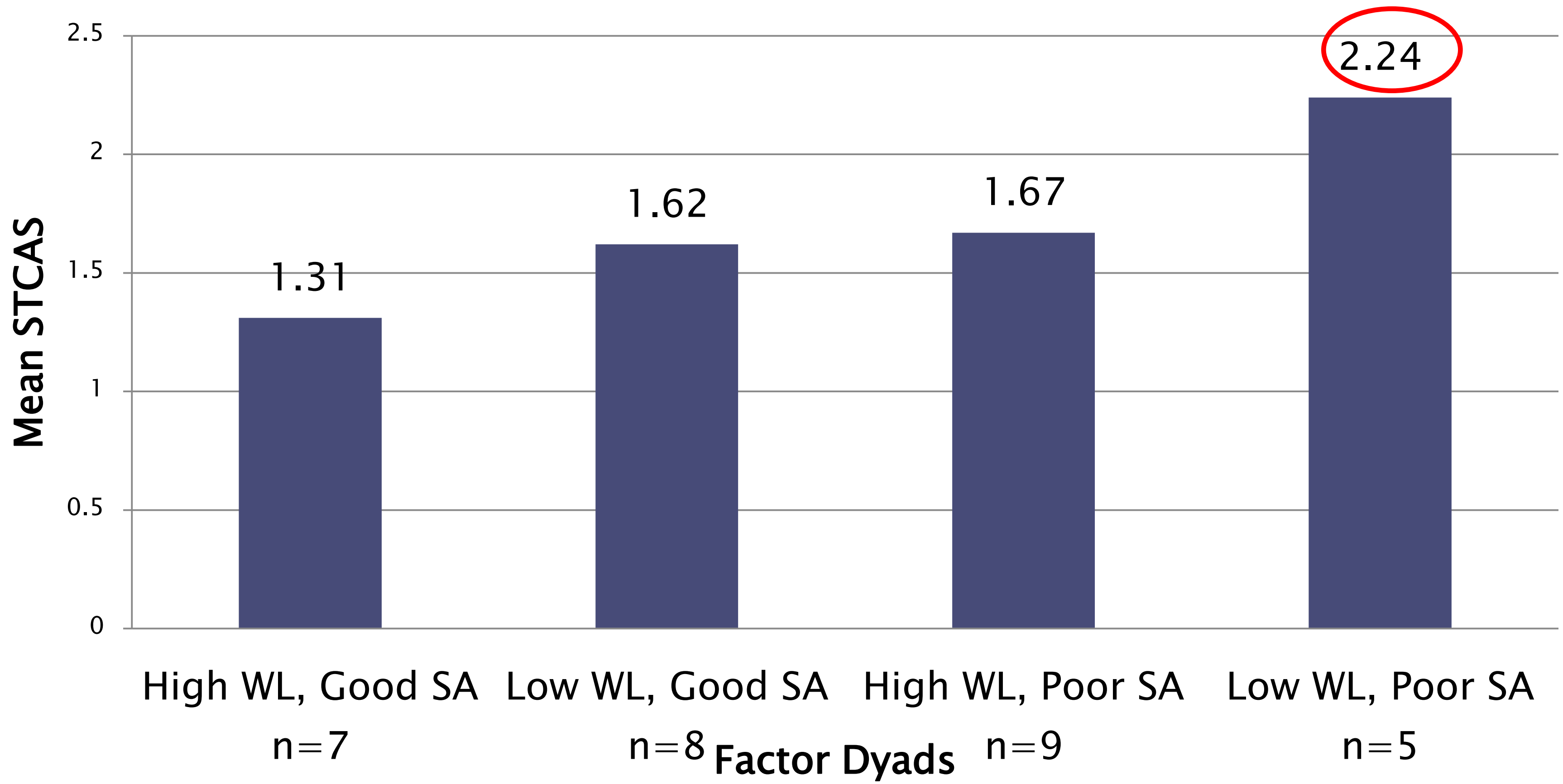
- Participants
  - ❑ 29 male students aged between 18-30
  - ❑ All received a 4 hour training session
  - ❑ Score of ≥80% on a simulation-related competency test

Results: Factors occur together

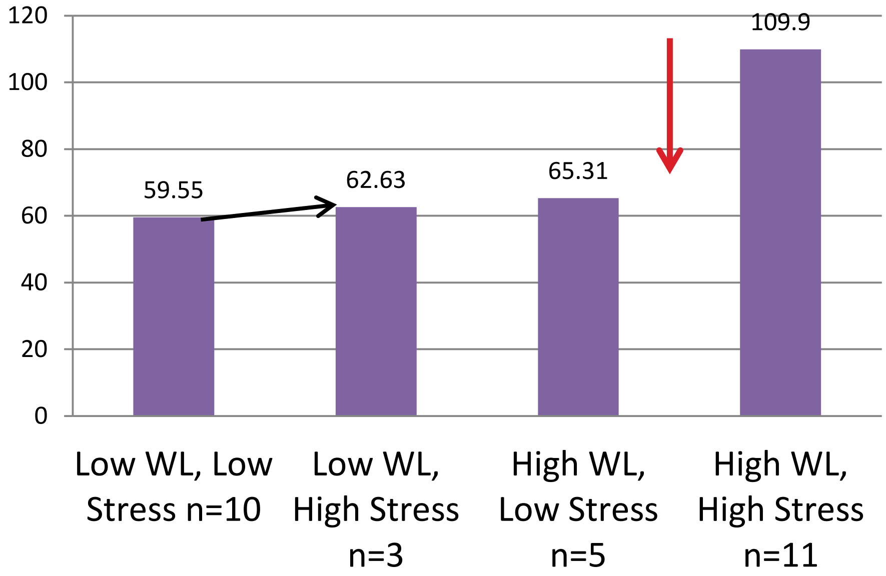


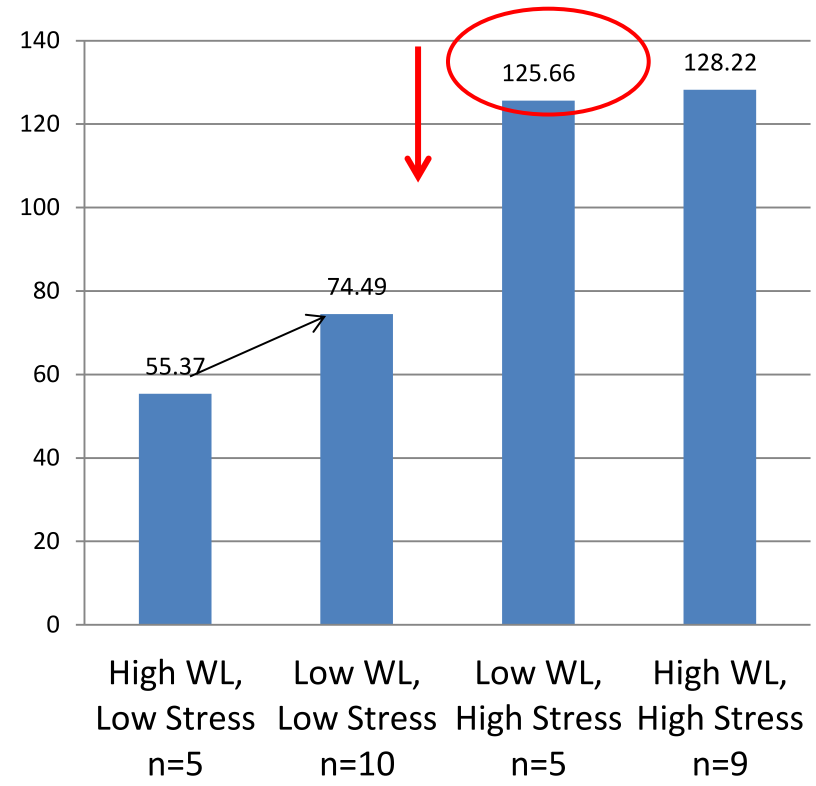
Results: Co-occurring factors-a cumulative effect?

- Factors may combine in a cumulative way and associate with poorer performance



Results (2) Time on task: Less resilient performance





Behavioural markers of performance limits

- Apparent link between some behaviours and self reported measures
  - Example: Indicators associated with fatigue
    - Yawning
    - Looking away from screen
    - Posture changes

- Interviews
  - 22 ATCOs took part (17 males, 5 female)
  - What markers have you used that informed you about your performance?

Edwards et al., 2014

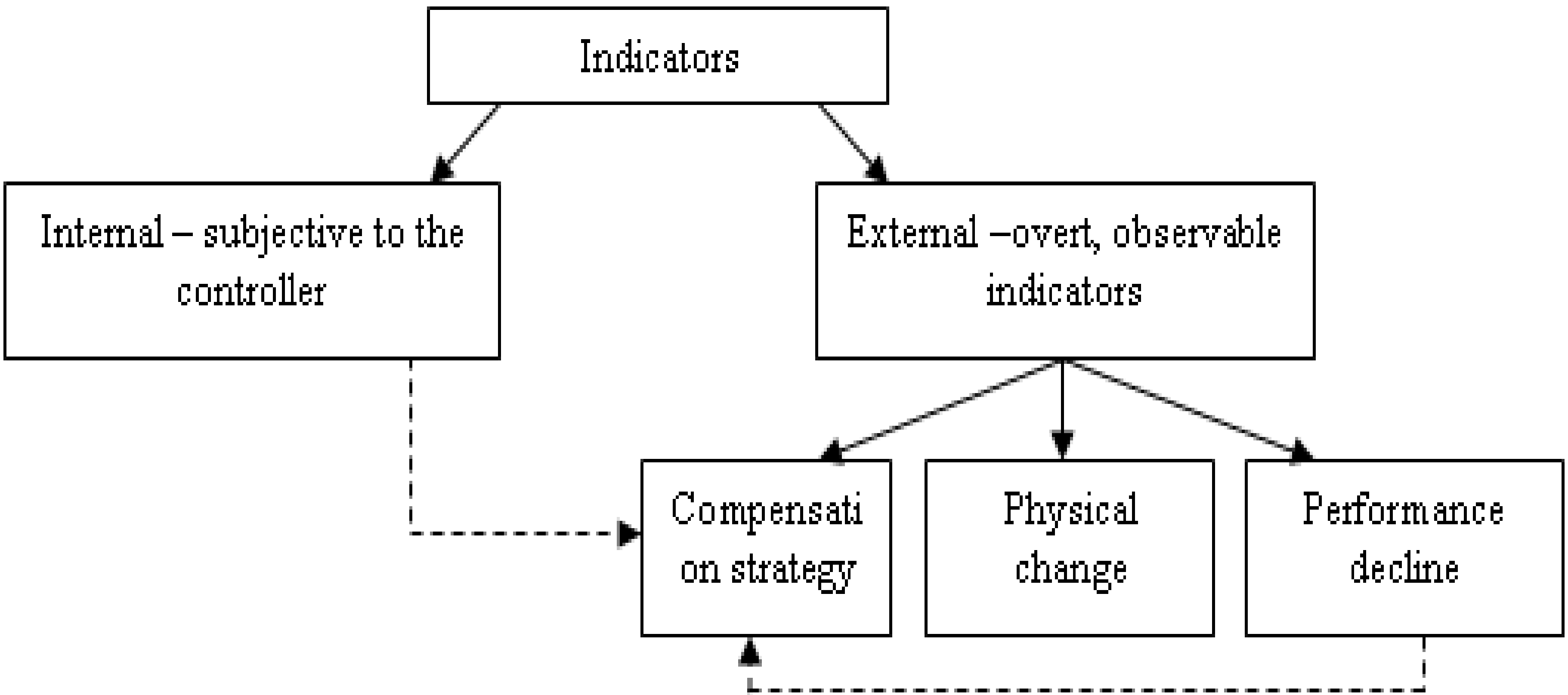
Key findings

- Controllers use internal and external markers

" If someone's getting stressed they can get louder or sit closer to the screen or something so if you see these things then you pay more attention yourself."

Edwards et al., 2014

Markers are used to indicate edges of performance



Key findings

- Controllers use internal and external markers
- Markers are similar between controllers

Edwards et al., 2014

Key findings

- Controllers use internal and external markers
- Markers are similar between controllers
- Developed from experience

“You start to know that you’ve been burning your fingers before on this kind of situation and you really have to pay attention”

Edwards et al., 2014

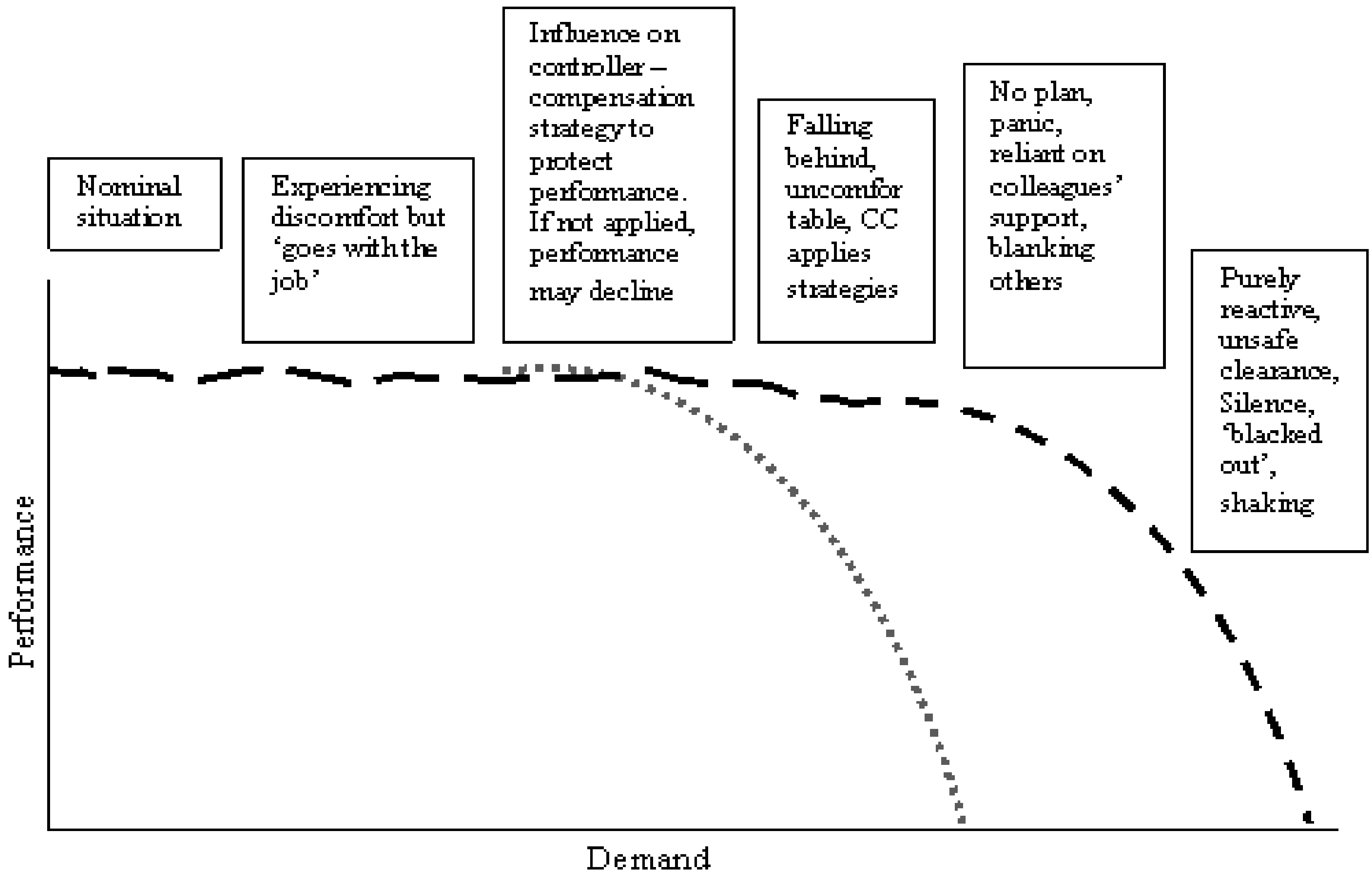
Key findings

- Controllers use internal and external markers
- Markers are similar between controllers
- Developed from experience
- Markers are used to support performance

"I'd say 300%, if you know that you're not being top performing today then that's fine, just adapt your working style. But if you don't know it, it might end in tears"

Edwards et al., 2014

Key findings (2) Markers are used to support performance



Edwards et al., 2014

Conclusions at the end of this research…

- Multiple factor relationships:
  - Multiple factors co-occur to influence controller performance
  - Interactions between factors may create a cumulative influence on performance
  - But limitations of study challenge generalisability of results

- Behavioural markers:
  - Markers indicate limits of performance
  - Controllers use markers to support performance

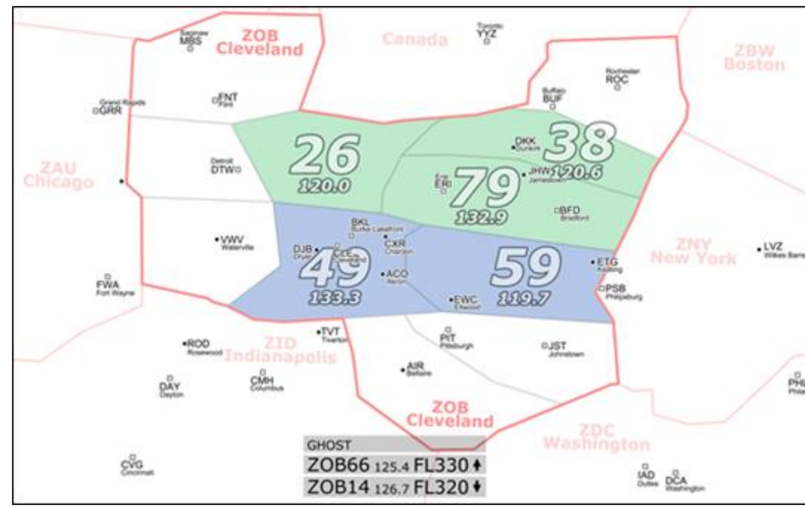
Edwards et al., 2014

Research overview

- Overall Aims
  - Identify the effect of automation in the ATC task on:
    - Workload
    - SA
    - Performance
  - Identify and verify interactions that threaten performance
- Potential Outcomes
  - Better understanding of ‘difficult’ human performance factors in Air Traffic Control (ATC)
  - Signs and symptoms that performance is threatened

Method: Simulation

- Human in the loop, en-route high fidelity simulation (Part task)
  - Single high-altitude sector in Cleveland ARTCC (79)
  - Mix of level flight and
    transitioning aircraft
  - No winds
  - All aircraft CPDLC equipped
  - All aircraft FMS and ADS-B equipped



Method: Design (1)

- Within subjects design
- Conducted as part of a larger study
- 4 task sets, Decreasing levels of automation:
  - Task set 1: Conflict detection only (CD)
  - Task set 2: Conflict detection and routine tasks (CD+RT)
  - Task set 3: Conflict detection, coordination and pilot requests – decision making (CD+DM)
  - Task set 4: Conflict detection, routine tasks, coordination's and pilot requests (CD+RT+DM)
- Conflict probe running, but hidden

Method: Design (2)

- Measures:

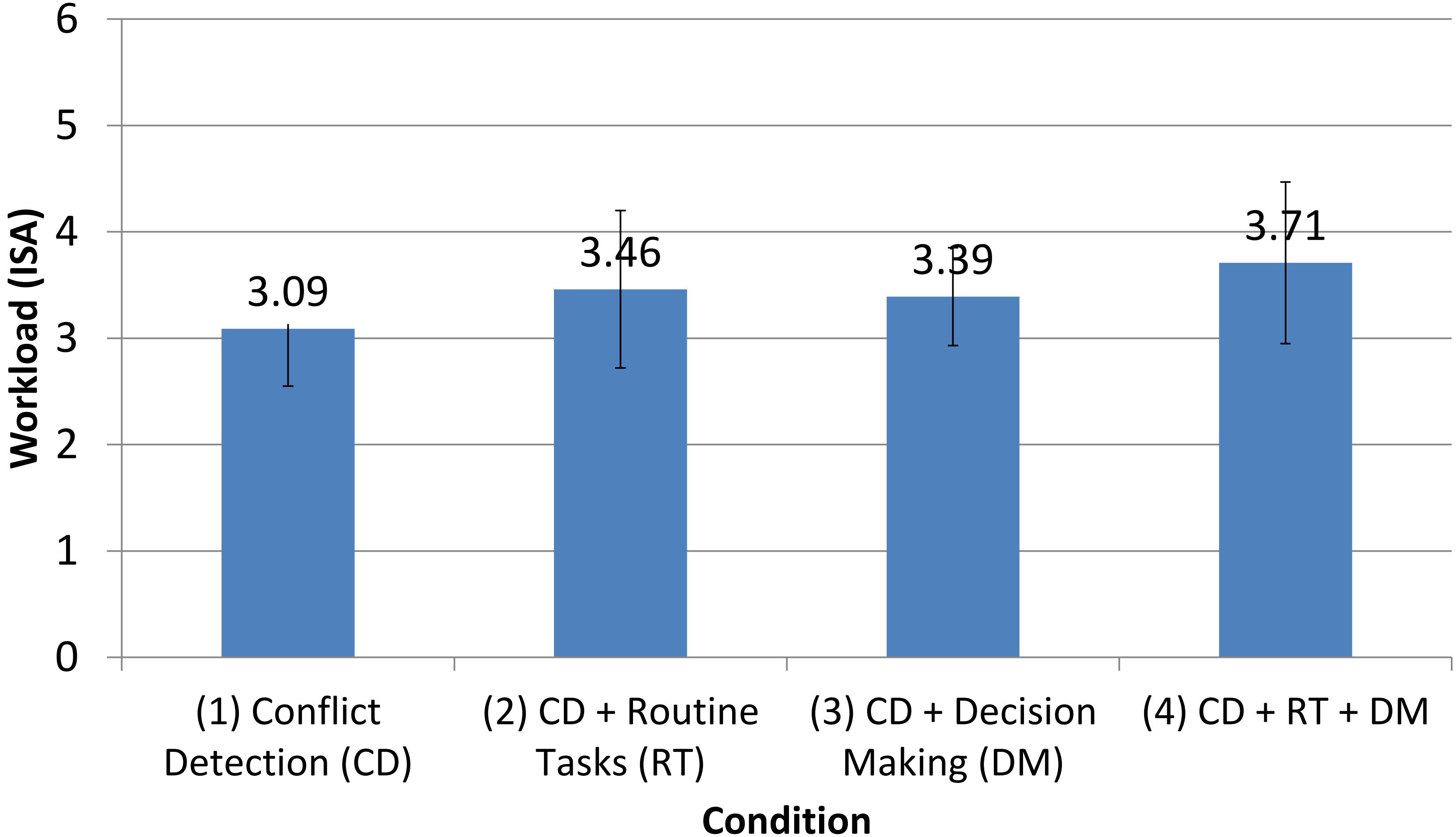
Variable	Workload	SA	Performance
Measure	ISA	SPAM	Time to correctly detect conflicts
Interval (Mins)	3	3	Continuous

- Participants
  - 8 retired controllers from ZOA staffing the test sector
  - Age range 50-69
  - Experience in en-route ATC ranged from 23 – 29.5 years (M=24.94 SD=2.54)

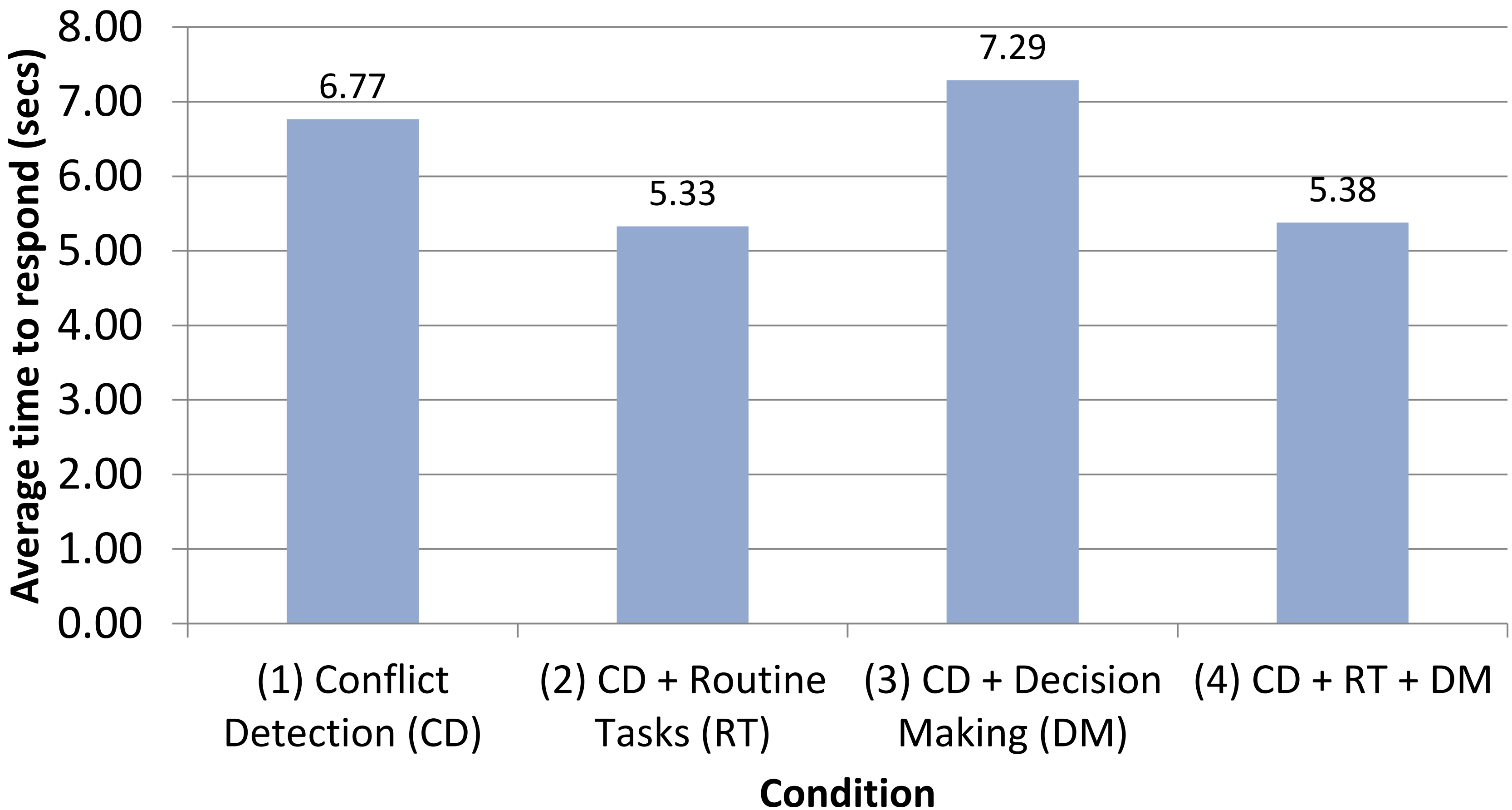
Results

- Workload significantly different between conditions
  - Task 1 – lowest workload
  - Tasks 2 and 4* highest
- SA response times significantly different between conditions
  - Times slowest task 1 and task 3
  - Fastest task 2* and task 4
- Time to detect conflicts significantly different between conditions
  - Slowest in task 1, fastest in task 2

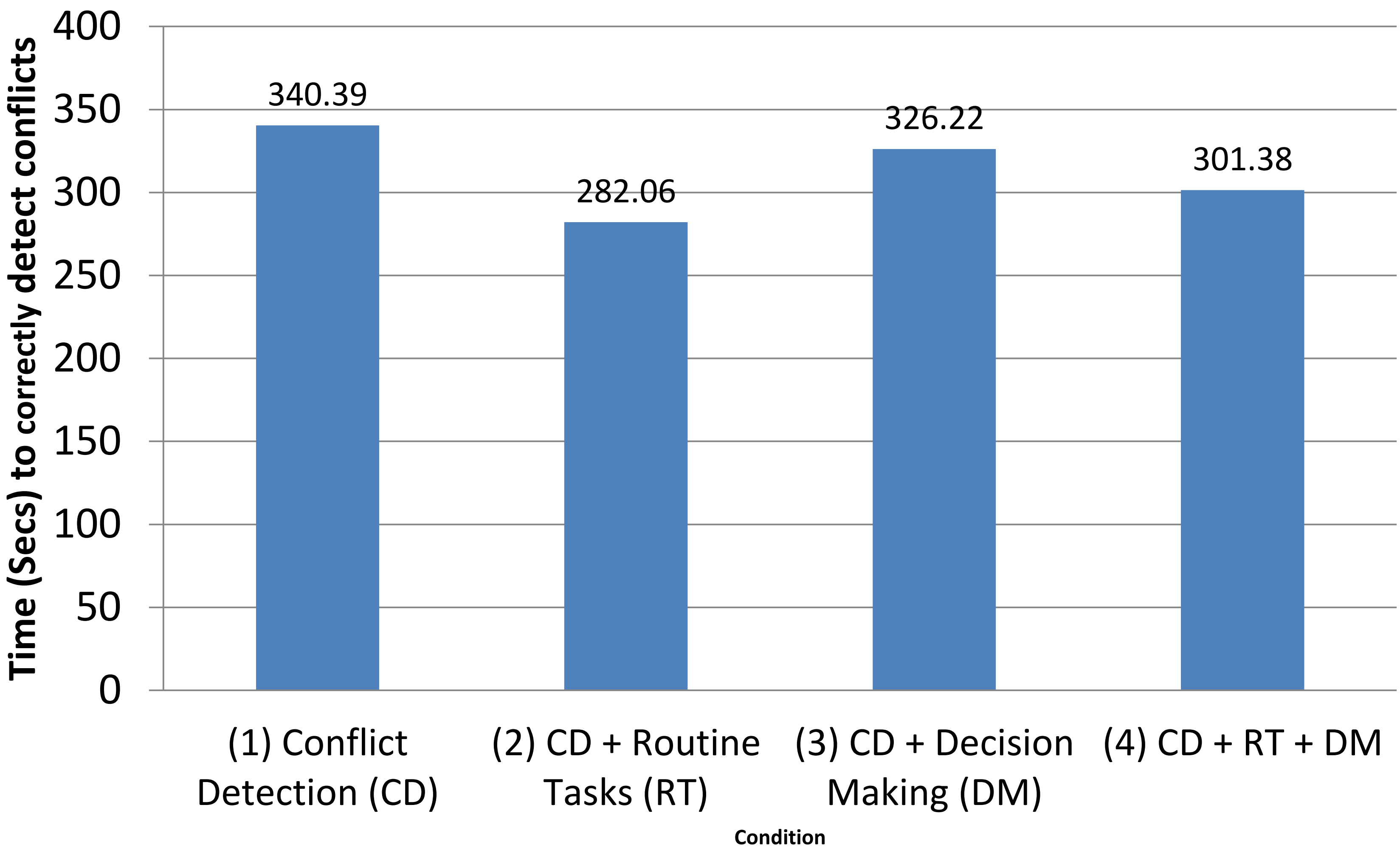
Results (1): Automation significantly affects controller workload



Results (2) Automation significantly affects controller situation awareness



Results (3) Automation significantly affects controller performance



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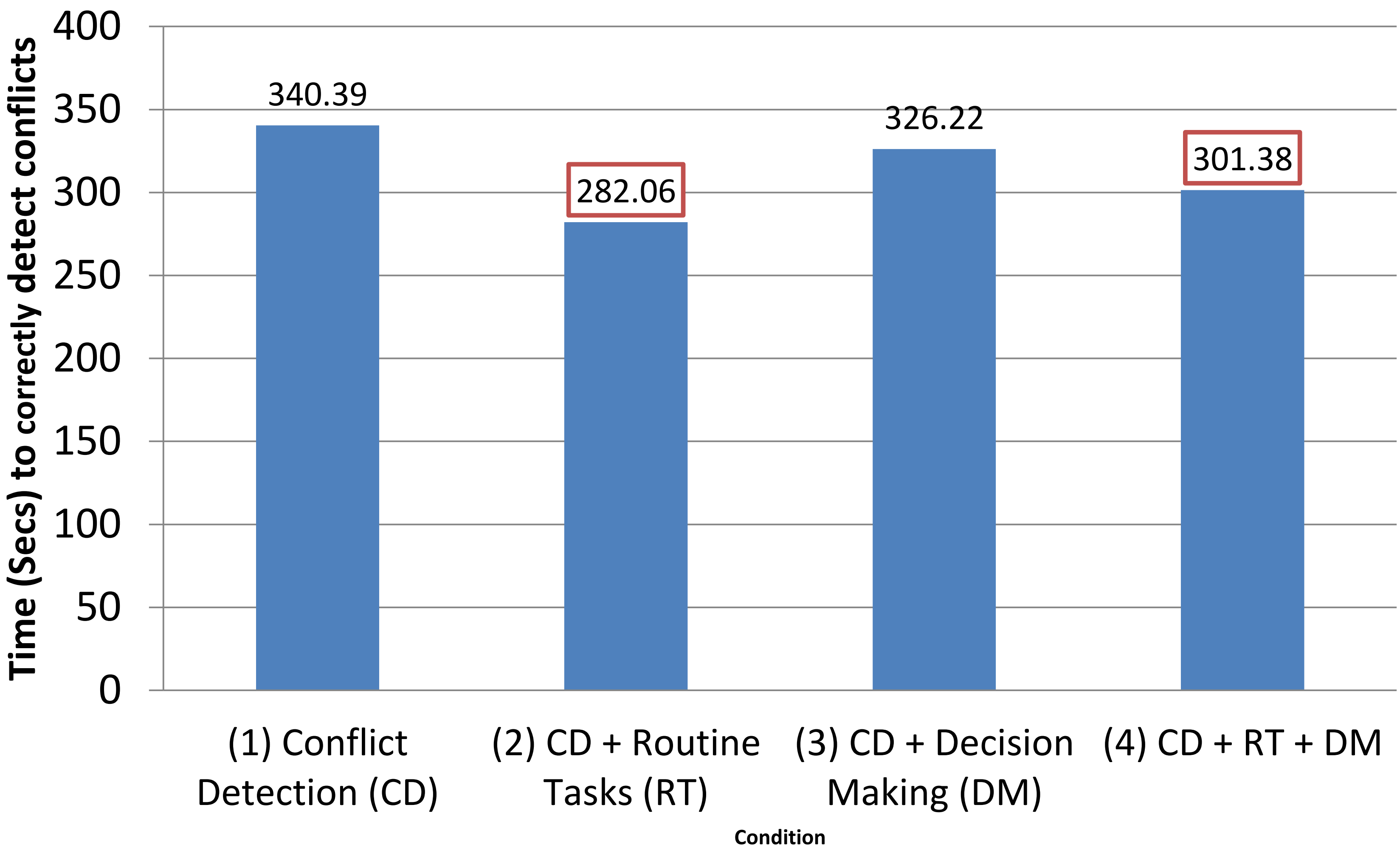
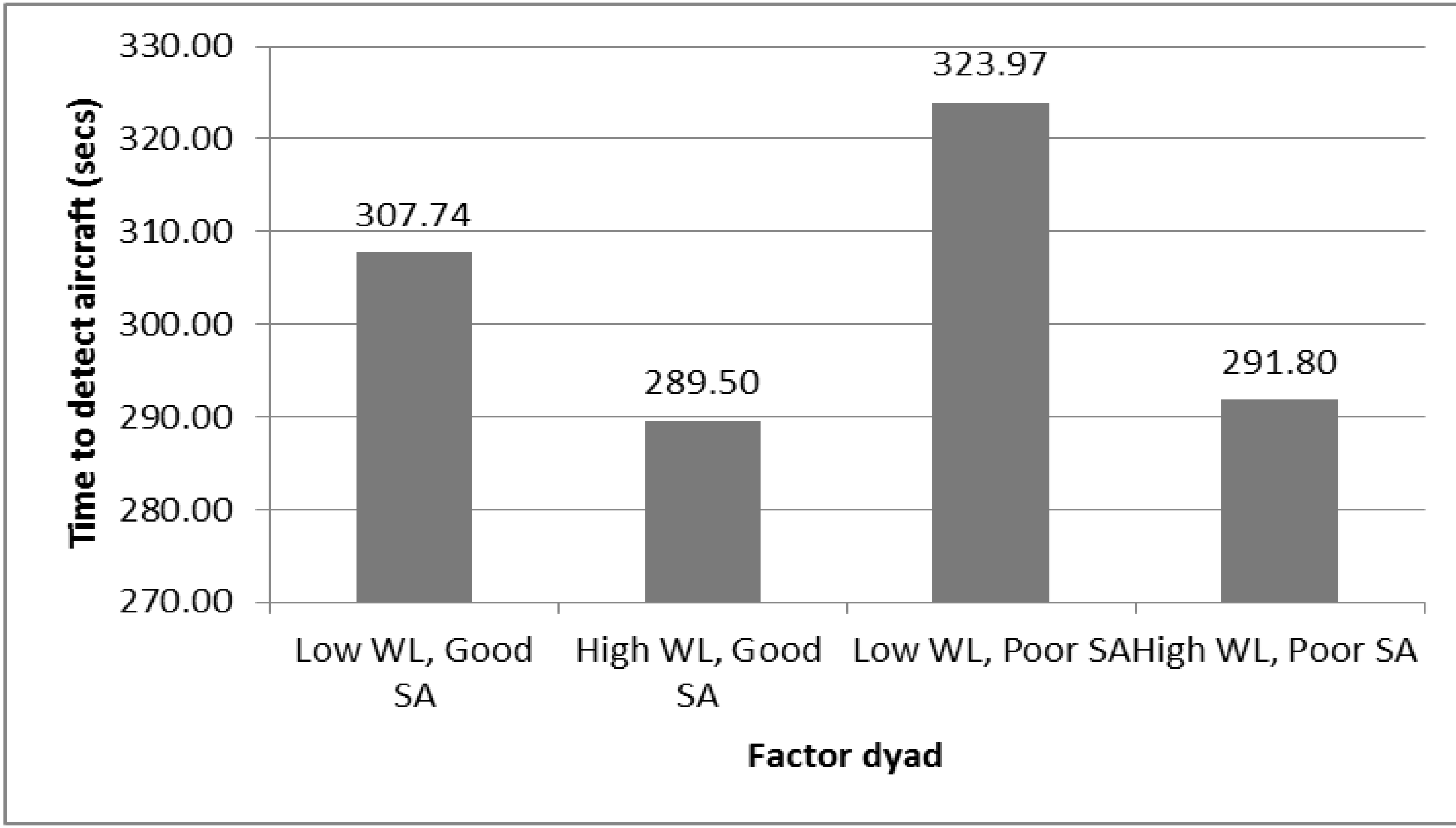
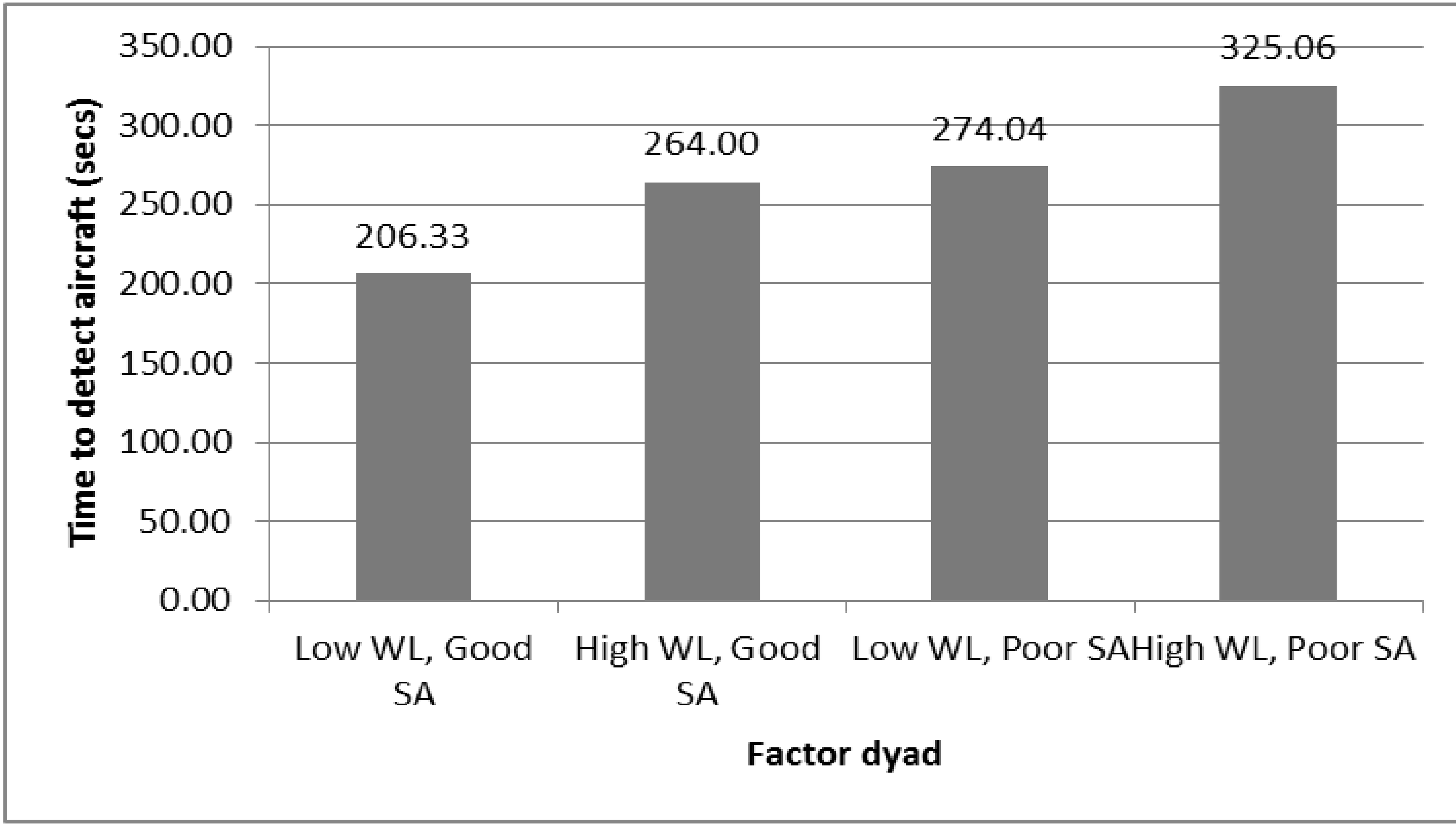


Results –Factor interactions: Task set 1



Results(2) –Factor interactions: Task set 2



Conclusions

- Factors that influence controller performance (e.g. workload, fatigue) co-vary and appear to interact to create cumulative effect on performance
- Results appear to be confirmed in a second experiment with a small, but expert, sample
- Factor influences on performance may change with control context – e.g. automation

Future directions

- HF Expert workshop
  - AHFE 2016
  - Concept development and (face) validation
- Collaboration between Future Sky and NASA Ames
  - Parallel development of human performance envelope model for pilots and controllers
  - Collaboration of Europe and US research
- Controlled simulations with expert participants
  - Part task and high-fidelity
- Factor scaling
- Further specification of edges of performance envelope
  - Markers
  - Psychophysiological measures?

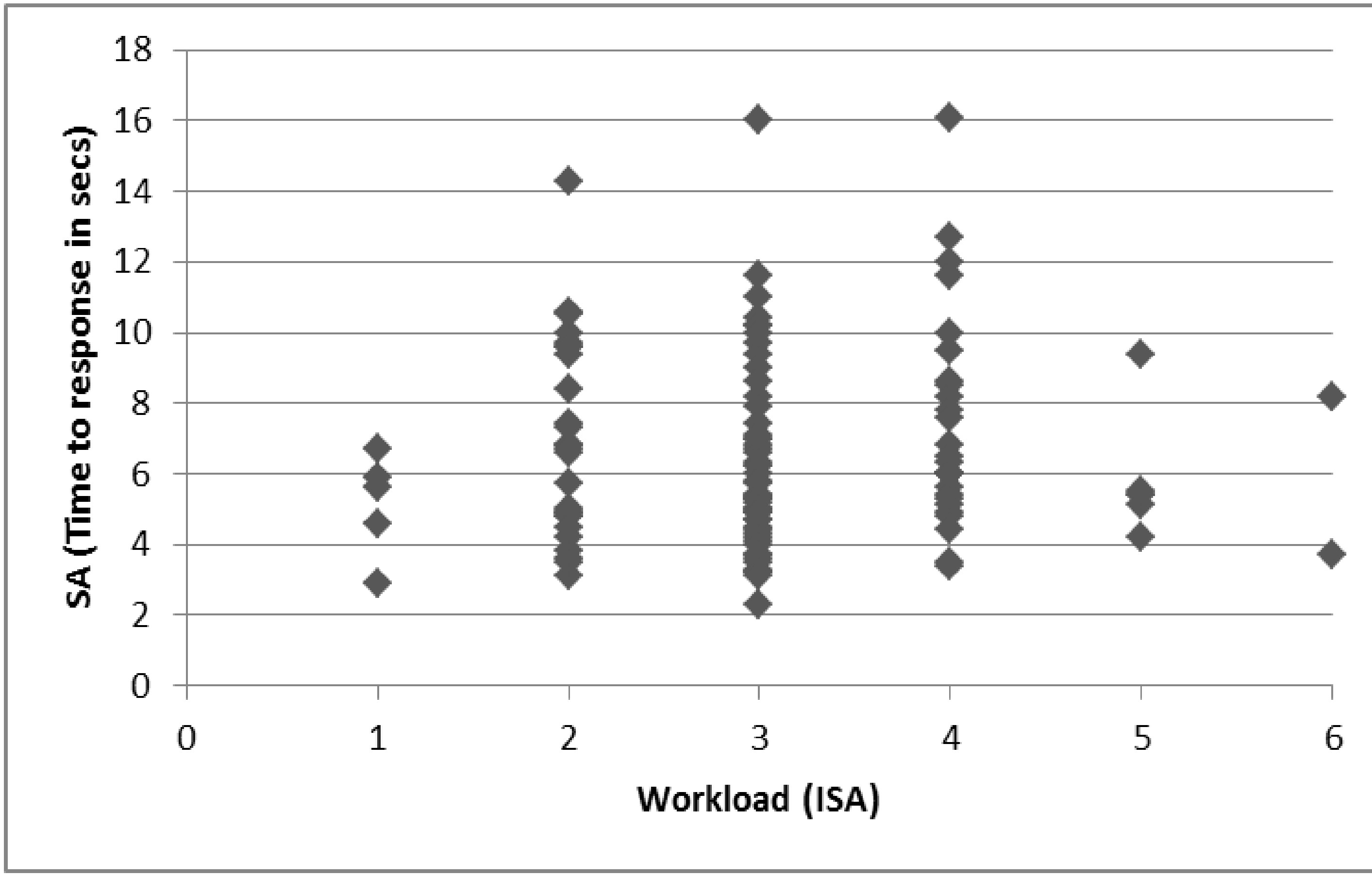
Implications

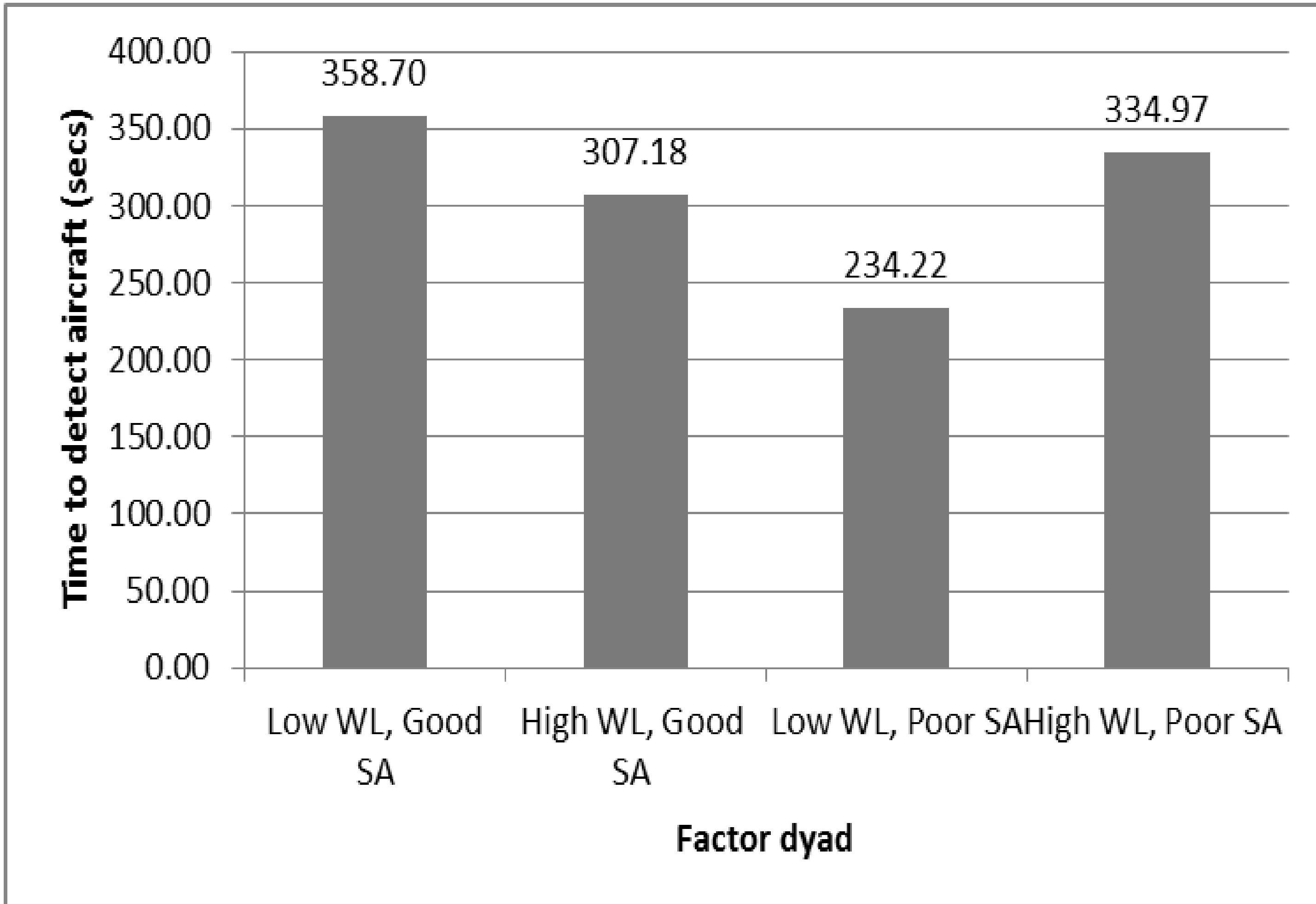
- Findings support a shift towards research investigating multi-factor co-occurrences and performance associations
- Training in markers
  - Predictive measures of human performance and prevention of performance decline
- Multifactor relationships - Performance prediction
  - Mitigation in the control room
  - Prevention of multifactor combinations
- Design of controller workstation/flight deck
- Adaptive automation implications

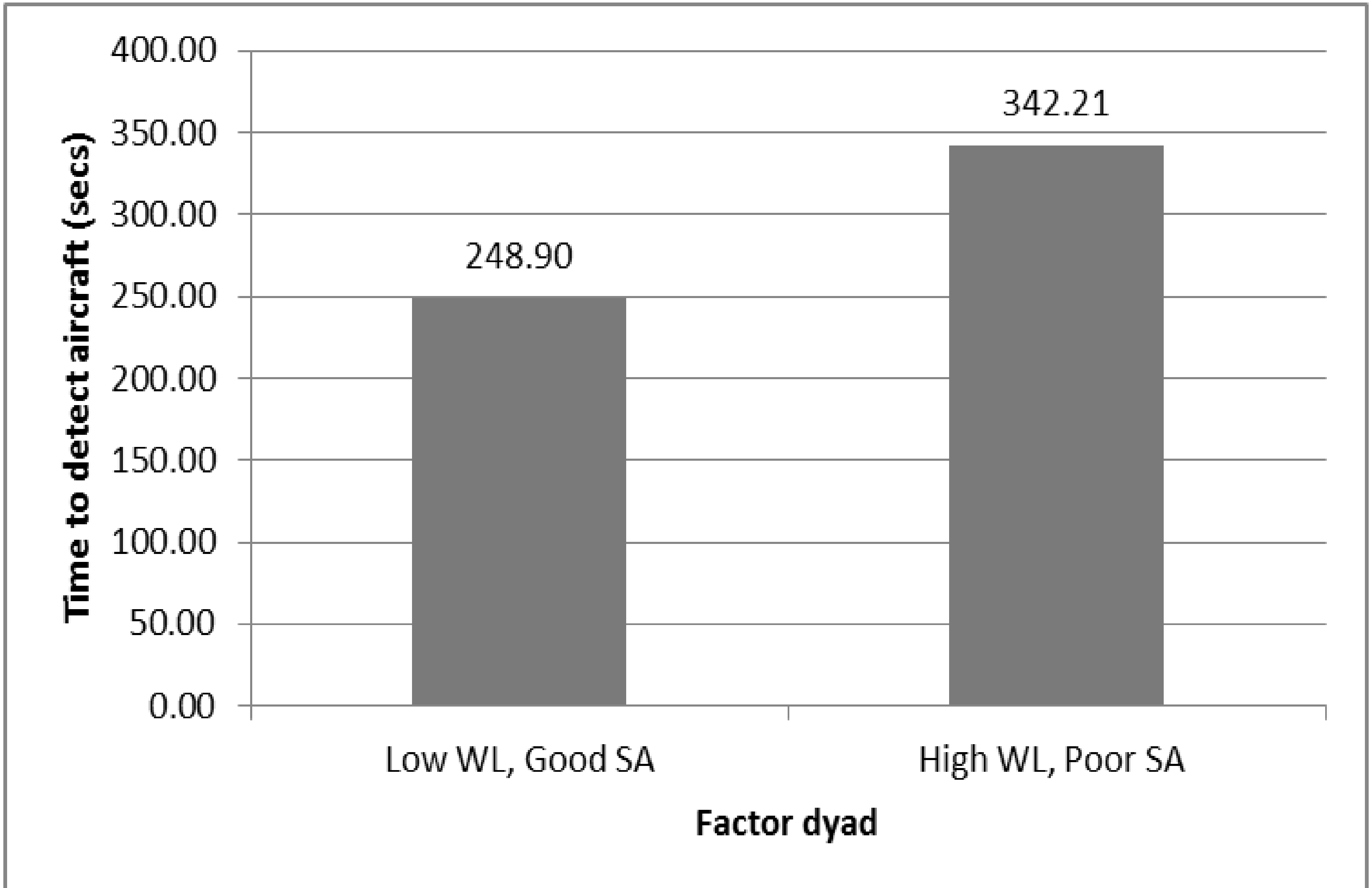
Thank you!

Back up slides

Back up slides




400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Time to detect aircraft (secs)
358.70
307.18
234.22
334.97
Low WL, Good SA
High WL, Good SA
Low WL, Poor SA
High WL, Poor SA
Factor dyad



400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
Time to detect aircraft (secs)
248.90
342.21
Low WL, Good SA
High WL, Poor SA
Factor dyad

Conflict Detection Study

- How well can controllers detect conflicts?
  - …when it’s their only responsibility?
  - Could the addition of a secondary task impact their performance?
    - Routine tasks, such as hand-offs, check-ins, and frequency changes
    - Decision-making tasks, such as responding to flight crew requests or coordination requests from other controllers
  - 4x2x2 within-subjects experiment design
    - Primary independent variables:
      - Task set
      - Traffic density
      - Run length

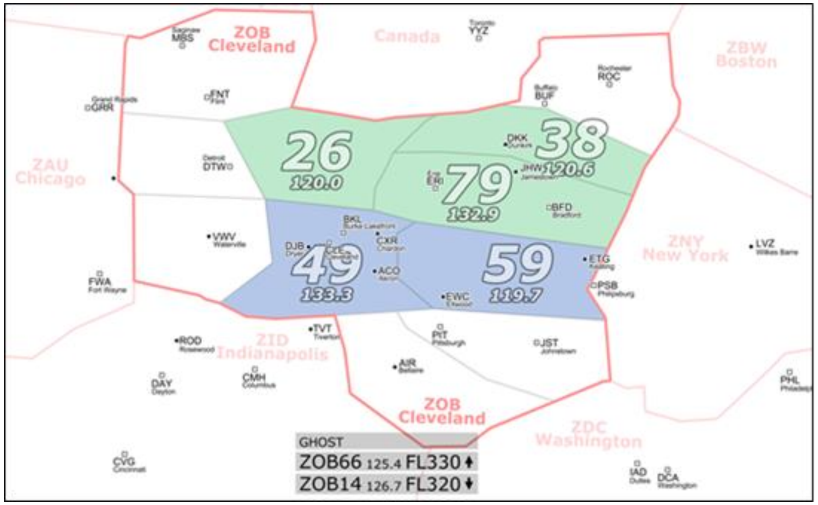
Conflict Detection Study

- 4x2x2 matrix

TASK SET	TRAFFIC DENSITY		SCENARIO LENGTH	
conflict detection	1x	1.2x	20m	60m
conflict detection + routine tasks	1x	1.2x	20m	60m
conflict detection + requests and coordinations	1x	1.2x	20m	60m
conflict detection + routine tasks + requests and coordinations	1x	1.2x	20m	60m

Conflict Detection Study

- Simulation backdrop:
  - Single high-altitude sector in Cleveland ARTCC
  - Mix of level flight and transitioning aircraft
  - Constant winds at altitude with forecast error
  - Conflict probe running, but hidden



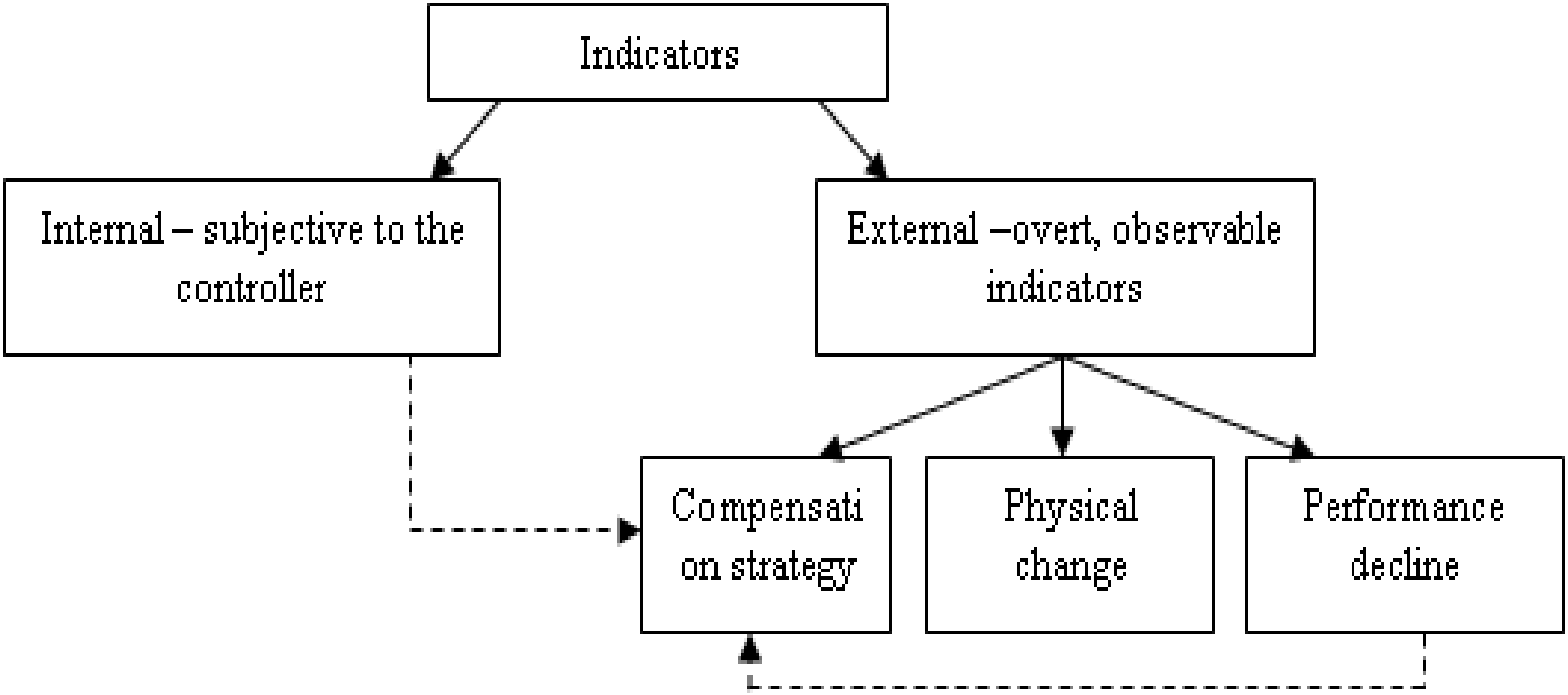
Conflict Detection Study

- Dependent measures:
  - Controller detections are compared to the conflict probe data, producing:
    - Correctly identified conflicts
    - False alerts
    - Missed alerts
  - Real-time subjective workload ratings
  - Safety (separation violations)
  - Feedback from questionnaires and debrief

Conflict Detection Study

- Participants:
  - 8 retired controllers from ZOA staffing the test sector
  - 4 retired controllers from ZOA staffing the confederate airspace
  - 12 aviation students / general aviation pilots staffing the pseudo pilot positions

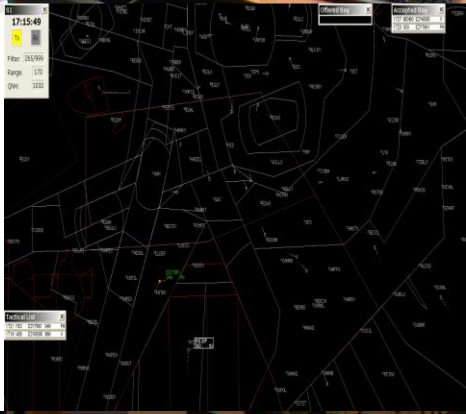
Results (3): Markers are used to indicate edges of performance



Key results

- Factors correlated as expected
- Factor interactions associated with a significantly larger performance decline compared to single factors
- Significant relationships between observed participant behaviours and self-report measures

ATC Exercise: Overview



- Aims:
  - ❑ Investigate multifactor relationships and association performance
  - ❑ Identify markers of performance edge

- Experiment: designed to reflect ATC working session
  - ❑ 116 minute task (20 minute break after 60 minutes)
  - ❑ Task used real sectors, routes and traffic flow data
  - ❑ Taskload varied every 20 minutes between low and high through number of aircraft and complexity

- Measures: arousal, fatigue, SA, stress, workload
- Participant behaviours observed and recorded

Behavioural markers of performance limits

- Apparent link between some behaviours and self reported measures
  - Example: Indicators associated with fatigue
    - Yawning
    - Looking away from screen
    - Posture changes

- Interviews
  - 22 ATCOs took part (17 males, 5 female)
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Markers of workload

- Different markers for high workload and low workload:
- High workload:

Category	Internal Marker
Cognitive changes	Don't know the next steps
	Increased focus
	Calls are a surprise
	Reduced self-awareness
Subjective feeling	Losing control
	More traffic than can handle
	Panic and uncertainty
	Not comfortable

Category	External Marker
Perception changes	Can’t talk to executive/ executive doesn’t hear you
Visible cues	Fidgety
	Move closer to screen
	Colleagues not talking
Verbal cues	Swearing
	Blaming others
Performance changes	Miss actions
	Mixing call signs

Markers of workload

- Low workload:

Category	Internal Marker
Cognitive changes	Pay less attention
	Easily distracted
	Reduced self-awareness
Changes to control	Leave situations develop
	Trying to create more complex situations
	Less safety buffer
Subjective feeling	Boredom
	Relaxed

Proposed category	External Marker
Perception changes	Incorrect assessment of a situation
Visible cues	Sit back in chair
	Away from radar screen
	Talking to colleague
Performance changes	Overlooking aircraft
	Forgetting aircraft
	Repeated 'sloppy' mistakes
	Fall behind traffic due to distraction

Markers of fatigue

Markers internal to the controller

Cognitive changes	Subjective experience
Concentration issues	More effort to control
Increased assumptions	Don't want to work busy traffic
Slower	Force self to pay attention
Mild confusion	Feel tired
Reduced awareness	Not looking forward to shift

Observable markers

Visible cues	Demeanour
Yawning	Less active
Laid back	Not as confident
Eyes closed	Quieter
Falling asleep	Distracted

Style of control	Performance
Less flexible	Overlook aircraft
Reduction in efficiency	Multiple, small mistakes
Less safety buffer	'Running behind traffic'
Incorrect plan	Slow to solve problems
Slower communications	Forget aircraft

Markers of stress

- Differentiation between positive stress and negative stress

"It's almost excited because there is more traffic coming. It's a different situation if someone is already in a complex situation, you realise he is falling behind

Category	Internal Marker
Cognitive changes	Start to think slower
Physiological changes	Heartbeat
	Sweat
Subjective feeling	Not coping
	Feeling uncomfortable
	Anxious (negative)
	Nervous
	Tense

Category	External Marker
Visible cues	Fidgeting
	Red cheeks/neck
	Flustered
Changes to voice	Speaks faster, louder
	Speaks higher
Demeanour	Easily frustrated
	Angry/confrontational
	Blame others

Markers of vigilance

Category	Internal Marker
Cognitive/ perception changes	Not as ‘sharp’
	Surprised
	Assume more
	Focused, ‘tunnel vision’
	Donut effect
	Not aware
Changes to control	Scan differently
	Not leaving a problem

Category	External Marker
Performance changes	Overlook aircraft
	Don't hear/see

Markers of losing the picture

- Differentiation between markers that indicate losing the picture, and having lost the picture:

"It starts off by just falling behind a bit. So you might just be a few steps behind what you're supposed to be doing and if that builds up too much then you will get to the point where you start to lose the picture"

Category	Internal Marker
Cognitive changes	Difficulty selecting priorities
	Thinking whilst giving the clearance
	Tunnel vision/hearing
Subjective feeling	Under confident

Category	External Marker
Visible cues	Slow at task
Performance changes	Running behind
	Time working ahead degrades
	Missing calls

Markers of having lost the picture

Category	Internal Marker
Cognitive changes	Lose awareness
	Everything a surprise
	No plan
	Cannot see a solution
Changes to control	Reactive control
Subjective feeling	Panic

Category	External Marker
Visible cues	Zig zagging head movement of where to look
	‘Blacked out’/ silent
Verbal cues	Asking for confirmation
Performance changes	Unsafe clearance
	Unexpected decisions
	Jumping from one aircraft to another
	Don't know who’s calling
	Don't react correctly

Inadequate communications

- Inadequate communications were described in relation to causes and contributory factors such as fatigue, lack of attention, or stress:

"Mixing call signs happens more if someone's tired or under pressure"

"If you have aircraft that aren't listening and you're busy…maybe the extra thing that sends you over"

Category	External Marker
Situational issues	Inadequate communications with aircraft
	Equipment failures
Performance changes	Mixing call signs
	Slip of the tongue

Conclusions

- Multiple factor relationships:
  - Multiple factors co-occur to influence controller performance
  - Interactions between factors may create a cumulative influence on performance
- Behavioural markers:
  - Markers indicate limits of performance
  - Controllers use markers to support performance

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