# I see what you did there: Deep learning algorithms can classify cognitive tasks from images of eye tracking data

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## BACKGROUND

- The relationship between mental state and eye movement patterns was first demonstrated by Yarbus [1] (see Figure 1).
- In recent decades, computational models have categorized eye movements based on functional theories of the associated cognitive and neural systems [2].

### Purpose

Design a neural network alternative to the previously implemented models by categorizing eye movements using a simple deep learning model free of theoretical assumptions.

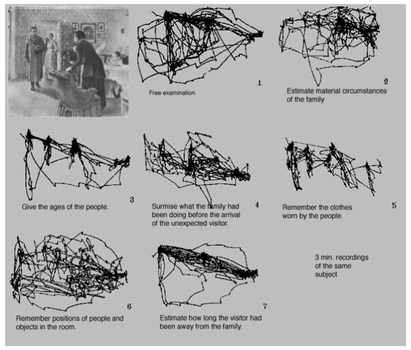



**Figure 1.** Figure from MacInnes et al. [2], originally adapted from Yarbus [1].

## DATASET

### Example Scenes

**Figure 2.** Scenes did not show any people or faces.

### Experiment

- Participants (N = 50) searched, memorized, or rated scene images (see Figure 2).

**Eye Tracking Data**

- Eye movements during the first 6s of each trial were tracked with SR Research EyeLink 2 eye tracker (1000Hz).
- After removing bad trials, N = 12177 trials were analyzed.

### Deep Learning Classification

- Implemented a convolutional neural network classifier using DeLINEATE, a deep learning toolbox [3].
- Data was split: Training: 70%; Test: 15%; Validation: 15%.
- Eye tracking coordinates were converted to **Plot Images** (**Filled** and **Hollow** Plots; see Figure 3).
- **Typical Eye Tracking** data was classified using X and Y coordinates, and Pupil Size data. Additionally, this data was systematically classified with **No X**, **No Y**, and **No Pupil Size** information.

### Example Images

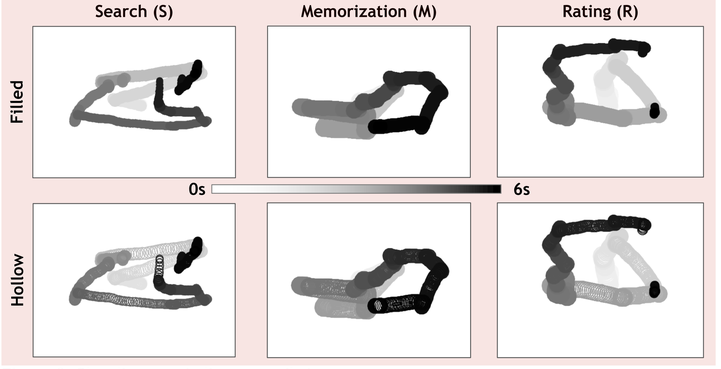
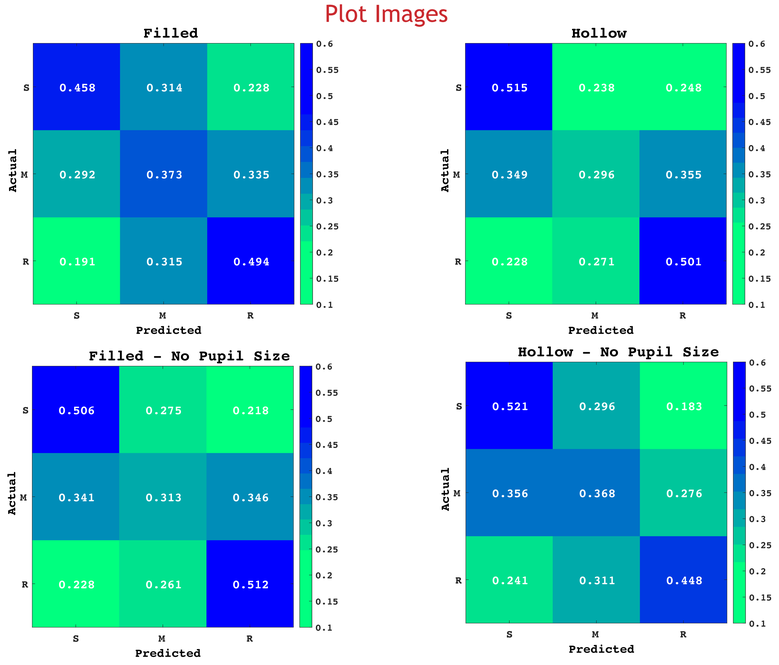



**Figure 3.** Plot diameter indicates pupil size measurements.

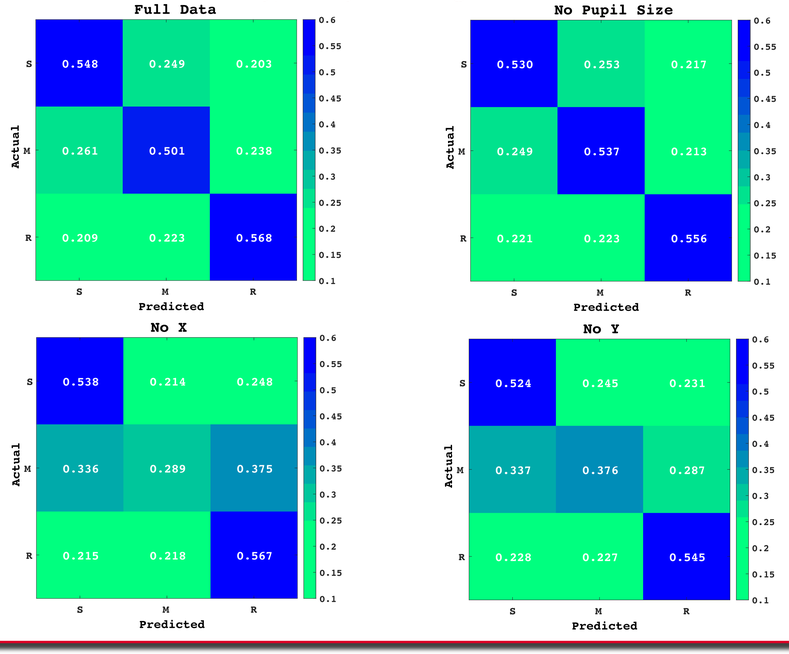
## CLASSIFICATION

- Confusion matrices (below) represent the probability of the actual trial type being classified (predicted) as a Search, Memorization, or Rating trial.

### Plot Images

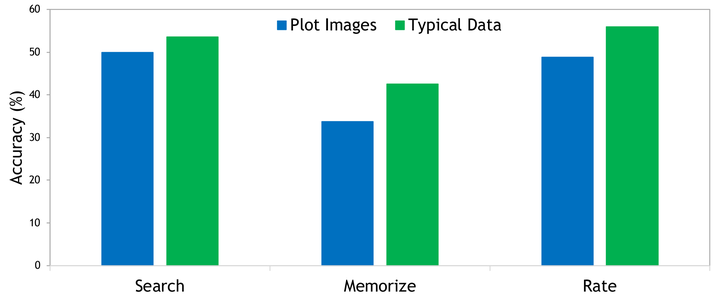



### Typical Eye Tracking Data

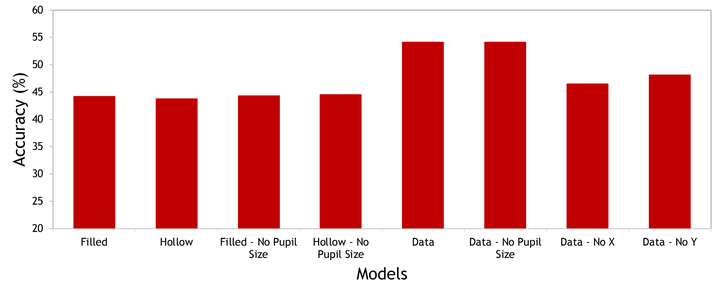



## OVERALL RESULTS

### Actual Task Classification Accuracy per Data Type




### Overall Classification Accuracy




## PRELIMINARY CONCLUSIONS

- The removal of pupil size did not negatively impact classification accuracy, but removing lateral and vertical eye movement information decreased classification accuracy.
- The shape of scene images and the natural distribution of objects within these images could be a factor in the apparent importance of the horizontal eye movements.
- When compared to eye tracking data from the other tasks, memorization data was not distinguishable.
- The images were classified at above chance levels of accuracy, commensurate to classifiers built on explicit cognitive models (see Figure 4).
- These findings suggest that deep learning models can extract a surprising amount of useful information from nearly-raw eye tracking data with minimal human guidance.

### Computer v. Theory

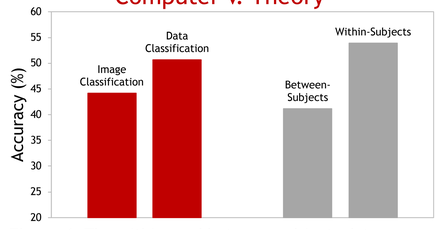



**Figure 4.** The within- and between-subjects data were classified by MacInnes et al. [2].

## REFERENCES & ACKNOWLEDGEMENTS

[1]Yarbus AL. Eye Movements and Vision, New York: Plenum. (Originally published in Russian 1965); 1967

[2]MacInnes JW, Hunt AR, Clarke ADF, Dodd MD. A generative model of cognitive state from task and eye movement. *Cognitive Computation*. 2018; 10: 703-717

[3]DeLINEATE: A deep learning toolbox for neuroimaging data analysis. Kuntzelman K, Williams JM, Samal A, Rao PK, Johnson MR. 2019. *Cognitive Neuroscience Society 26th Annual Meeting*, Poster B105. http://delineate.it

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