Saccadic and Pupillary Response as Biobehavioral Markers in a Perceptual Organization Task

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Abstract

Visual form perception involves grouping elements that occur along the border of an object. Sometimes borders are well defined, and sometimes less so. The perceptual organization (PO) task (Kurylo et al., 2017) employs 20 x 20 dot arrays differentiated by Color, Gabor or Luminance properties. Elements show different degrees of organization along either a horizontal or vertical axis. Organization is defined as the percentage of elements that are arrayed along the main orientation (100%, 90%, 80%, 70%). In the PO task, perceptual thresholds are measured using psychophysical staircase procedures. The present study uses eye tracking and pupillometry to examine biobehavioral markers associated with perceptual processing in the PO task. In particular, we investigated whether pupil diameter --an indicator of processing load-is related to % organization levels within the PO task, and whether this correlates with behavioral performance in terms of RT and accuracy. We also examined whether saccades in the horizontal vs. vertical direction were correlated with task difficulty for Color, Gabor and Luminance respectively. We tested 60 participants on the PO task using Tobii and Gazepoint eye trackers. %organization level (100>90>80>70) was correlated with RT ($p<.001$) and accuracy ($p<.001$). Saccades were identified by change in x,y coordinates above the 80th percentile, which segregated saccades from normal eye jitter. We found that total horizontal saccades were correlated with % organization ($p<.001$), whereas vertical saccades were not. These data represent the first evidence of biobehavioral markers for perceptual organization.

# The Perceptual Organization (PO) Task

- The PO Task taps into visual processing of form and texture under varying degrees of noise.
- This task has been found to be problematic for pathological populations such as Schizophrenia, indicating problems in processing of visual form.
- Stimuli consisted of 20 x 20 arrays of elements that indicate general organization in either Horizontal or Vertical direction.
- Degree of organization was varied across stimuli: 100%, 90%, 80%, 70%, where the percentages indicate the proportion of elements that conform to the dominant orientation alignment.
- We used three kinds of visual elements that defined orientation:
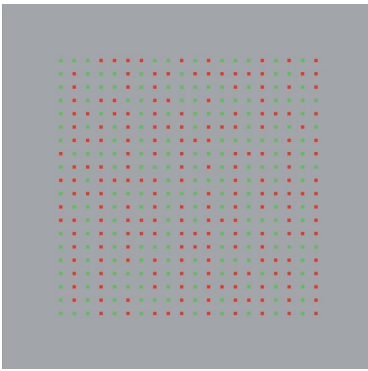 Color, Luminance, and Gabor.

Color Stimuli

H
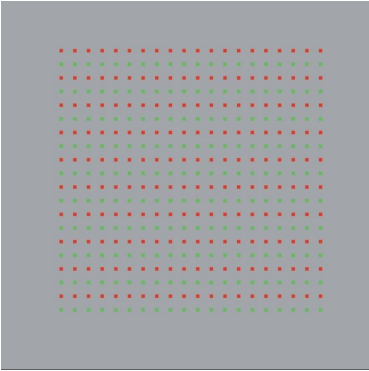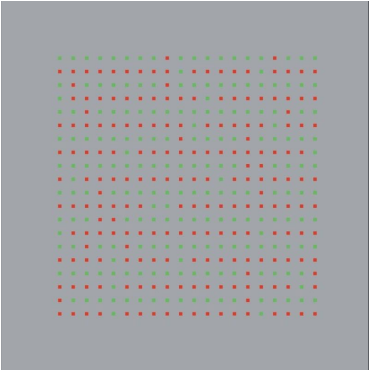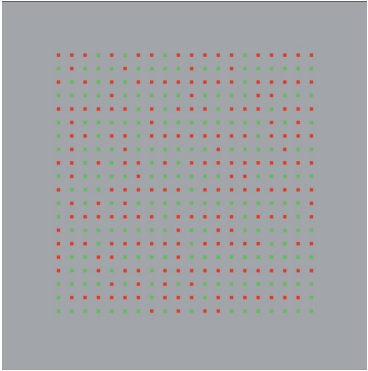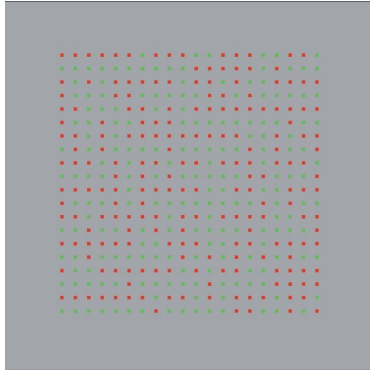
100% 90% 80% 70%

V
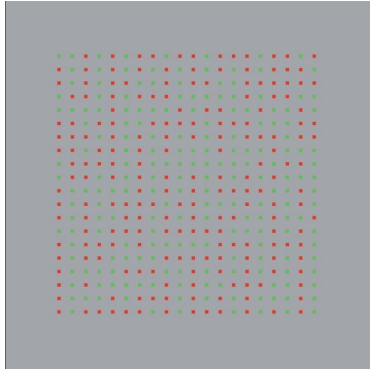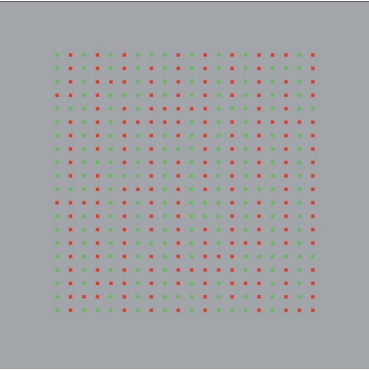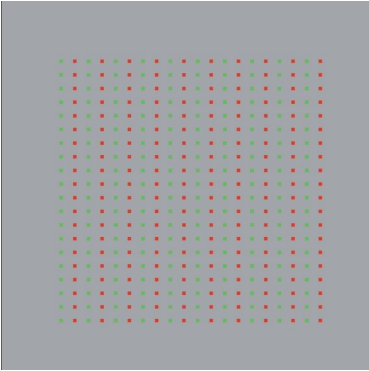
Gabor Stimuli

H
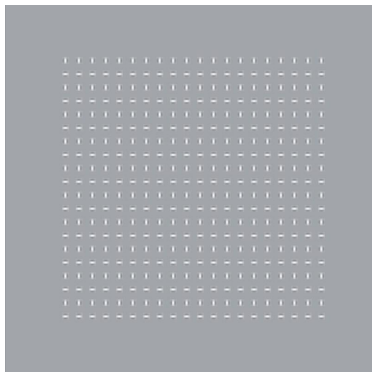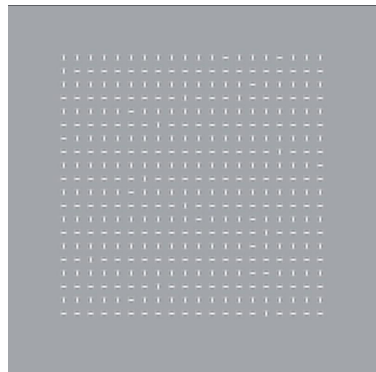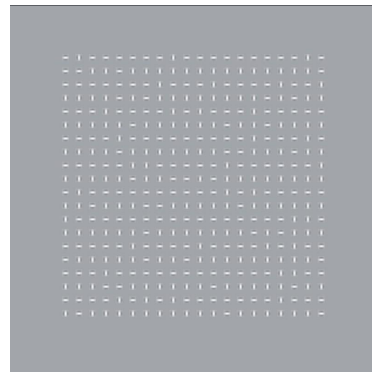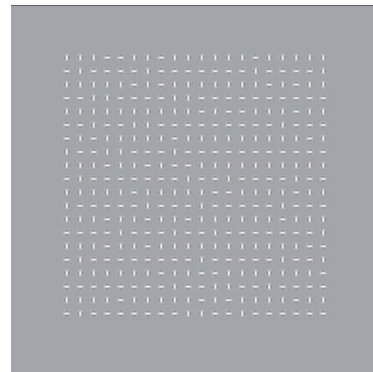
100% 90% 80% 70%

V
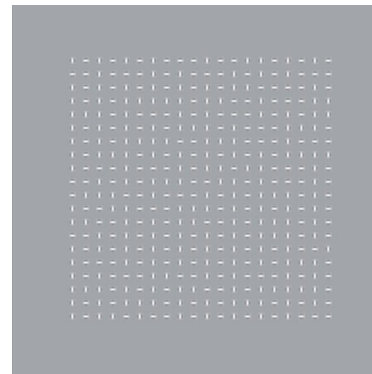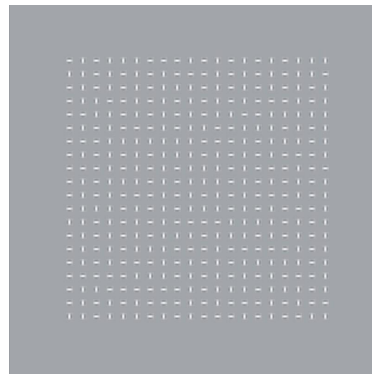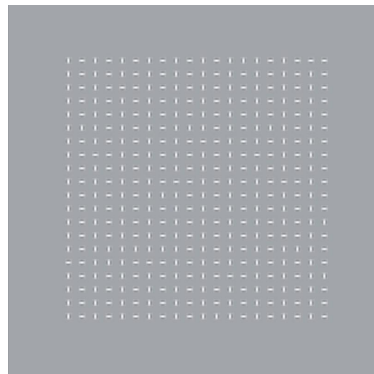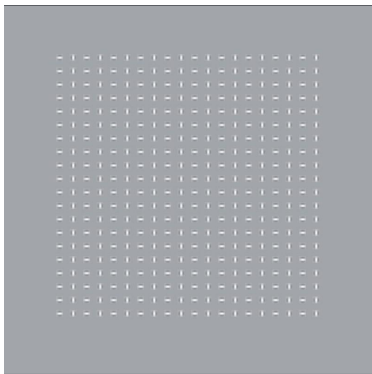
Luminance Stimuli
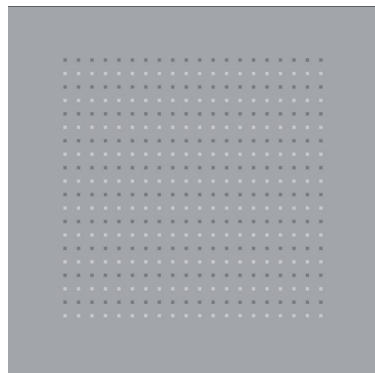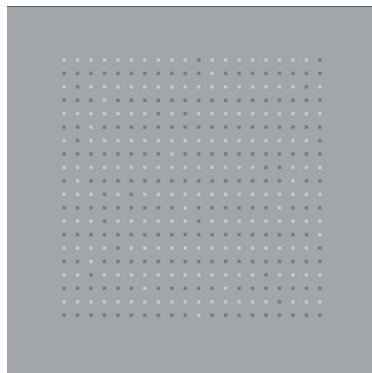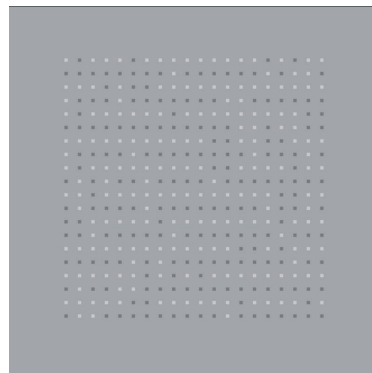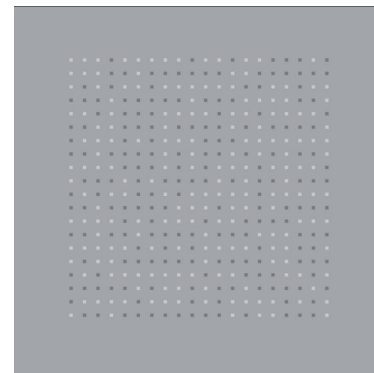
H			
100%	90%	80%	70%
V			
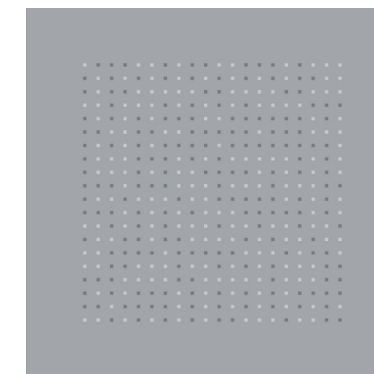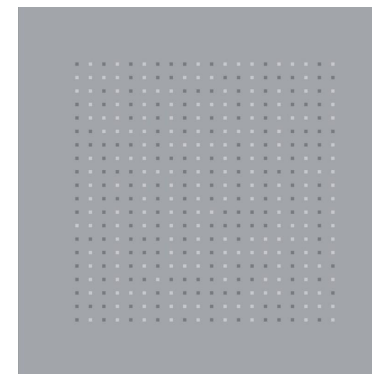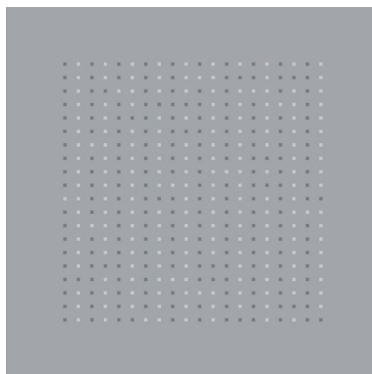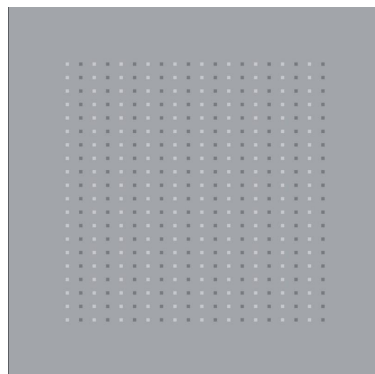
Behavioral Response

- Participants responded with one of two key presses indicating whether they thought the orientation of the Stimulus was Horizontal (H) or Vertical (V)
- Accuracy and Reaction Time data were collected on this response

Pupil Dilation and Saccadic Response Measures

- Delta Pupil Size was recorded by calculating difference scores between the first pupil diameter data capture of each trial and the last capture prior to response.
- Saccadic Response was calculated by collecting eye-movement data in either horizontal or vertical direction after filtering out jitter that was not part of an overall saccade.

Independent Variables

1. IV 1: Percentage of Organization
   a. 100% (Easiest)
   b. 90%
   c. 80%
   d. 70% (Hardest)

2. IV 2: Task Category
   a. Color (Easiest)
   b. Luminance
   c. Gabor (Hardest)

Dependent Variables

1. Reaction Time
2. Accuracy
3. Pupil Dilation
4. Horizontal and Vertical Saccadic Eye Movement

Methodology

2 eye trackers used: Tobii T60 (Pupil Dilation) and Gazepoint GP3 (Saccades)

- Tobii: n = 26 (14 males, mean age: 26.5 yrs);
- Gazepoint: n = 36 (8 males, mean age: 23.5 yrs)

(All participants had normal/corrected vision, with no color blindness nor history of visual deficits)

Task:

- 6 Blocks of 40 trials (3 type * 2 orientation * 4 levels)
- Stimulus appeared for 417 msec, preceded by a white fixation cross
- Participants responded by pressing keys to indicate stimulus orientation
- Accuracy and reaction time were recorded

Reaction time across levels

Estimated Marginal Means of Reaction Time

Error bars: 95% CI

Accuracy across levels
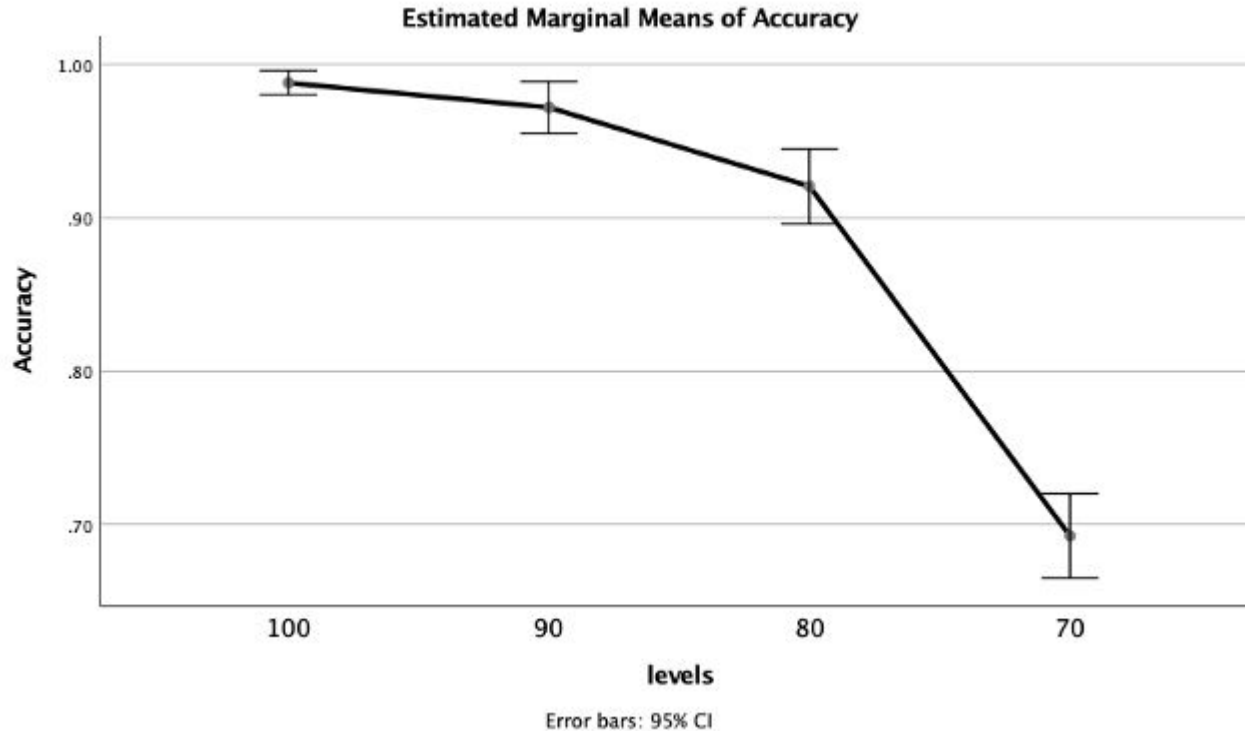

Estimated Marginal Means of Accuracy

Error bars: 95% CI
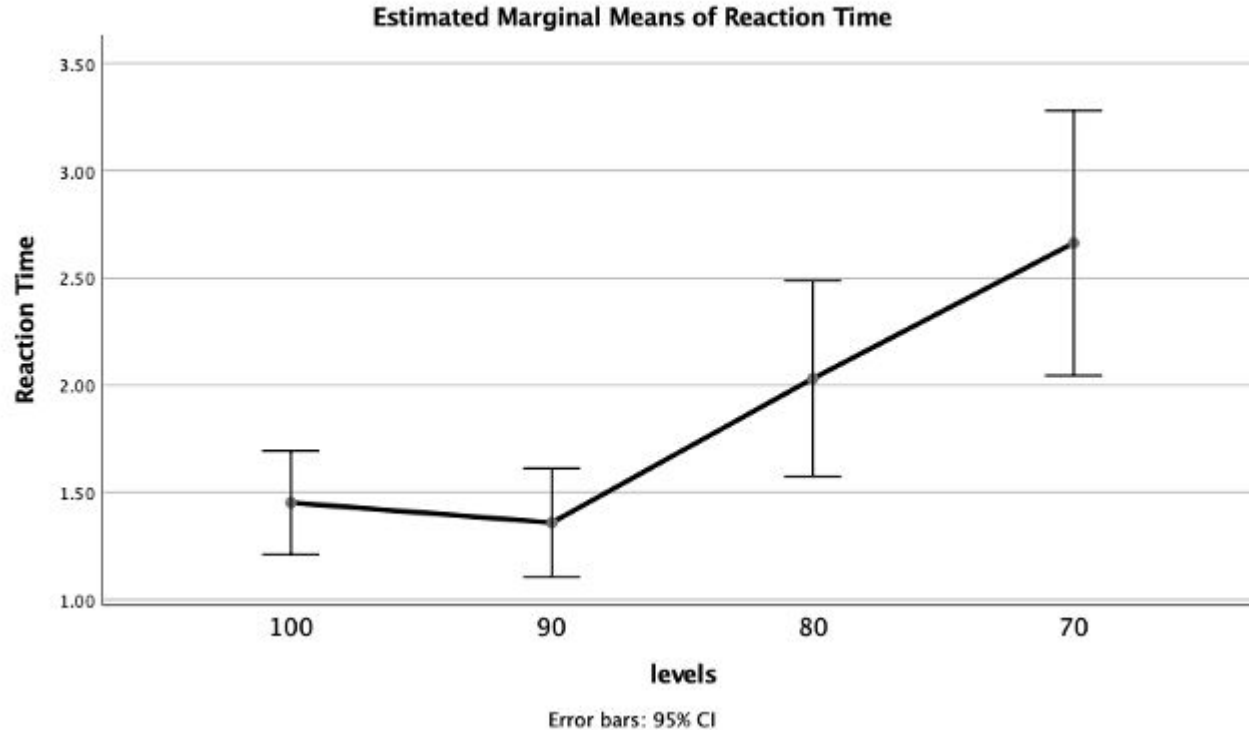
Summary of Behavioral Data

- Accuracy was significantly correlated with task difficulty across levels and stimulus types ($F_{(3, 31)} = 167.762$, $p < 0.001$).
- Reaction Time was also significantly correlated with task difficulty across levels and stimulus types ($F_{(3, 31)} = 21.298$, $p < 0.001$).

Dilation - Color

Dilation - Lumin

Estimated Marginal Means of Pupil Dilation (Lumin)

Estimated Marginal Means of Pupil Dilation (Lumin)
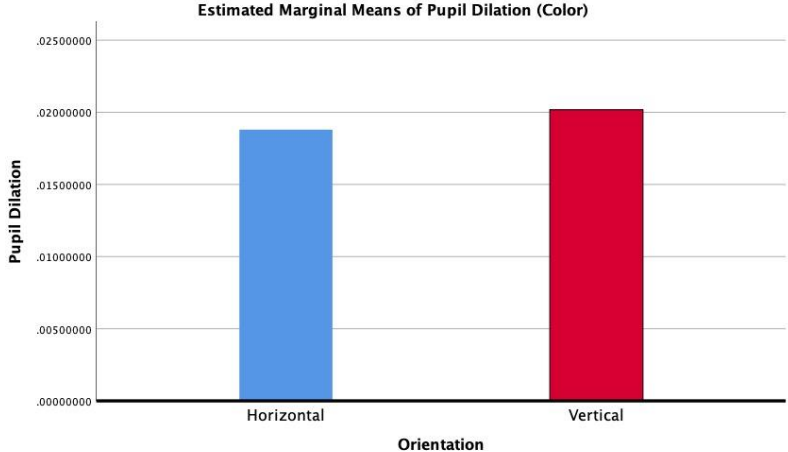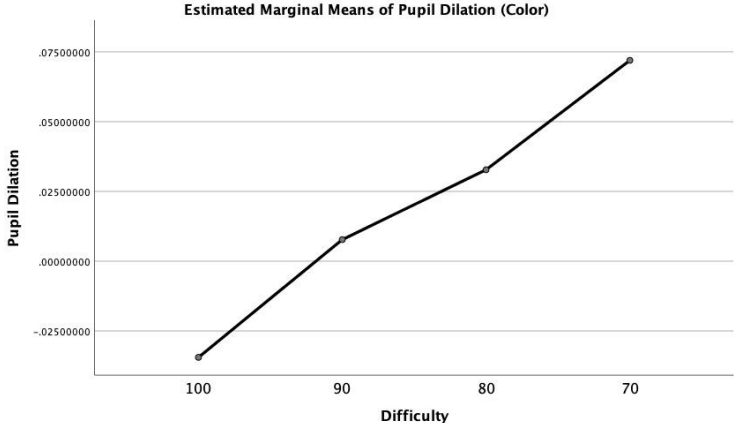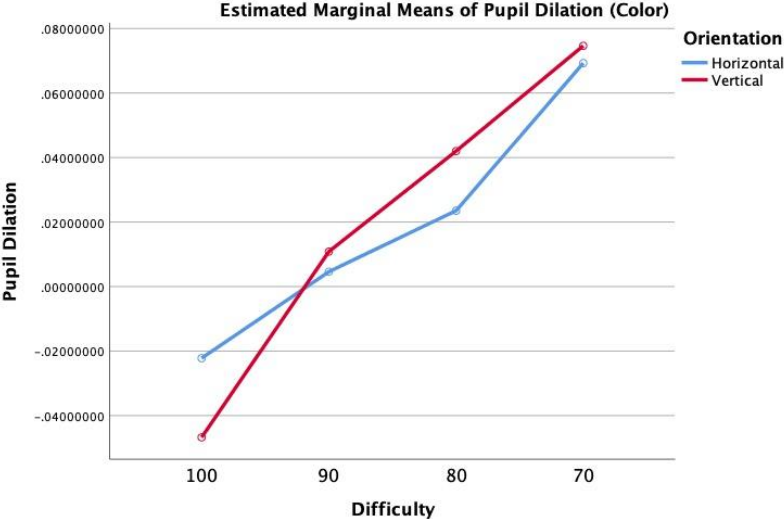
Estimated Marginal Means of Pupil Dilation (Lumin)

Dilation - Gabor
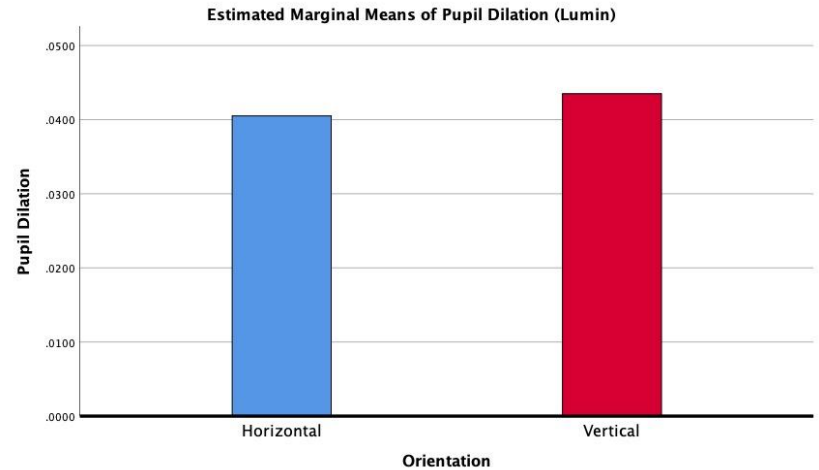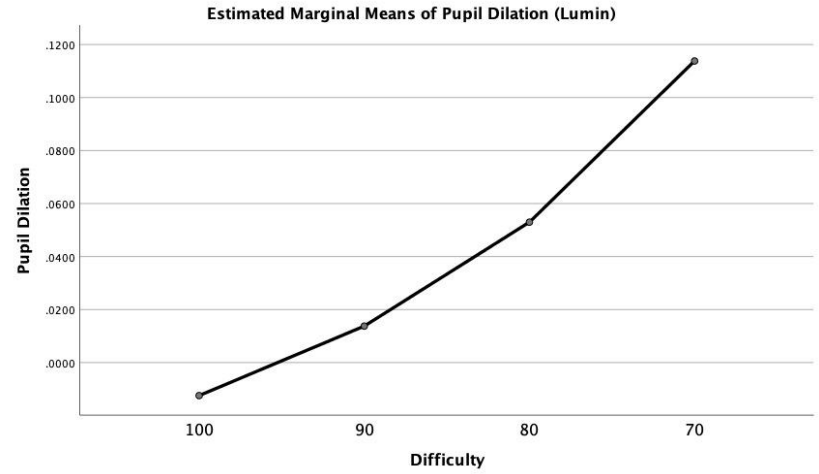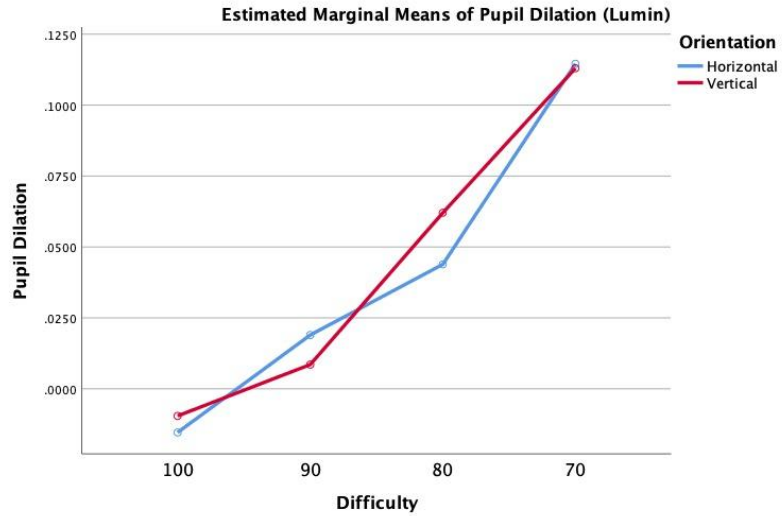
Estimated Marginal Means of Pupil Dilation (Gabor)

Dilation - across 3 types

Estimated Marginal Means of Pupil Dilation

Estimated Marginal Means of Pupil Dilation

Estimated Marginal Means of Pupil Dilation
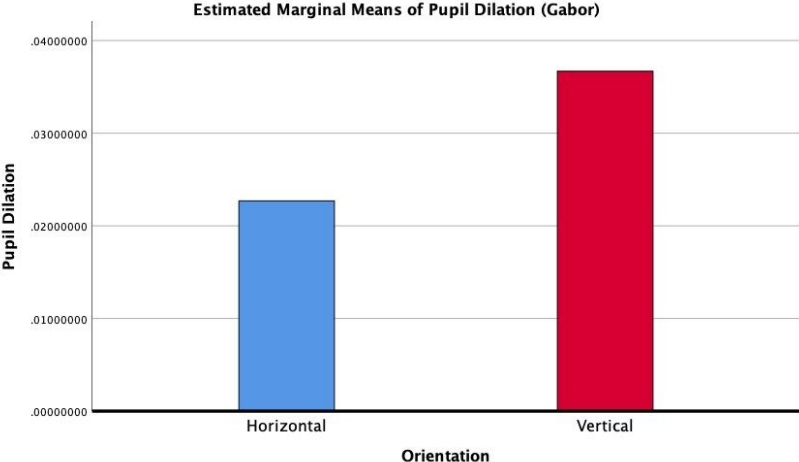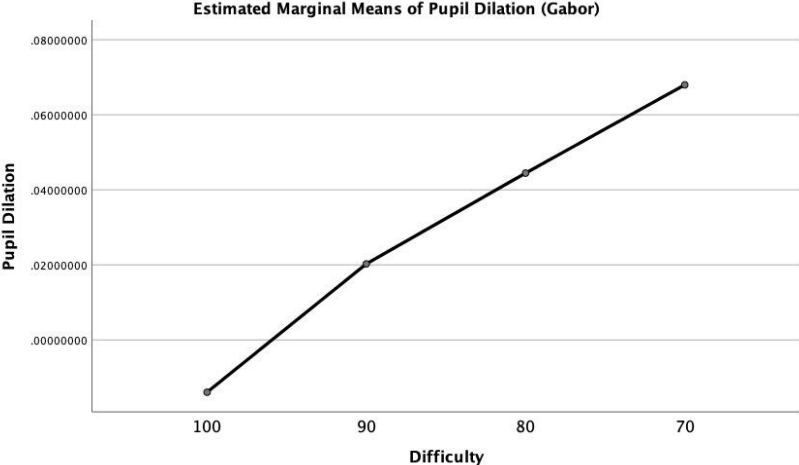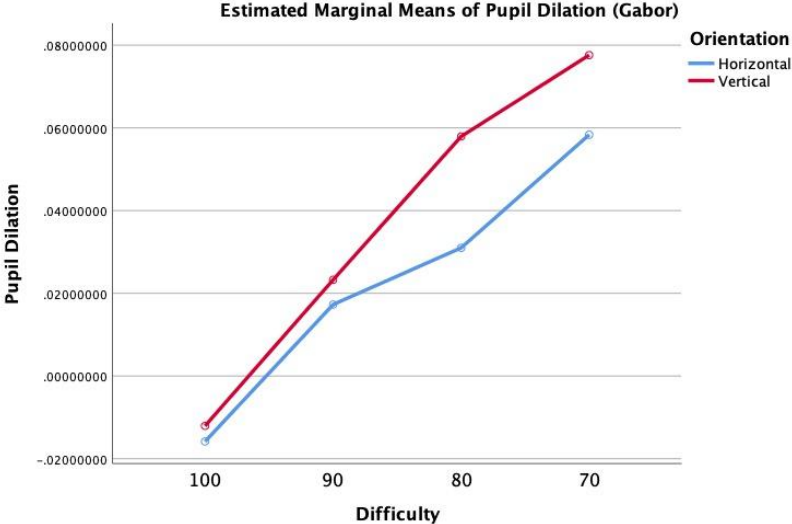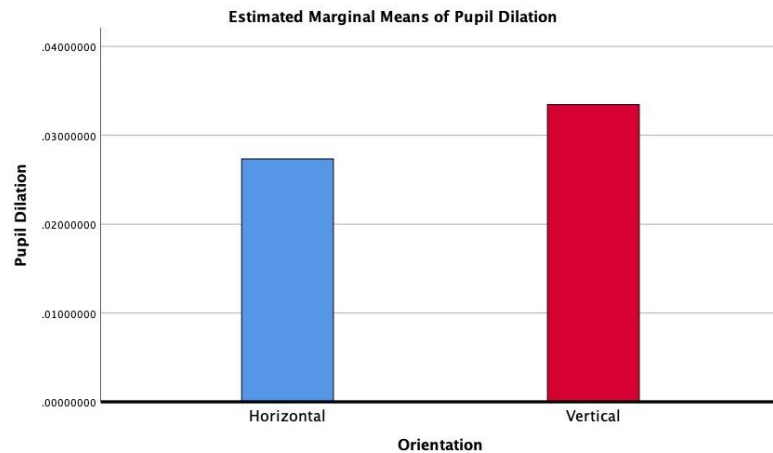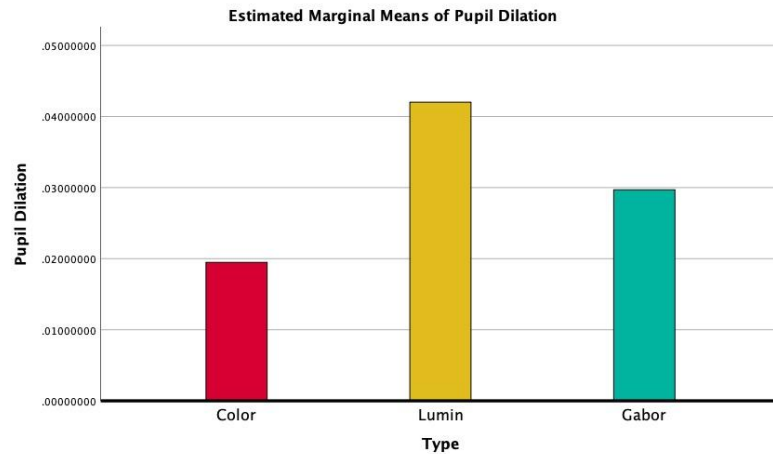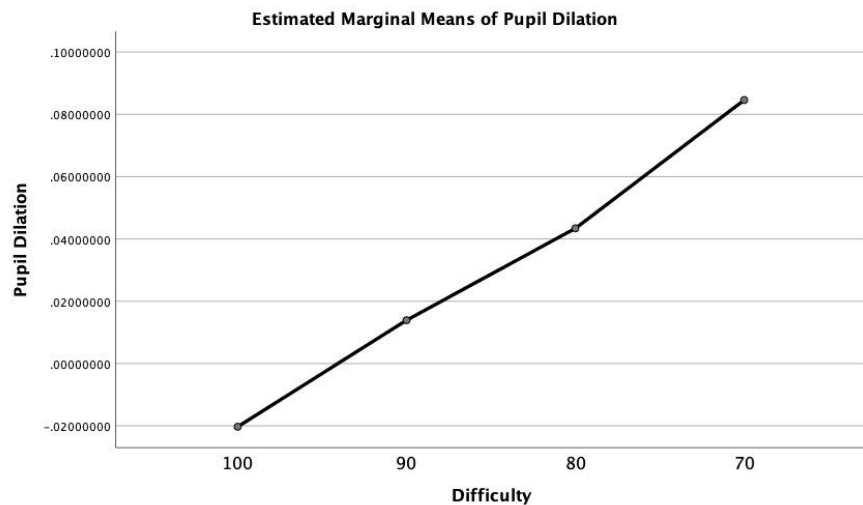
Summary of Pupil Dilation Effects

- For all stimulus types (color, luminance and gabor), pupil dilation (difference between initial and final diameter per trial) increased linearly with task difficulty ($F_{(3, 25)} = 15$, $p < 0.001$, $\eta 2 = .64$).
- Vertical Orientation induced significantly greater PD than Horizontal in all conditions.
- These data confirm the availability of pupil dilation as a biomarker of processing load in this task.
- NOTE: the delta pupil method must be used in this task, as simple comparisons of average pupil size across trials does not yield comparable effects due to noise in data capture.

Saccadic Exploration of Stimuli by Condition

Stimulus

- Stimulus Type (Color, Luminance, Gabor)
- Difficulty Level (100, 90, 80, 70)

Response

- Horizontal Saccades (total horizontal saccadic eye movement)
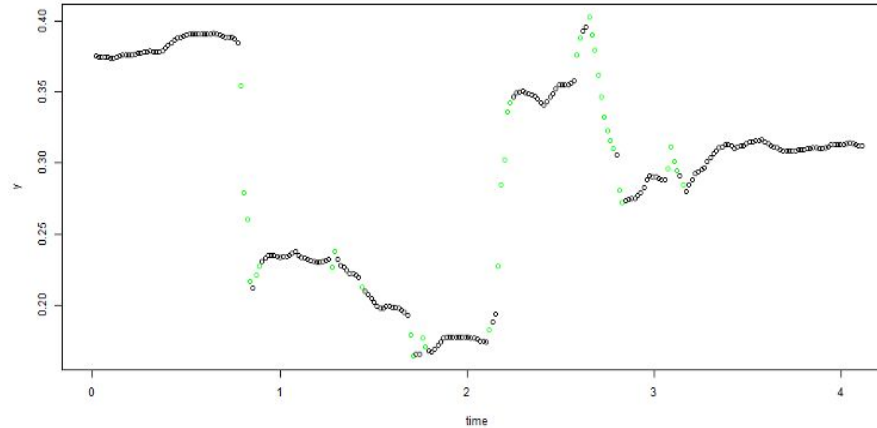- Vertical Saccades (total vertical saccadic eye movement)

Saccade and Movement Direction Definition

- Data points were categorized as saccades if either velocity on x-axis or y-axis were beyond 80th percentile of velocity (rate of change in X,Y coordinates) for each participant

Eye movement on y axis for a sample trial: Dots are highlighted in green if their velocity exceeds 80th percentile.

If abs (tan (Vy/Vx)) > tan (60) → Vertical Movement; If abs (tan (Vy/Vx)) < tan (30) → Horizontal Movement

(velocity-based threshold algorithm: Salvucci & Goldberg, 2000).

Horizontal Saccades: Color Stimuli by Difficulty Level

Estimated Marginal Means of Horizontal Saccades (Color)
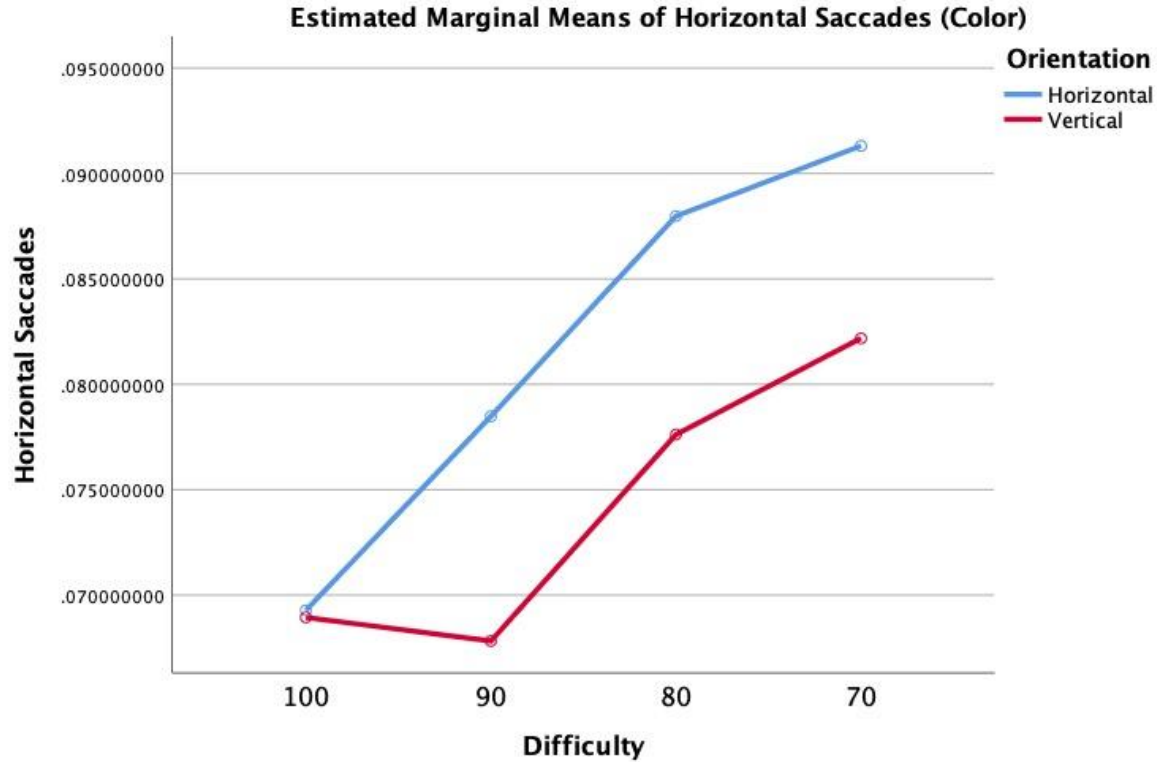
Horizontal Saccades: Gabor Stimuli by Difficulty Level

Horizontal Saccades: Luminance Stimuli by Difficulty Level
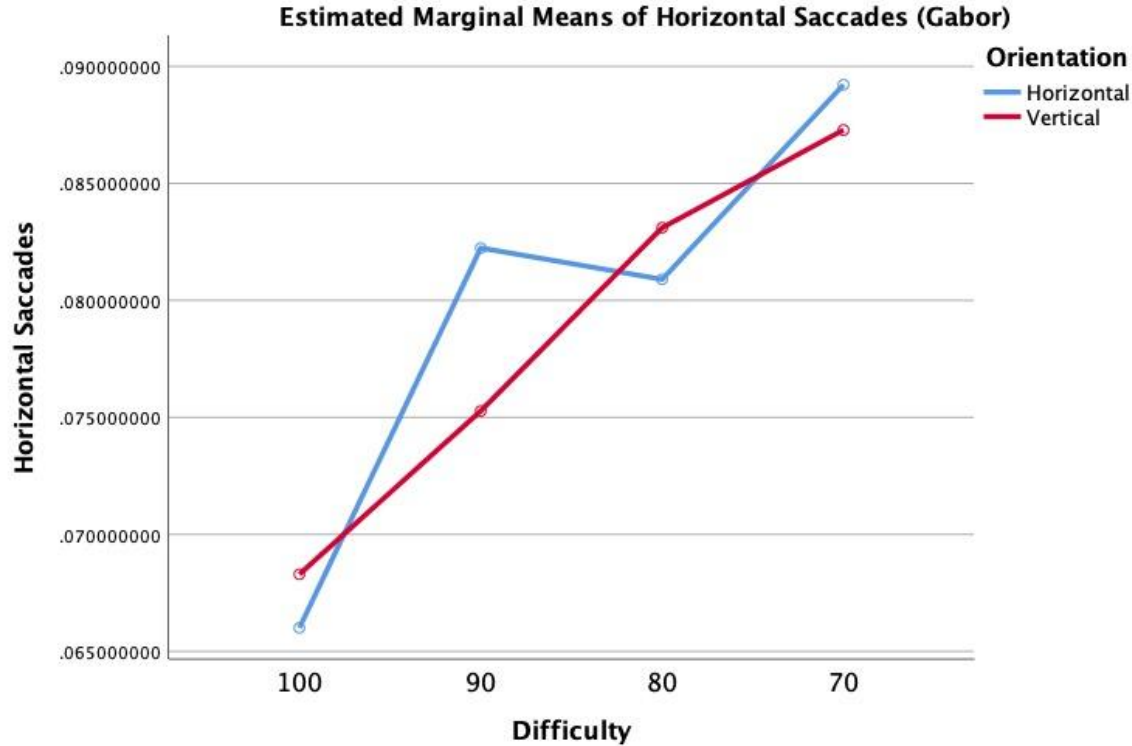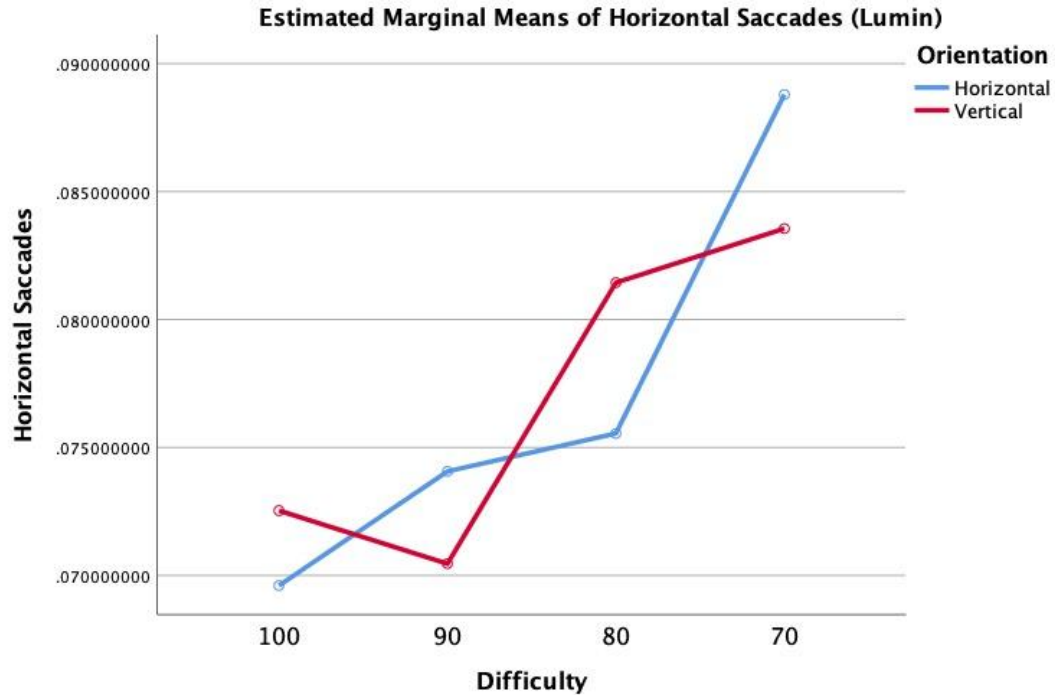
Estimated Marginal Means of Horizontal Saccades (Lumin)

Vertical Saccades: Color Stimuli by Difficulty Level

Estimated Marginal Means of Vertical Saccades (Color)

Vertical Saccades: Gabor Stimuli by Difficulty Level

Estimated Marginal Means of Vertical Saccades (Gabor)
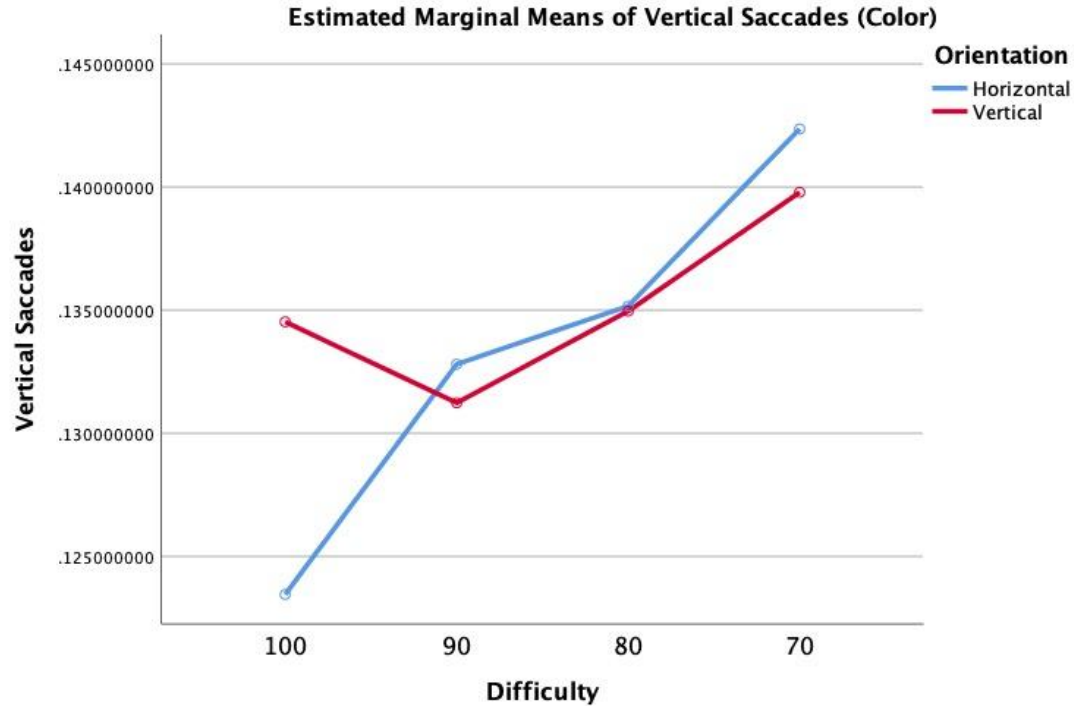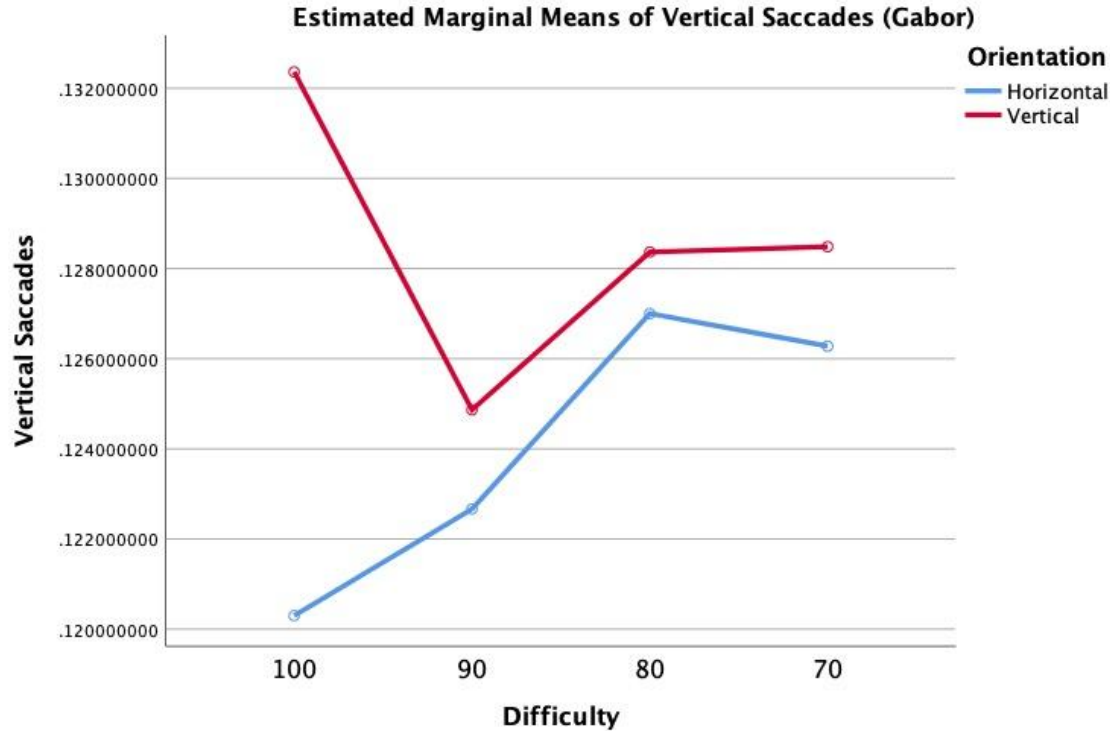
Vertical Saccades: Luminance Stimuli by Difficulty Level
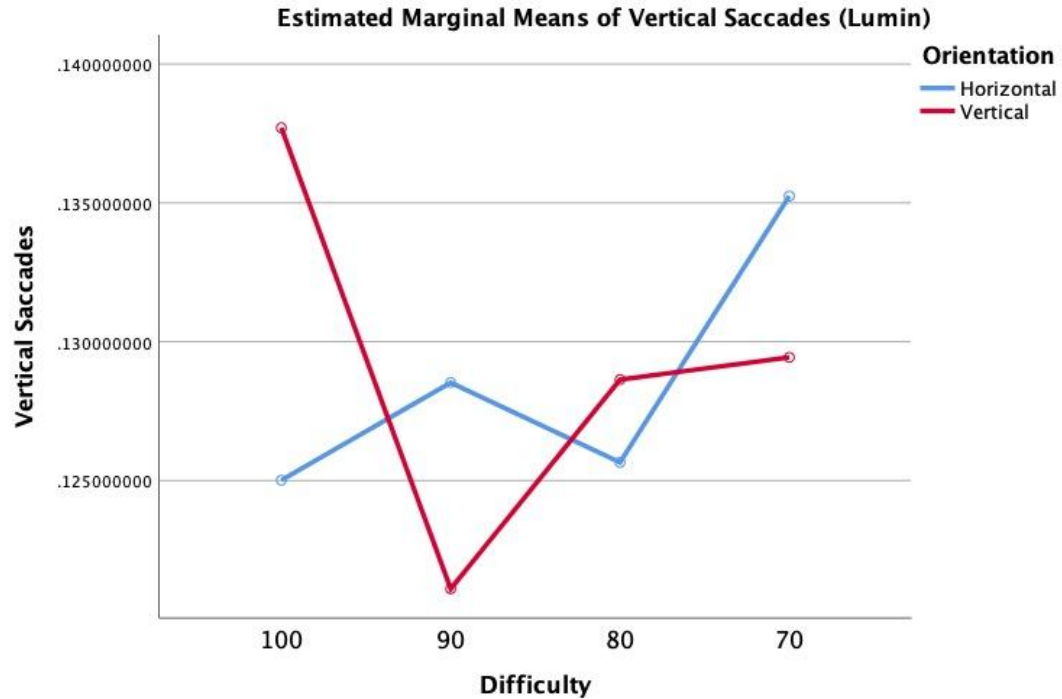
Summary: Saccade Results

- Horizontal saccadic activity was positively correlated with task difficulty in all conditions for stimulus type and orientation ($F_{(3, 33)} = 11$, $p < 0.001$)
- Vertical saccades did not show correlations with task difficulty in any conditions except one (possibly due to chance).
- Only horizontal saccadic activity is a reliable biomarker of visual processing in this task.

General Conclusions

- The present experiment reveals that, along with accuracy and RT, pupil dilation and horizontal saccadic activity both correlate with level of organization (task difficulty) in the Perceptual Organization Task.
- These results provide reliable biomarkers of visual processing in this task.
- We propose to use these biomarkers, along with ERP MMN, to identify the specific biological and behavioral deviations in schizophrenic and other populations showing deficits in perceptual organization.

References

Kurylo, D. D., Waxman, R., Kidron, R., & Silverstein, S. M. (2017). Visual training improves perceptual grouping based on basic stimulus features. *Attention, Perception, & Psychophysics*, 79(7), 2098-2107.

Salvucci, D. D., & Goldberg, J. H. (2000, November). Identifying fixations and saccades in eye-tracking protocols. In *Proceedings of the 2000 symposium on Eye tracking research & applications* (pp. 71-78). ACM.