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Challenges and Strategies for Extending ACT-R Visual Perception

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Motivation – We Could do More with ACT-R

General Areas

- Human factors/usability research
- Realistic tasks and stimuli (visual and auditory)
  - e.g., air tanker refueling/search and rescue at night
- Phenomena of interest
  - Cognitive load, executive control during multitasking, attention control, and fatigue/vigilance

Specific Efforts:

- Detecting fatigue and its effects on visual search
- Measuring cognitive load in radar monitoring
- Target identification with night vision googles

Why Use ACT-R?

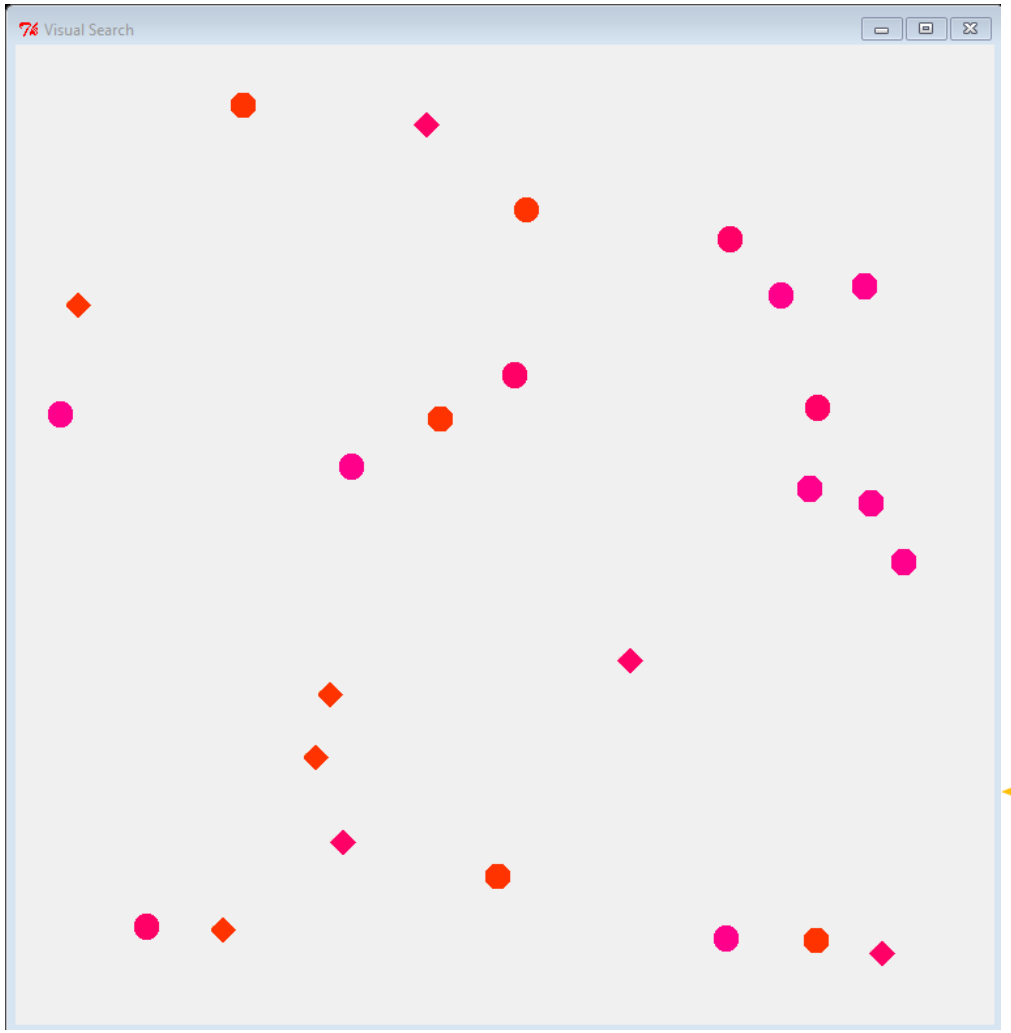
- Cognitively plausible and scientifically validated
- Interactions between cognitive processes
  - Fatigue from sleep/time on task
  - Memory
  - Attention
  - Executive control
- Predict and explain behavior
- Human representation in large simulations

Challenges and Open Questions

- Challenges
  - Visual/auditory perception limitations
  - Fatigue module scaling/updating
  - Scaling-up closer to real-world tasks
- Technical Questions
  - Bottom Up - Visual attention?
  - Fatigue mechanisms
  - Low-level perception – Acuity and contrast?
- Theoretical Questions
  - Fatigue – perceptual or executive control?
  - Fovea and peripheral?
  - Perceptual vs Productions

Top-down and Bottom-up Visual Processing

Visual Search with Fatigue – Experiment

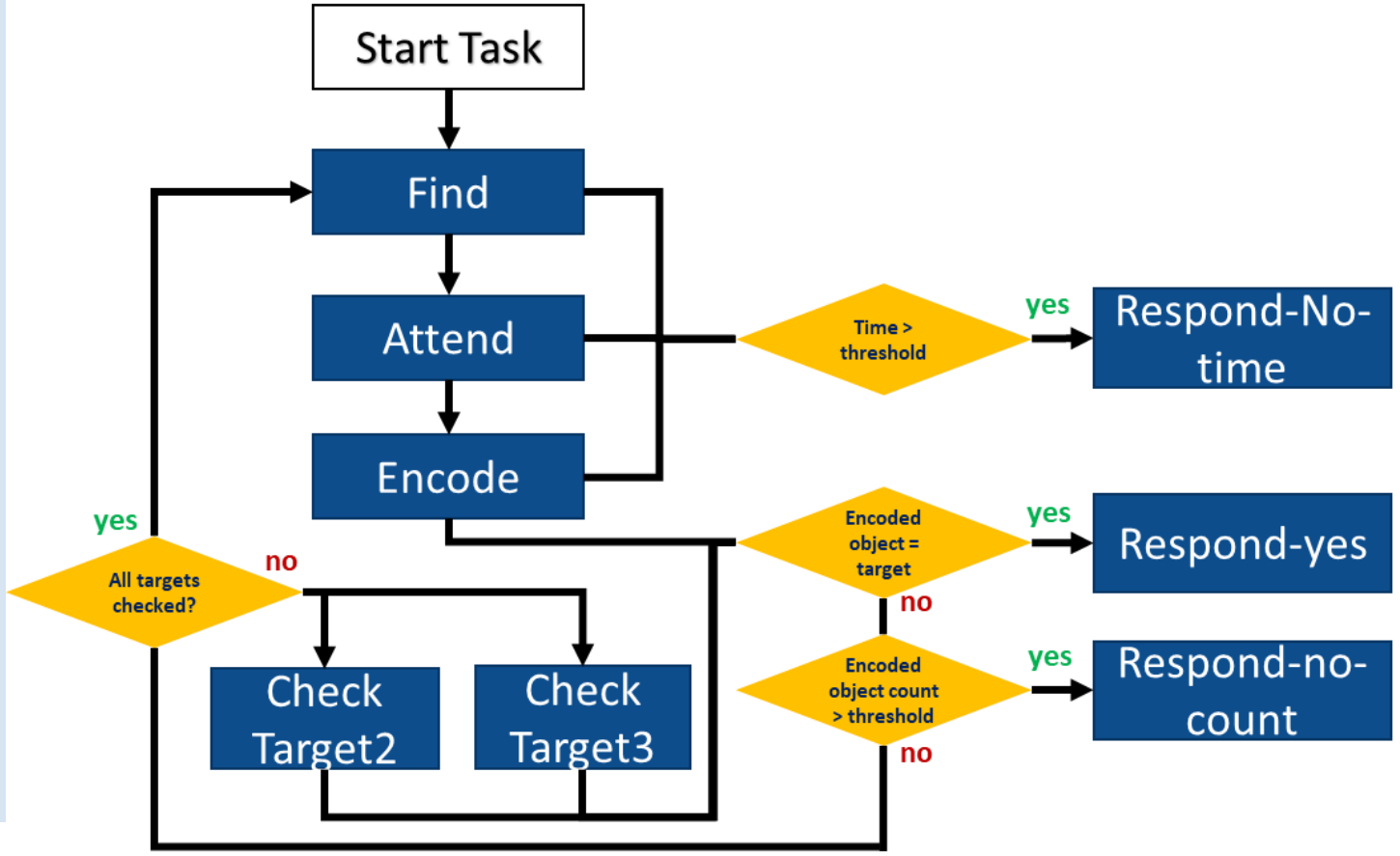


Shapes: ● ⬢ ◆

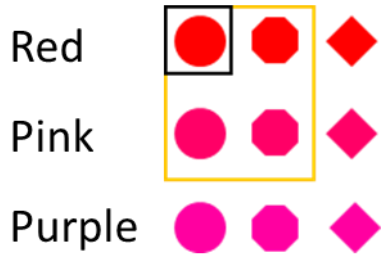
Colors: red - pink - purple

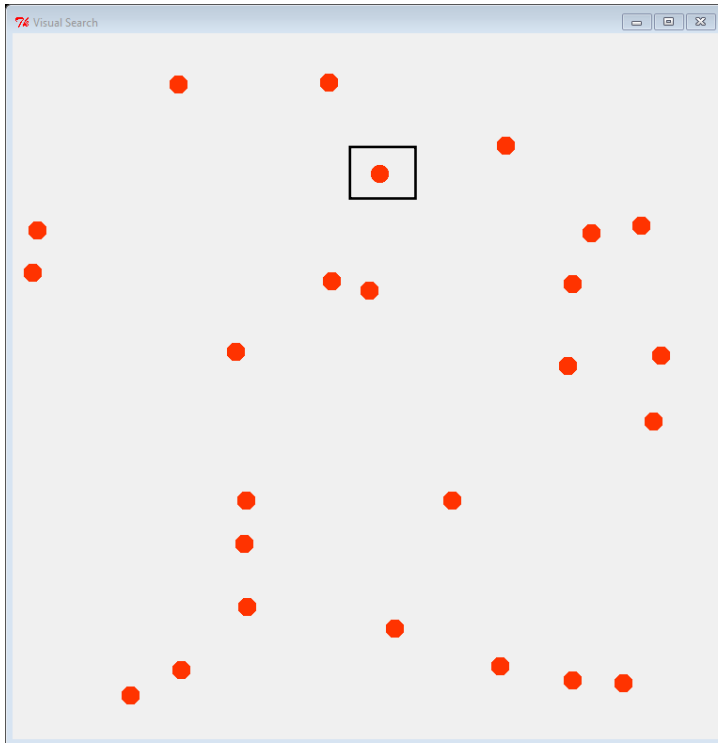
Amount of targets (1 or 3)

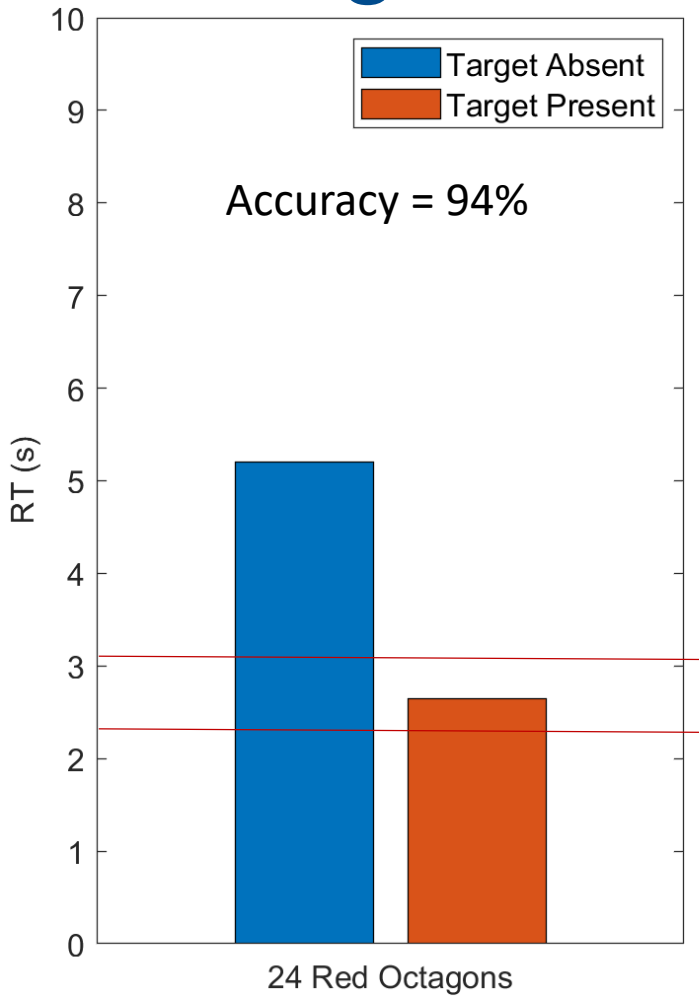
Target-present trials (10% or 50%)

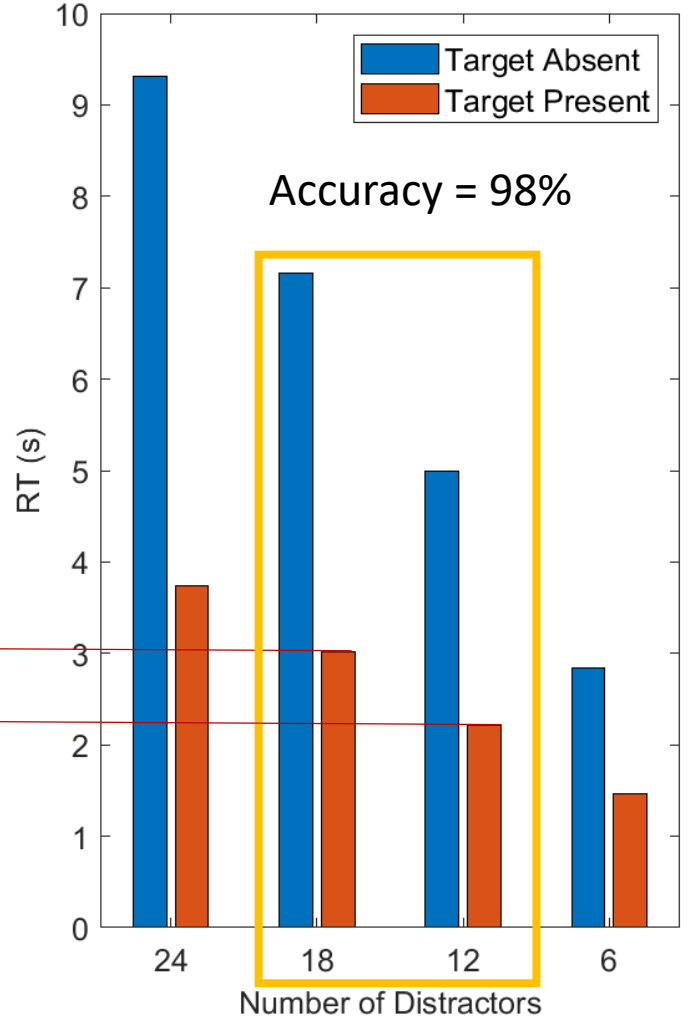


Visual Search with Fatigue – Model



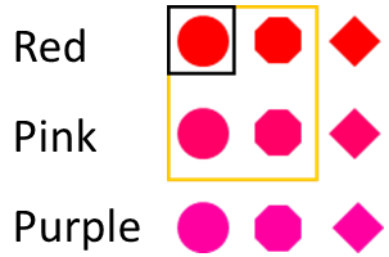


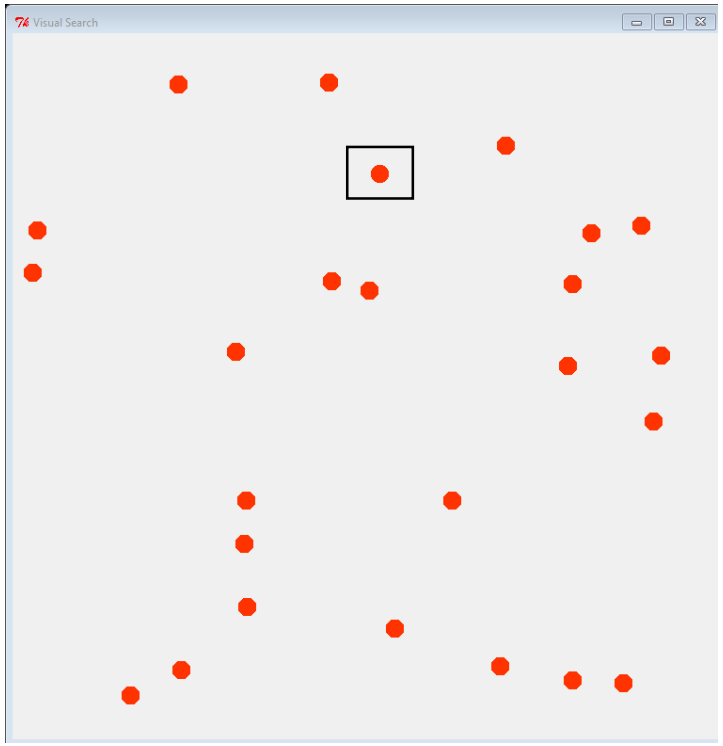


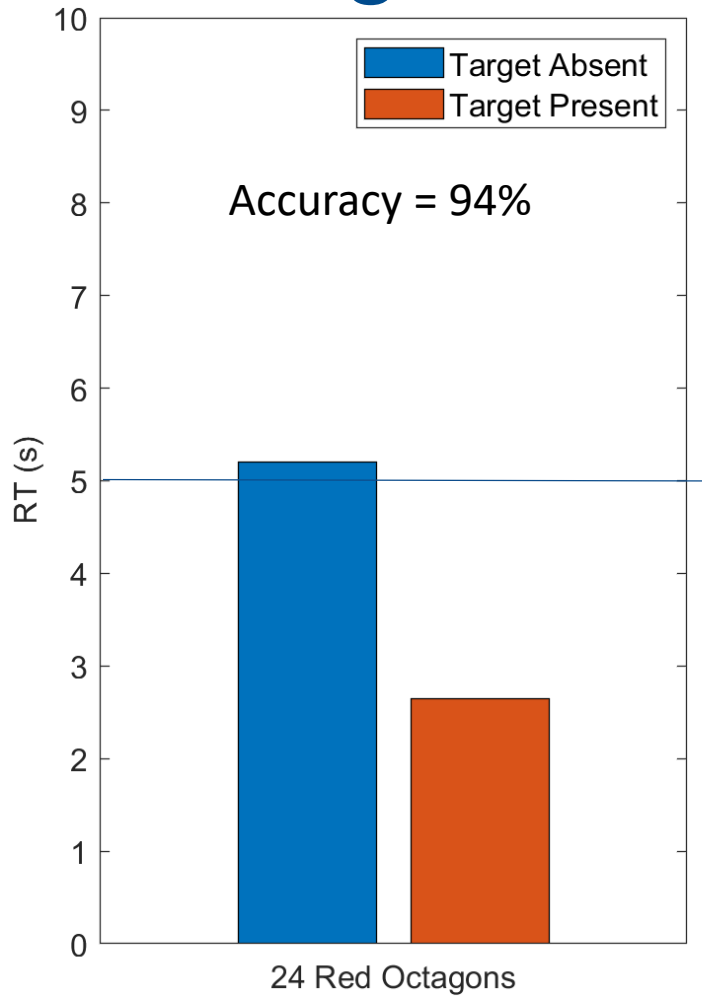


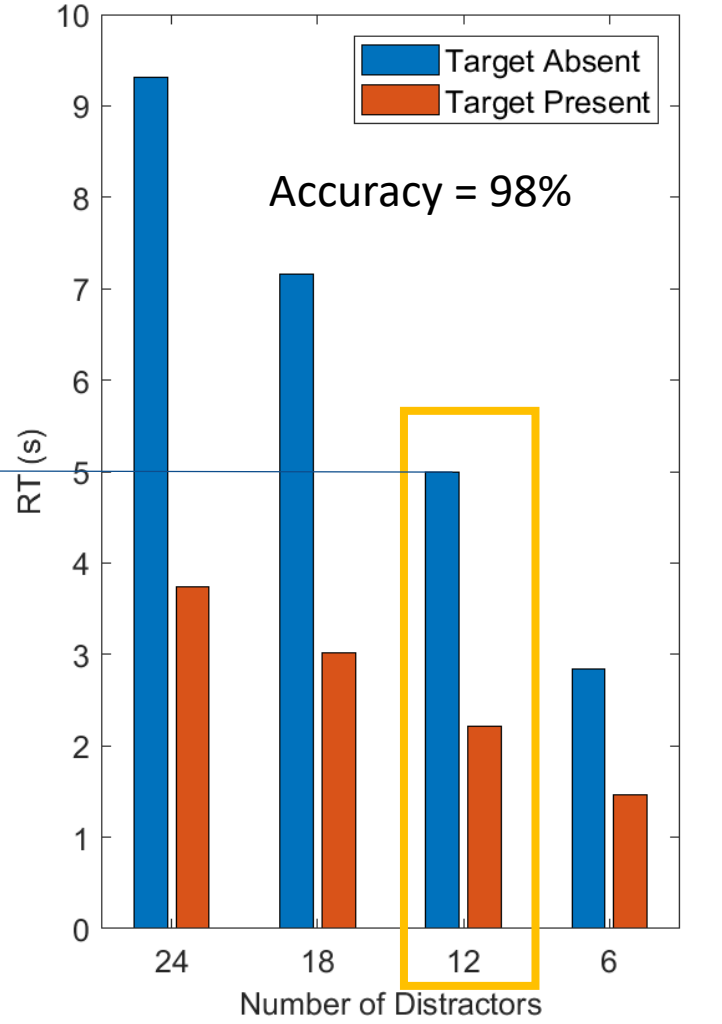
Glavan et al. (2020) **Model**

Visual Search with Fatigue – Model



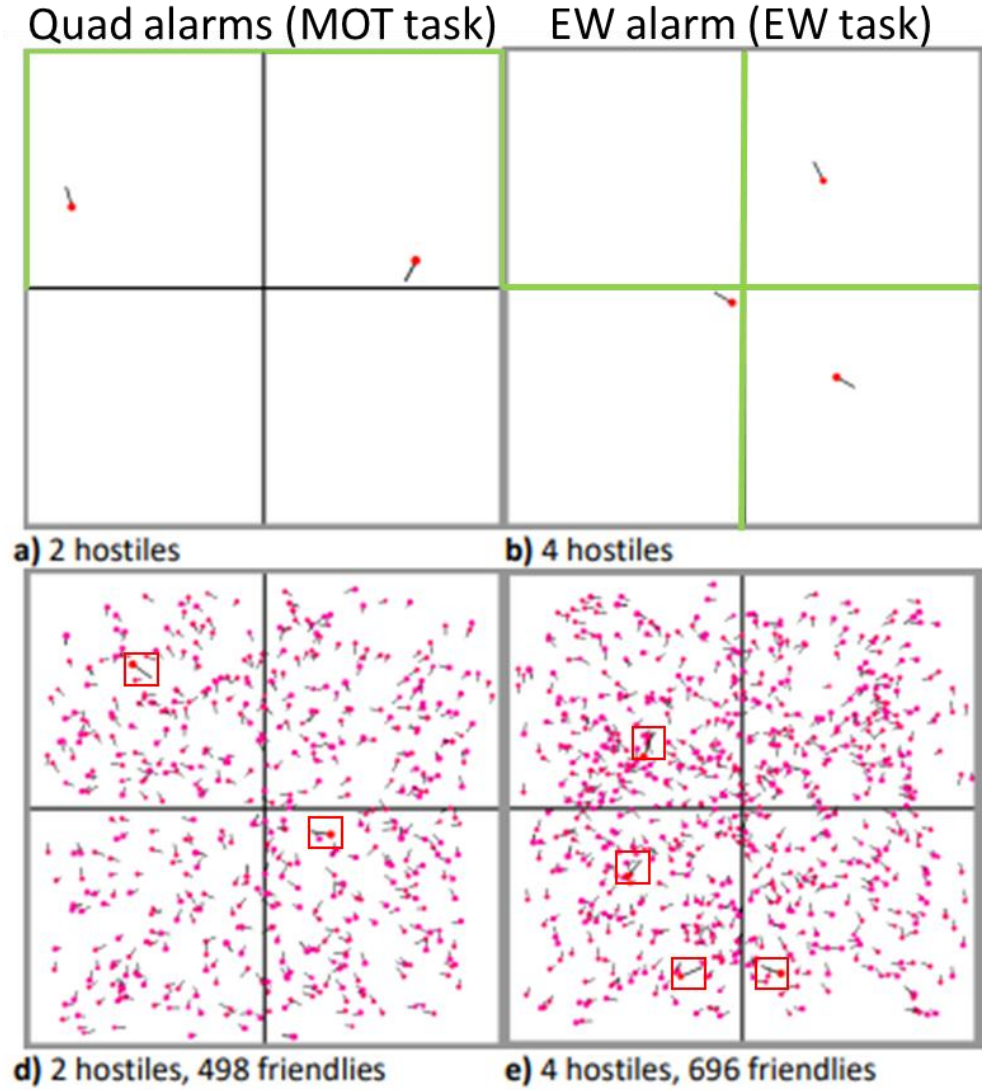




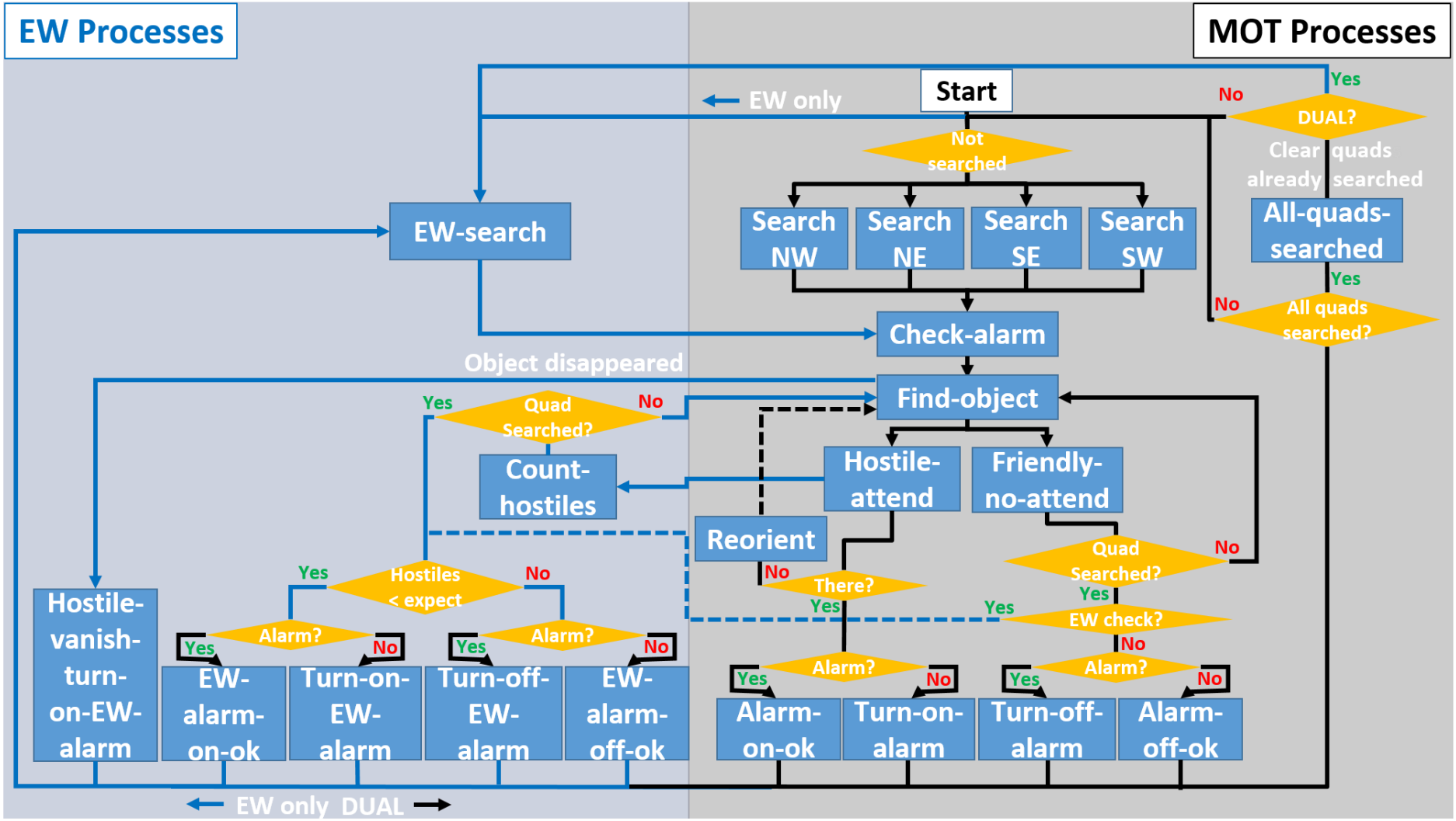


Glavan et al. (2020) **Model**

Radar Detection – MOT-EW Task (Fox et al., 2023)

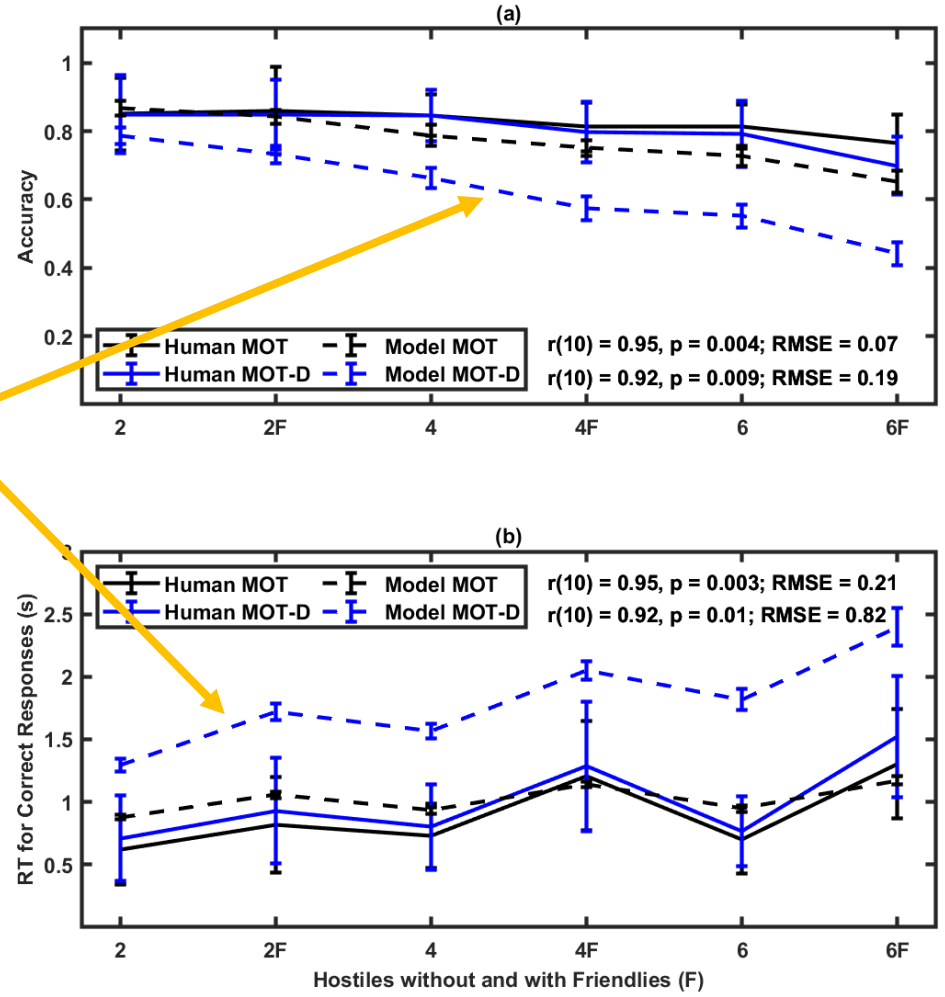


Radar Detection – MOT-EW Model (Hough et al., 2023)

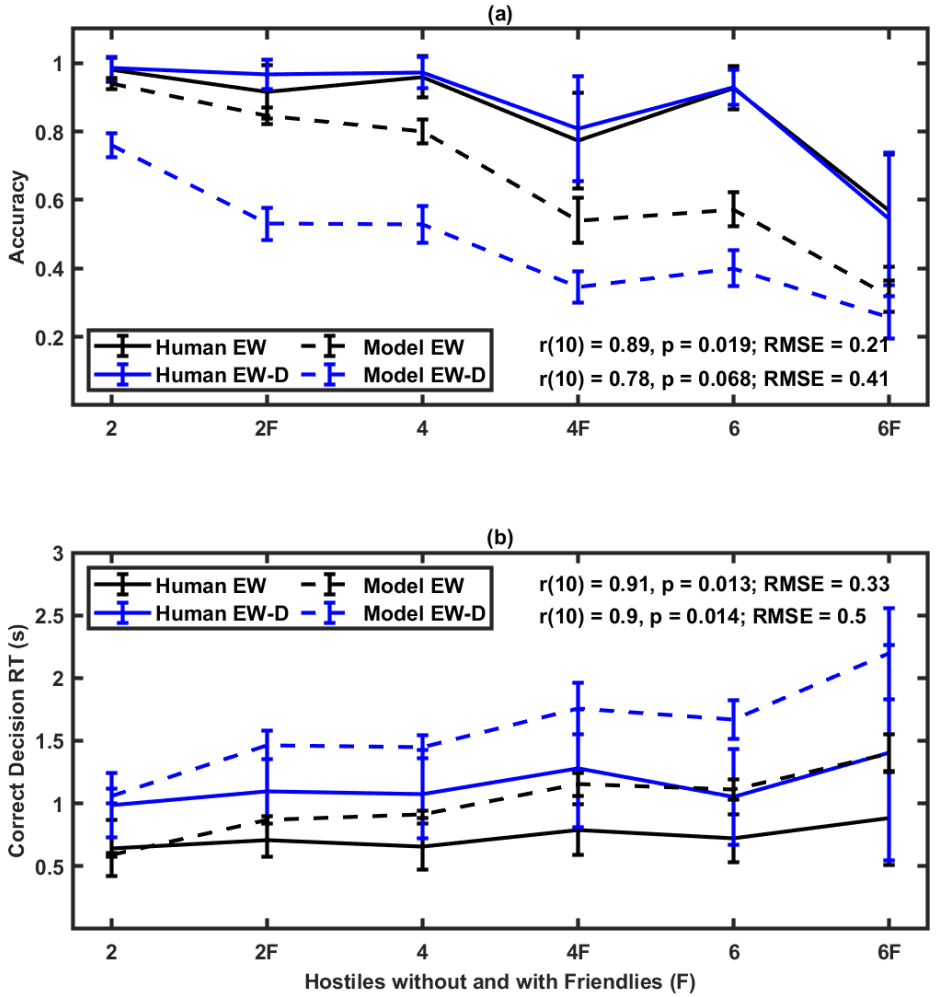


Radar Detection – MOT-EW Model (Hough et al., 2023)

MOT



EW



How to Extend ACT-R Visual Attention?

Challenges

- Selective visual attention
- Overloading the visicon
- Finsts – number and span

Potential and Previous Methods

- Perception span and buffer stuffing (Swan et al., 2023)
- Preattentive and attentive visual module (PAAV) (Nyamsuren & Taatgen, 2013)
- PAAV inspired Java implementation (Fisher et al., 2022)
- “Light” PAAV in Julia (Fisher et al., 2023)
- ACT-R and PAAV outside architecture (Jokinen et al., 2020)
- JSegMan (Tehranchi & Ritter, 2018)
- EPIC (Kieras, 2019)

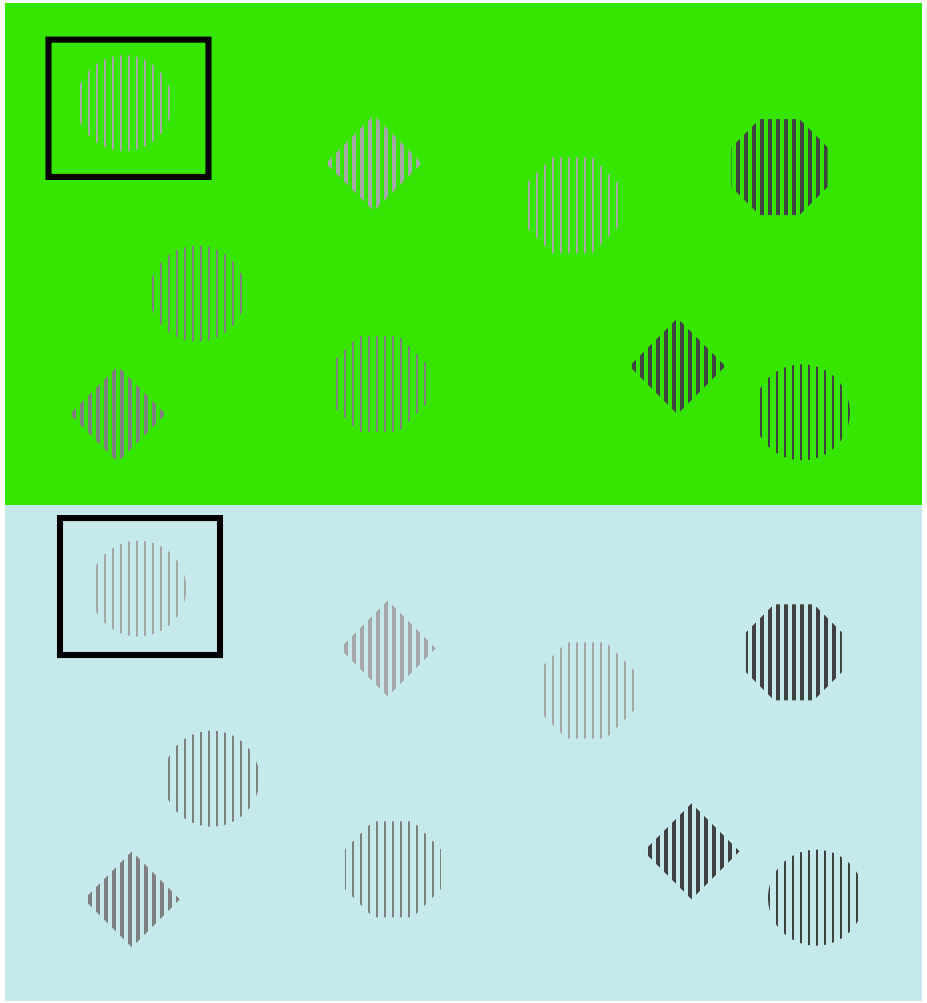
Considerations

- **ACT-R module(s)**
- Computational costs
- Task independence and scaling

Low-level Visual Perception (Pre-processing)

Visual Search and Eye-strain Fatigue with NVGs

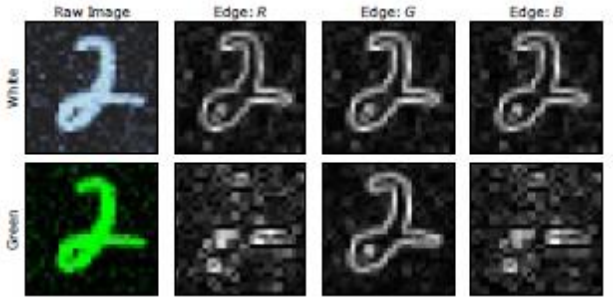
- Modified visual search task
  - Difficulty manipulations
  - Acuity, contrast, line orientation instead of color
- Goals:
  - Experiment and modeling
  - Perceptual/performance differences
  - Eye-strain related fatigue/impacts
  - Predict/explain/simulate behavior
- Modeling Needs
  - Perception of gradients
  - Acuity and contrast effects



Visual Search and Eye-strain Fatigue with NVGs

- Leabra (O'Reilly, 2006; O'Reilly et al., 2017)
- NVG test cases using Julia (Curley, 2022)
  - Prefer white over green
  - Weak opponent processes?
  - Stimuli with MNIST digits simulating NVGs
- Low-level perceptual features for ACT-R?

- Preliminary results
  - Model has more trouble with green edge detection
  - Opponent processes



How to Extend ACT-R Low-level Visual Perception?

Challenges

- Bottom-up attention not sufficient
  - Visicon or iconic visual memory
- Computation costs
- Integration with ACT-R

Potential and Previous Methods

- Integration with Leabra or other architectures
- Adding additional features to visicon

Considerations

- Low computational/time costs
- Selective decomposition
- Scaling and generalization
- **ACT-R module?**

Discussion

Why, What, and How?

- Why?
  - Human factors/usability research
  - Realistic tasks and stimuli (visual and auditory)
    - Cognitive load, multitasking, attention control, and fatigue/vigilance
- What?
  - Bottom-up attention
  - Low-level perception
  - Generalizable module(s) maintained with architecture
- How?
  - Leveraging previous work
  - Open discussions and collaboration
  - Post-docs, proposals, grants…

THANK YOU!

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Christopher Stevens
Taylor Curley

QUESTIONS?

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References

Curley, T. (2022). Computational Exploration of Differences Between Green and White Phosphor Displays. Technical Report.

Fox, E. L., Stephenson, A., Stevens, C. A., & Bowers, G. (2023). Predictors of human efficiency in radar detection tasks. In *Proceedings of the 18th International Conference on Cyber Warfare and Security*. Towson, Maryland, USA.

Fisher, C. R., Curley, T., & Stevens, C. (2023). Using neural networks to create fast and reusable approximate likelihood functions for ACT-R. Paper presented at MathPsych/ICCM/EMPG 2023. Via mathpsych.org/presentation/1041.

Fisher C. R, Frame M. E, Stevens C. A. (2022). Using cognitive models to design dynamic task allocation systems. *The Journal of Defense Modeling and Simulation*. doi:10.1177/15485129221116897

Glavan, J. J., Haggit, J. M., & Houpt, J. W. (2020). Temporal organization of color and shape processing during visual search. *Attention, Perception, & Psychophysics*, *82*, 426-456.

Hough, A. R., Larue, O., Myers, C., & Leung, O. (2023). Integrated Cognitive Model Framework for Analogical Reasoning. *Paper presented at Virtual MathPsych/ICCM 2023*. Via mathpsych.org/presentation/1287

Jokinen, J. P., Wang, Z., Sarcar, S., Oulasvirta, A., & Ren, X. (2020). Adaptive feature guidance: Modelling visual search with graphical layouts. *International Journal of Human-Computer Studies*, *136*, 102376.

Kieras, D. E. (2019). Visual search without selective attention: A cognitive architecture account. *Topics in Cognitive Science*, *11*(1), 222-239.

Nyamsuren, E., & Taatgen, N. A. (2013). Pre-attentive and attentive vision module. *Cognitive Systems Research*, *24*, 62-71.

O'Reilly, R. C. (2006). Biologically based computational models of high-level cognition. *Science, 314*(5796), 91–94.

O'Reilly, R. C., Hazy, T. E., & Herd, S. A. (2017). The leabra cognitive architecture: How to play 20 principles with nature and win! *The Oxford Handbook of Cognitive Science*, *91*, 91-116.

Swan, G., Stevens, C., & Klosterman, S. (2023). A Cognitive Model of the Effects of Workload on Perceptual Span. *Paper presented at Virtual MathPsych/ICCM 2023*. Via mathpsych.org/presentation/1288

Tehranchi, F., & Ritter, F. E. (2018). Modeling visual search in interactive graphic interfaces: Adding visual pattern matching algorithms to ACT-R. In *Proceedings of ICCM-2018-16th International Conference on Cognitive Modeling* (pp. 162-167).

Visual Search with Fatigue – Literature

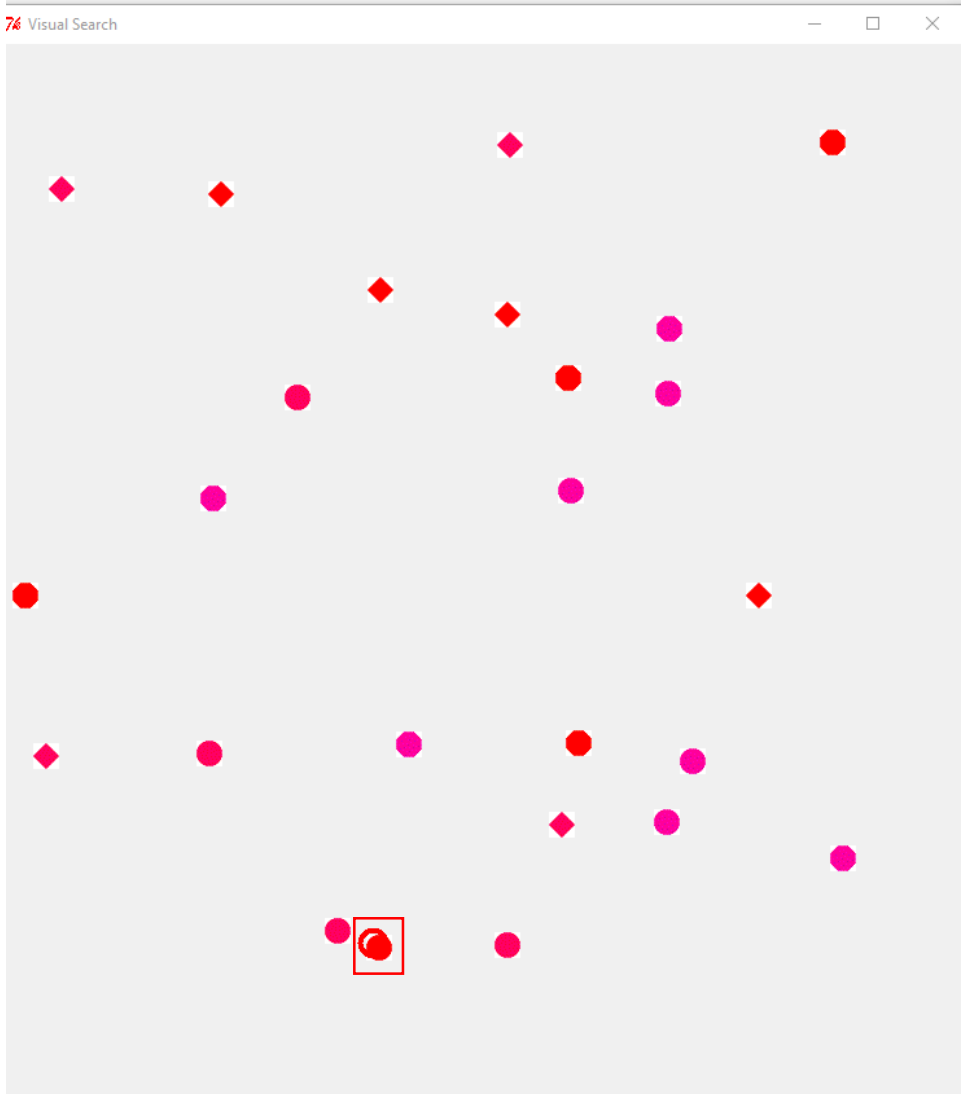
Time-on-task fatigue/vigilance decrement

- Performance declines over time (Grier et al., 2003; Parasuraman, 1979; Helton et al., 2007)
- Resource depletes → workload/TOT (Helton & Russell, 2013; Shaw et al., 2013; Warm et al., 2008)
- Lack cog/physio understanding – TOT fatigue in complex tasks

Visual search

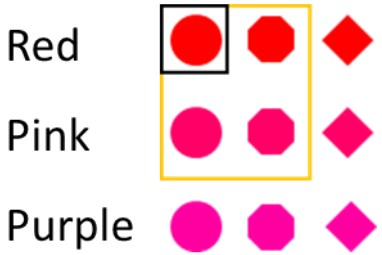
- TOT → more missed targets (Horowitz et al., 2003; Wolfe et al., 2007)
- Increased difficulty - # distractors, similarity, # targets, & target prevalence (Treisman & Gelade, 1980; Treisman & Paterson, 1984; Wolfe et al., 2005, 2007; Wolfe, 2012)
- Lack - cog models & understanding of fatigue in visual search

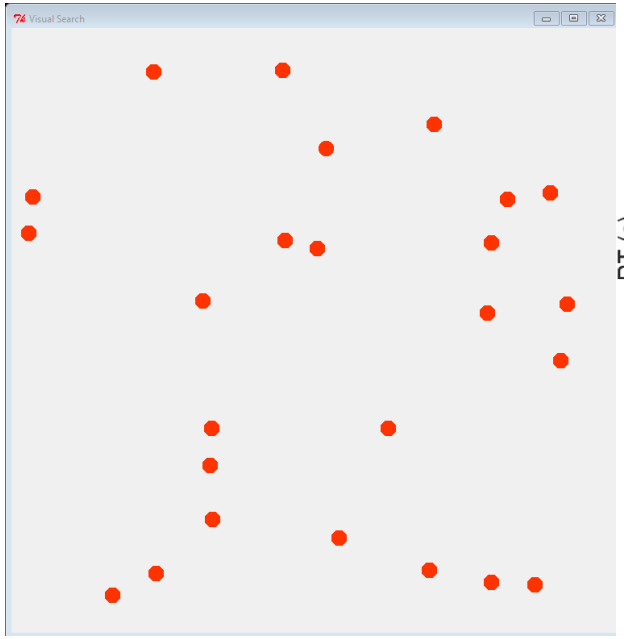
Visual Search with Fatigue – Experiment

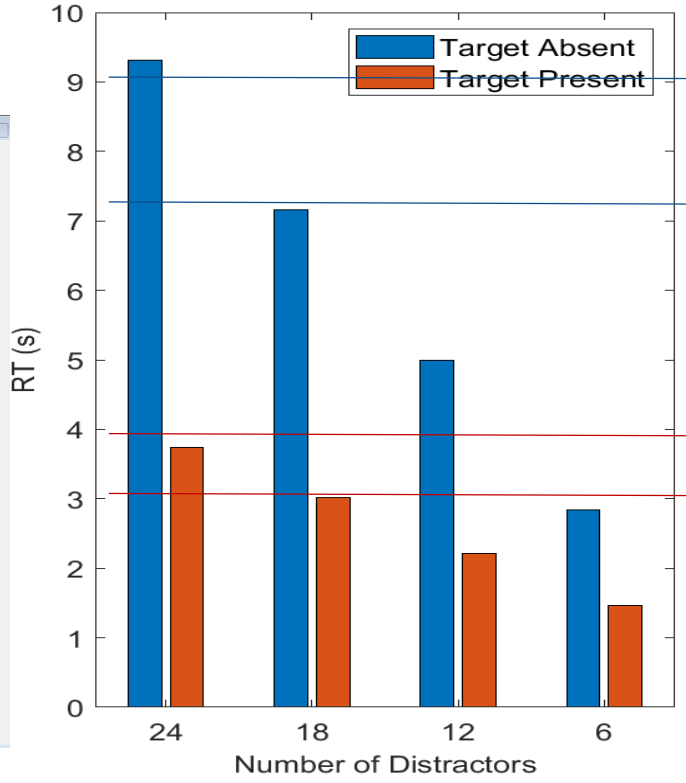


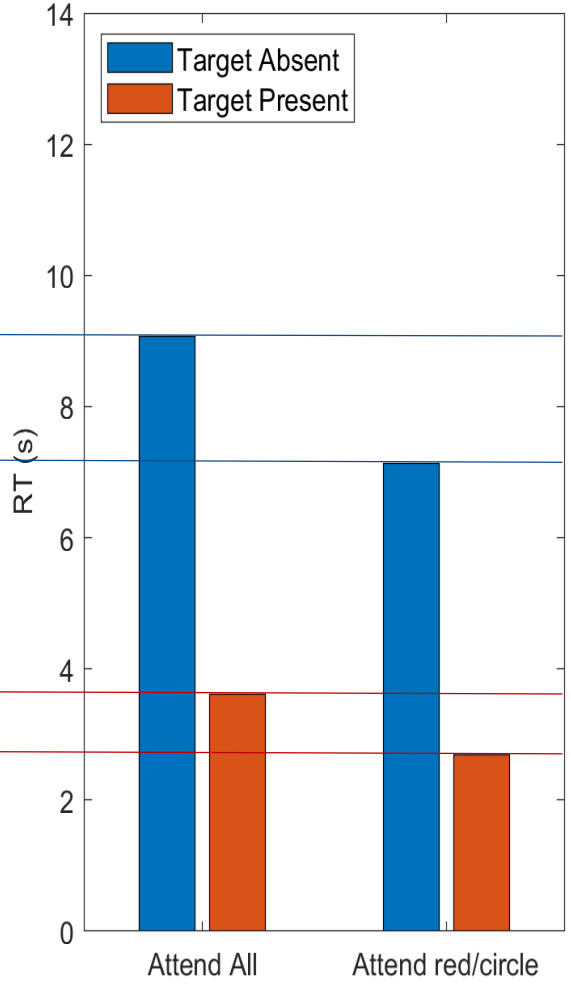
- Stimuli (Glavan et al., 2020)
  - Distractors (24)
    - Shapes: ● ⬢ ◆
    - Colors: red - pink - purple
- Design
  - 500 trials
  - Two IVs – 4 conditions
    - Target-present trials (10% or 50%)
    - Amount of targets (1 or 3)
  - Measures
    - Accuracy, RT, eye tracking, and EEG

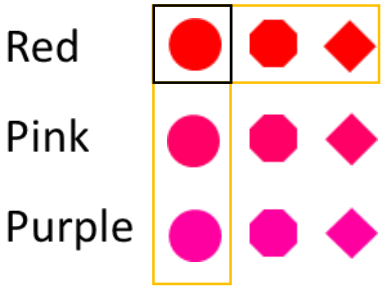
Visual Search with Fatigue – Model

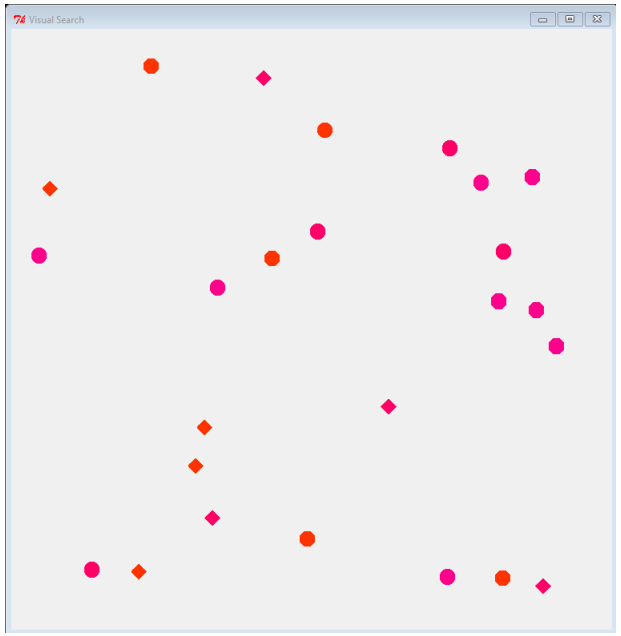












Red octagons

Varied distractors

Radar Detection – MOT-EW Task (Fox et al., 2023)

- MOT Task (Fox et al., 2023)
  - Hostiles (targets)
  - Friendlies (distractors)
  - MOT- Hostiles and quad alarms
  - EW – Attacks and EW alarm
  - Conditions – single/dual and # objects
- MOT Model
  - Need human-like visual search