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

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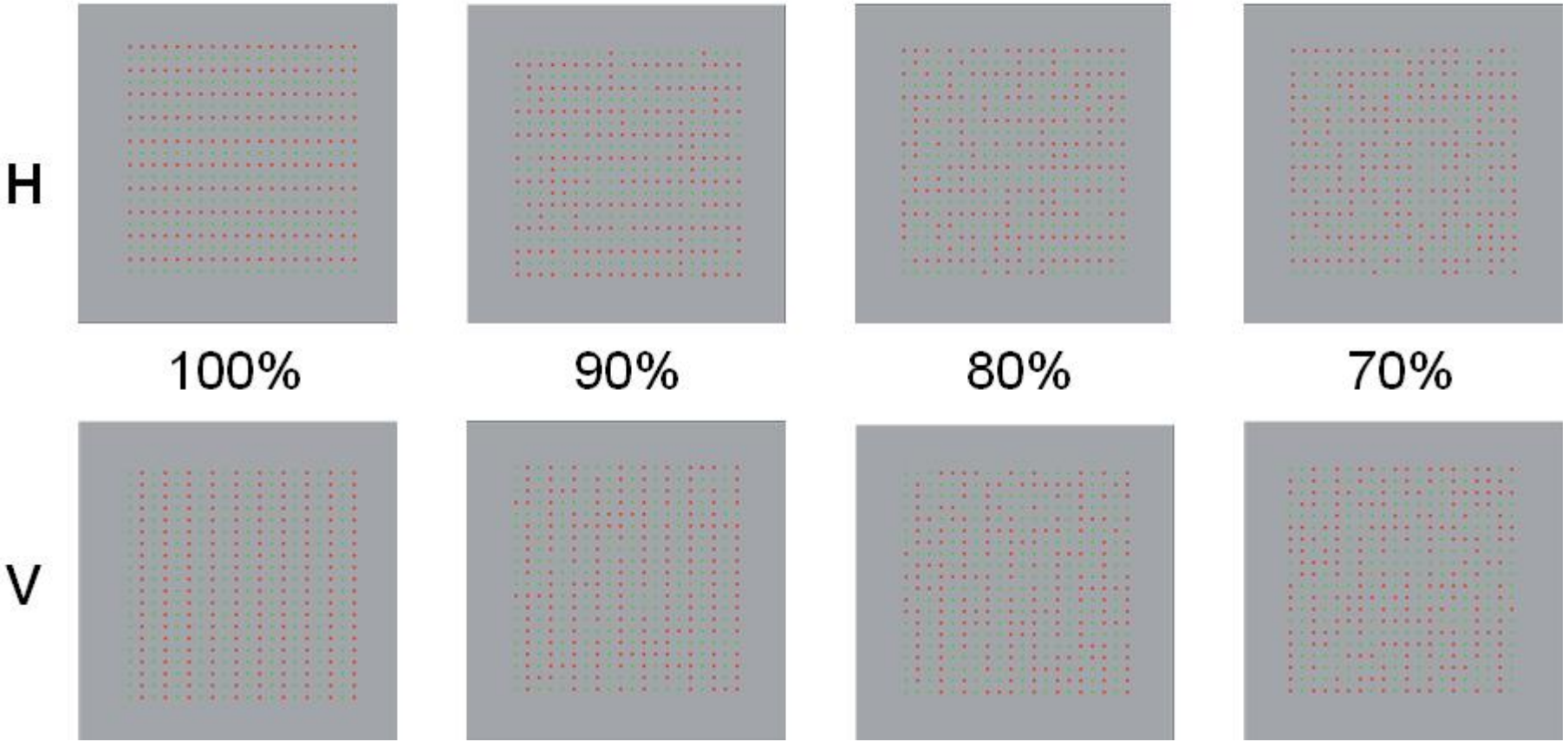
Abstract

- 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.

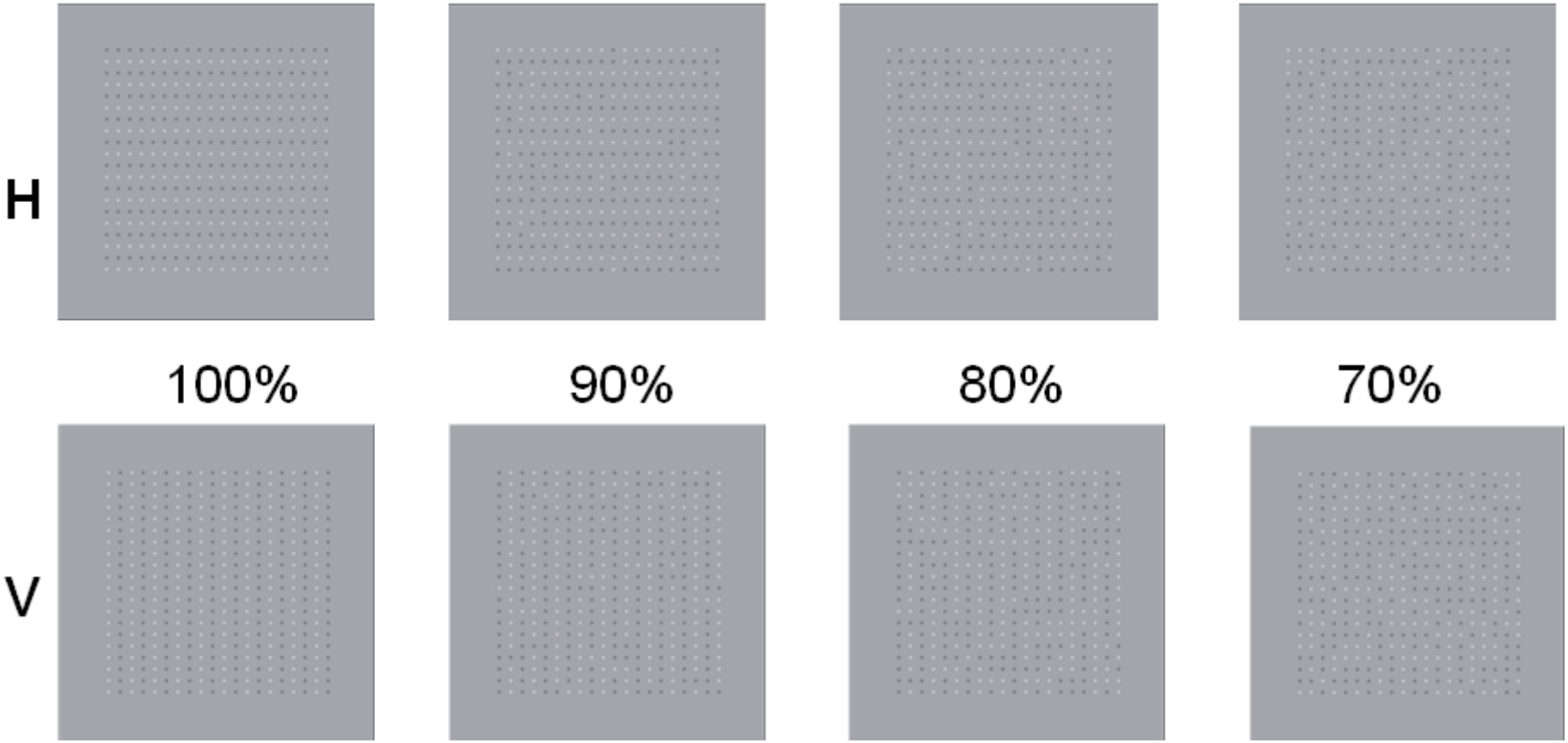
The Perceptual Organization (PO) Task

- The PO task by Kurylo et al. (2017) taps into visual processing of form and texture under varying degrees of noise.
- This task is problematic for pathological populations (e.g., Schizophrenia), indicating problems in organizing perceptions of visual form (Kurylo et al., 2018).
- Stimuli consisted of 20 x 20 dot arrays of elements that indicate general organization in either a Horizontal or Vertical orientation.
- 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 (**Horizontal** or **Vertical**).
- We used eye-tracking methods to analyze pupillary and saccadic responses in a PO task with three types of visual elements that defined stimuli orientation: Color, Luminance and Gabor.

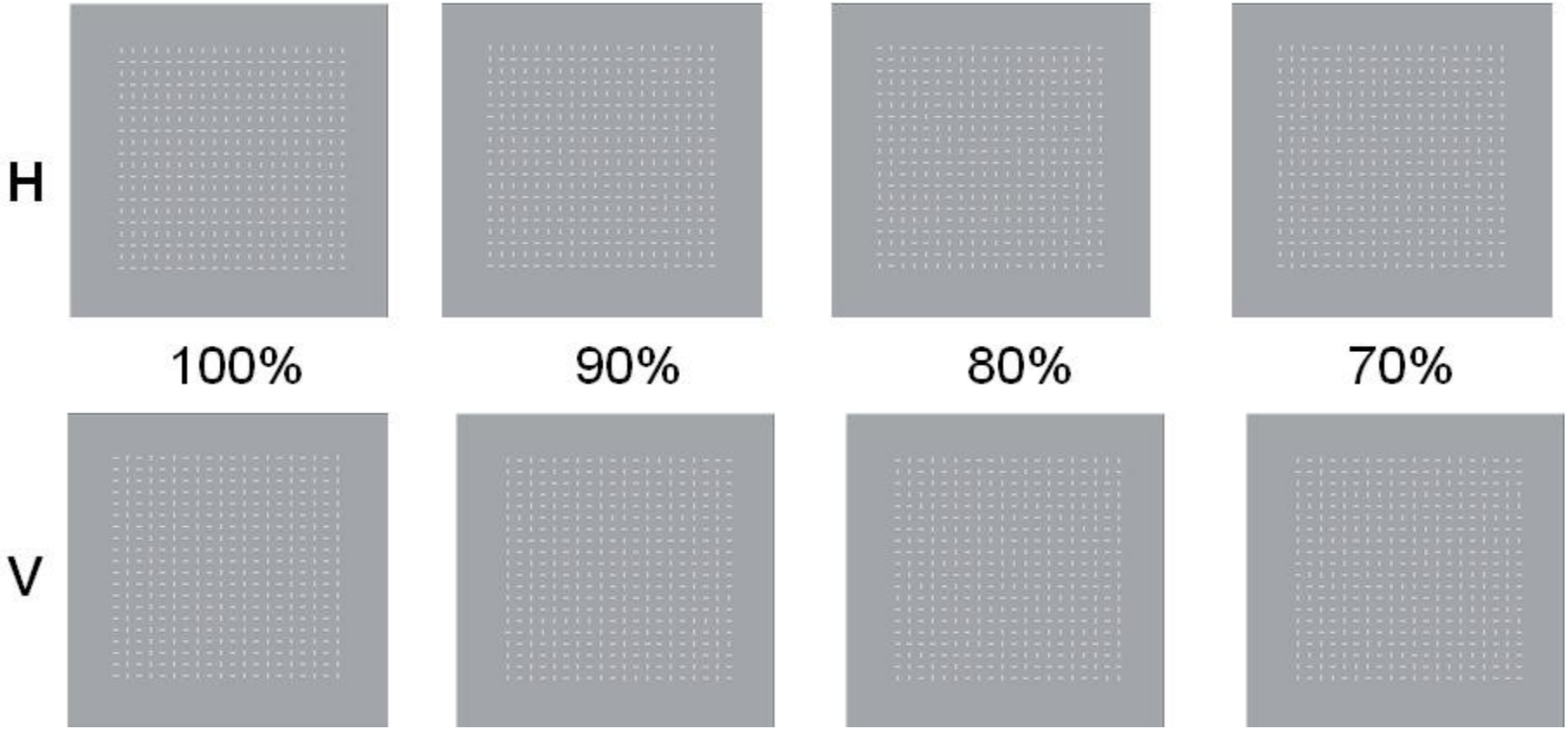
Color Stimuli



Luminance Stimuli



Gabor Stimuli



Behavioral Measures:

- Participants responded with one of two key presses to indicate whether they perceive that the orientation of the stimulus was either Horizontal **(H)** or Vertical **(V)**.
- **Accuracy**: Participants' key responses were recorded to assess if they accurately identified the correct orientation of the stimulus.
- **Reaction Time**: Latency to key press (milliseconds)

Pupil Dilation and Saccadic Response Measures

- **Pupil Dilation**: Pupil size delta values were attained by calculating difference of scores between the first pupil diameter data capture of each trial and the last capture prior to response.
- **Saccadic Response**: 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

Equipment: 2 eye trackers used: Tobii T60 (Pupil Dilation) and Gazepoint GP3 (Saccadic measures)

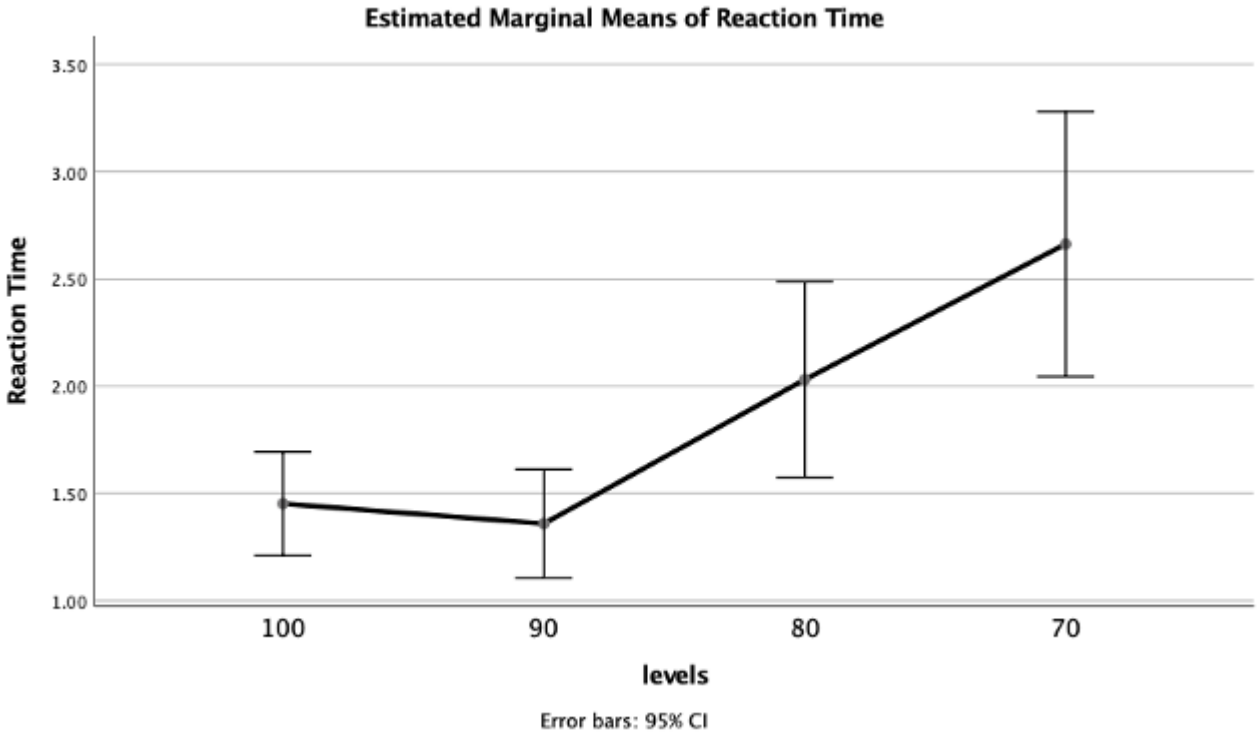
Participants:

- 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 history of visual deficits, and their visual acuity was assessed using a Snellen chart and an Isihara color-blindness test.

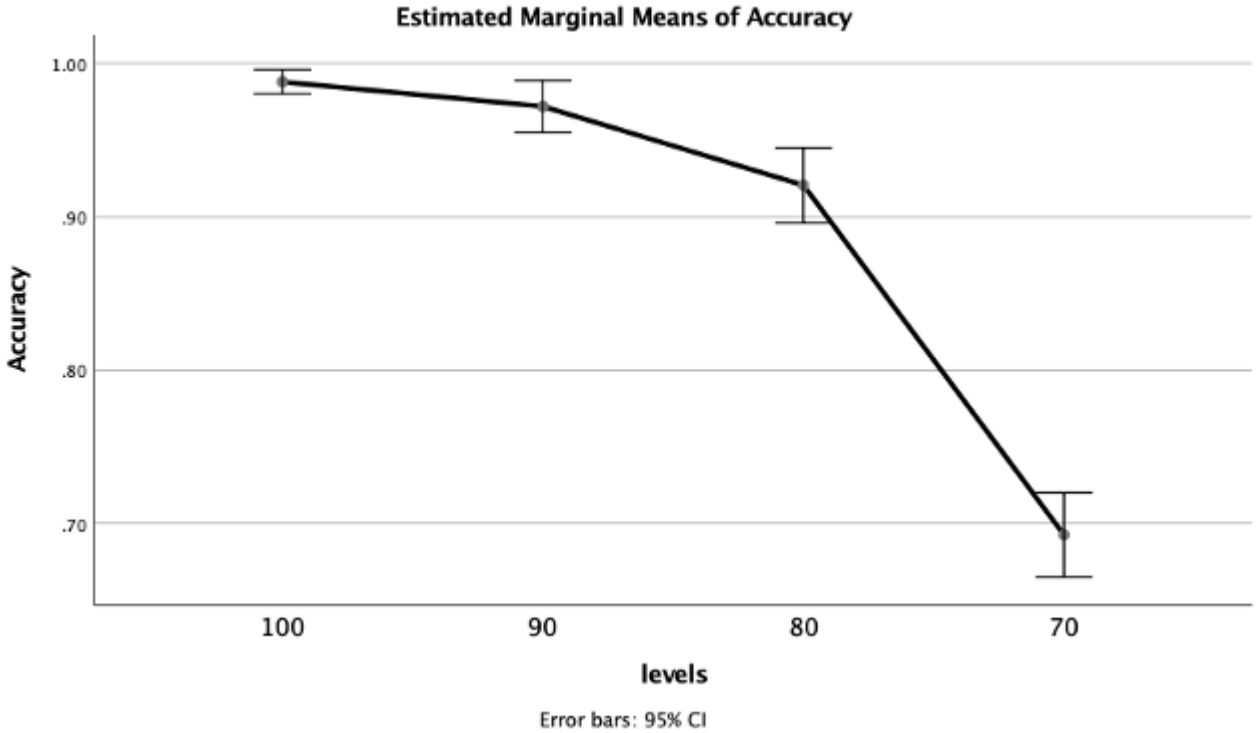
Task Design

- Presented: 6 blocks of 40 trials (3 stimuli types x 2 orientations x 4 levels)
- Stimulus appeared for 417 msec, preceded by a white fixation cross.
- Participants responded by pressing keys to indicate stimulus orientation.
- Pupillary response, reaction time and accuracy were recorded.

Reaction time across levels



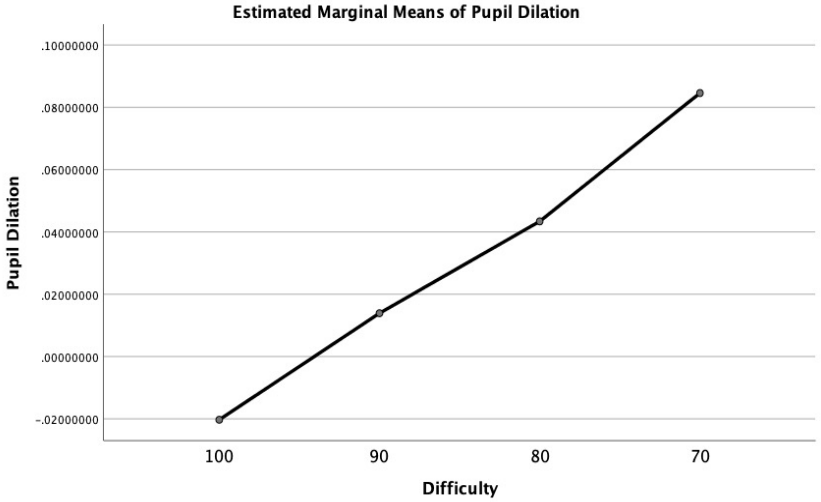
Accuracy across levels



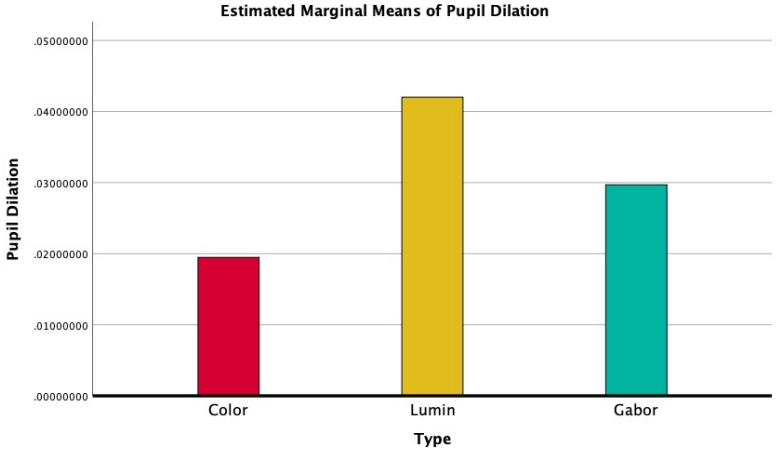
Summary of Behavioral Data

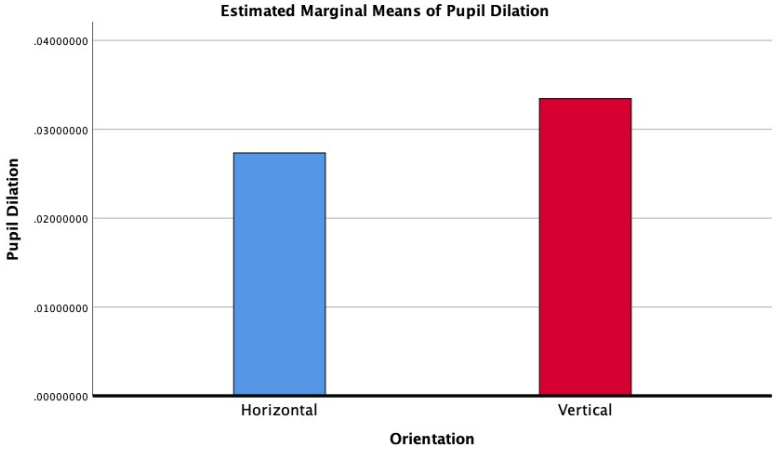
- Accuracy was significantly correlated with task difficulty across levels and stimulus types (F (3, 31) = 167.8, p < 0.001).
- Reaction Time was also significantly correlated with task difficulty across levels and stimulus types (F (3, 31) = 21.3, p < 0.001).

Pupil Dilation: Across 3 stimuli types

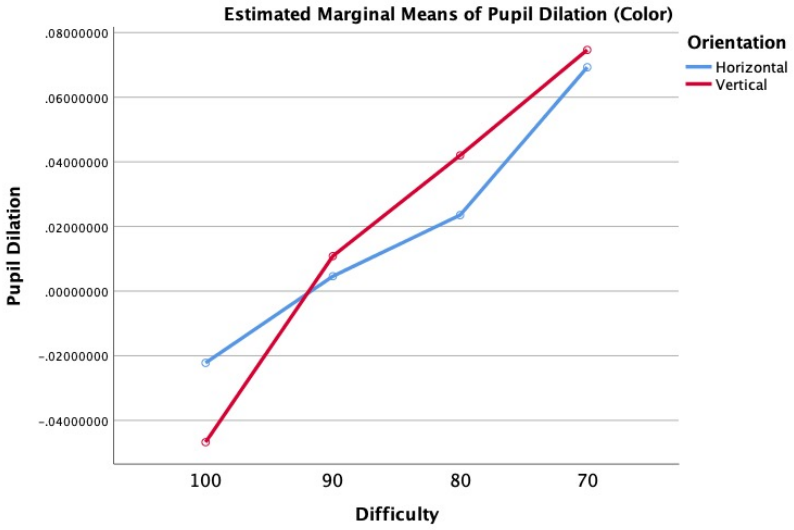


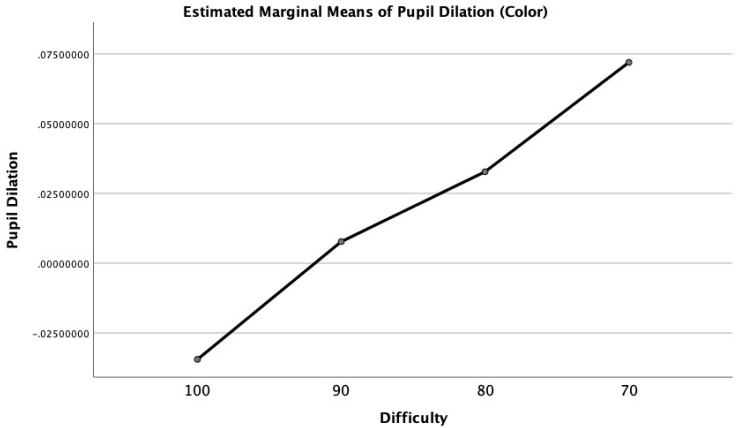
F (3, 25) = 15, *p* < 0.001, η2 = 0.64

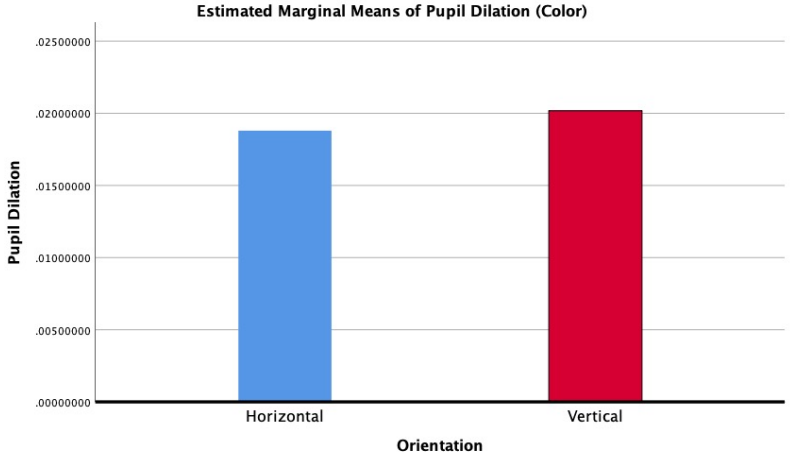




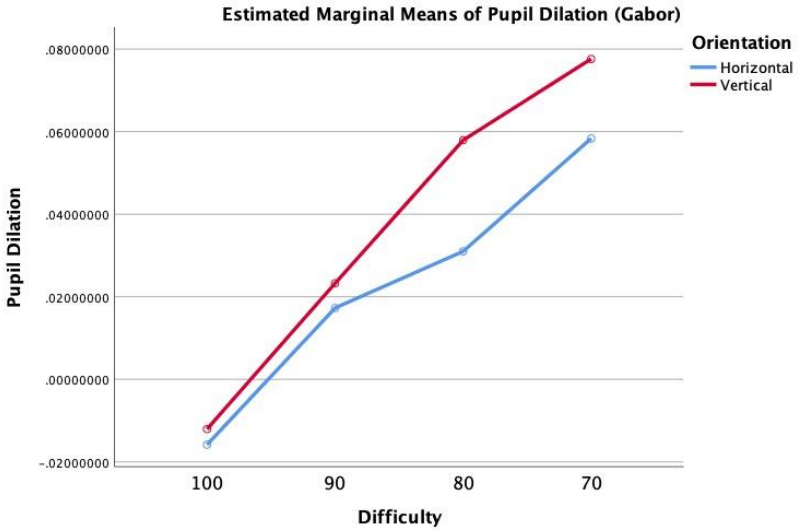
Pupil Dilation: Color Stimuli

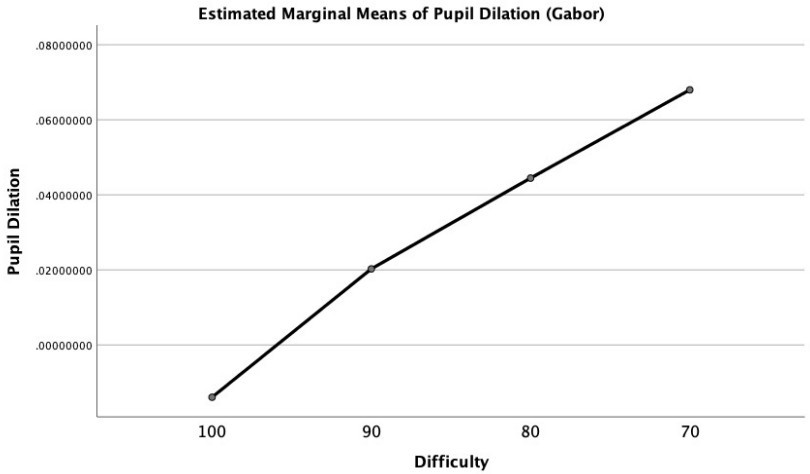


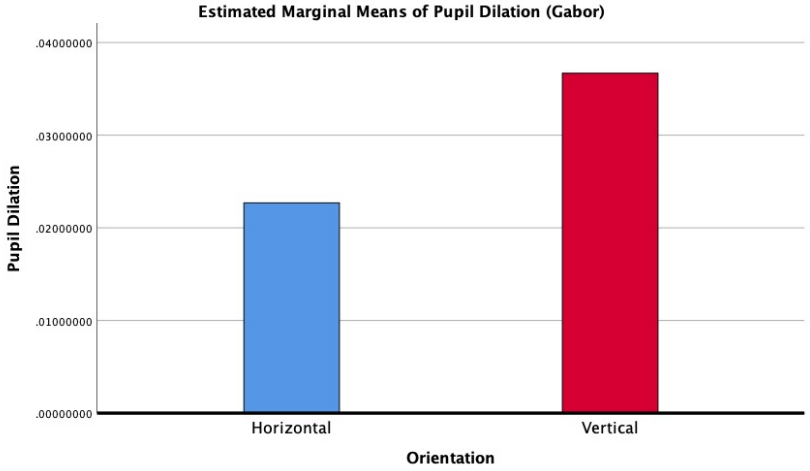




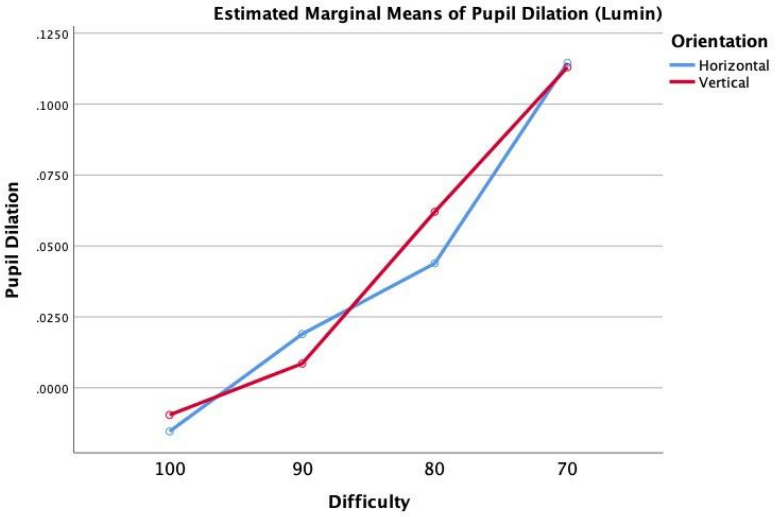
Pupil Dilation: Gabor Stimuli

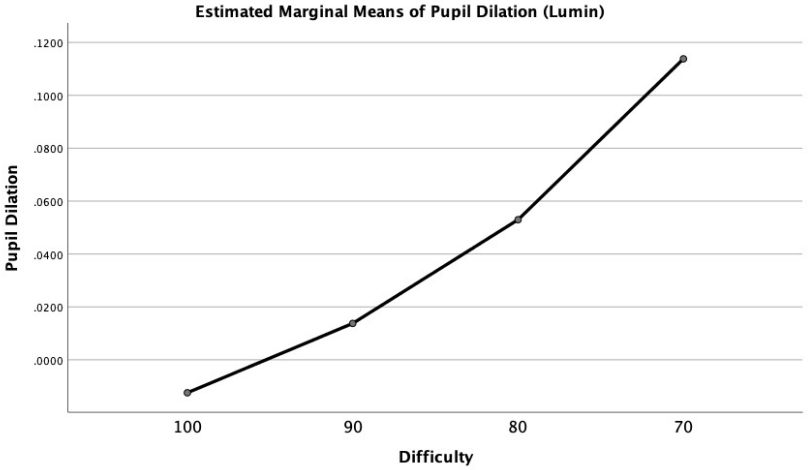


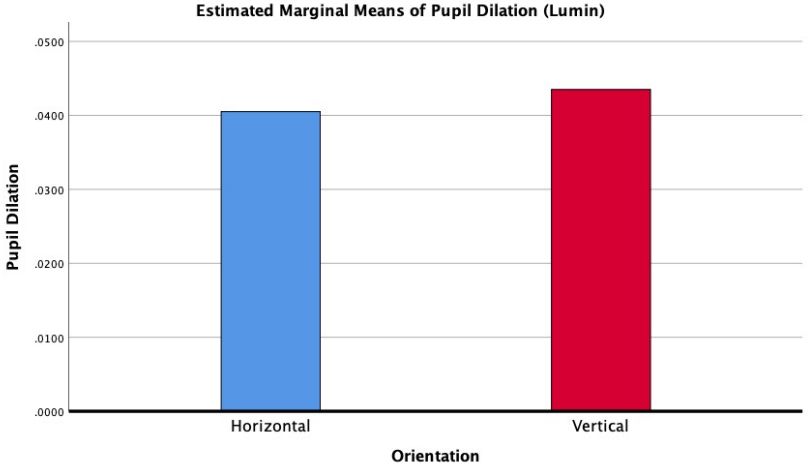




Pupil Dilation: Luminance Stimuli







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, $p < 0.001$, $\eta 2 = .64$).
- These data confirm the availability of pupil dilation as a biomarker of processing load in this perceptual organization 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:

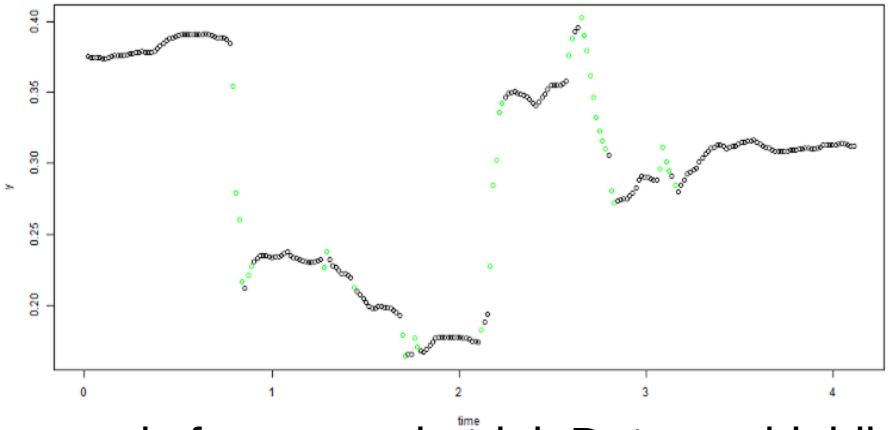
- Stimulus Type (Color, Luminance, Gabor)
- Difficulty Level (100%, 90%, 80%, 70%)

Response:

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

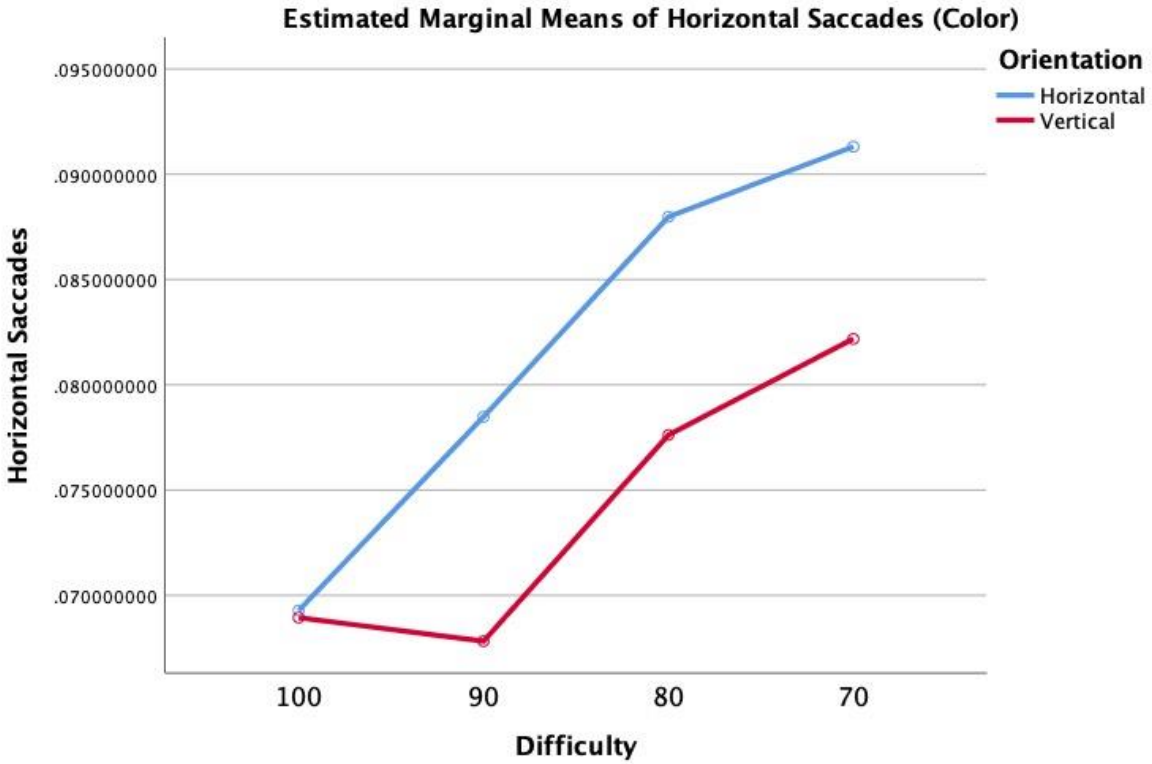
Saccade and Movement Direction: Definitions

- 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.

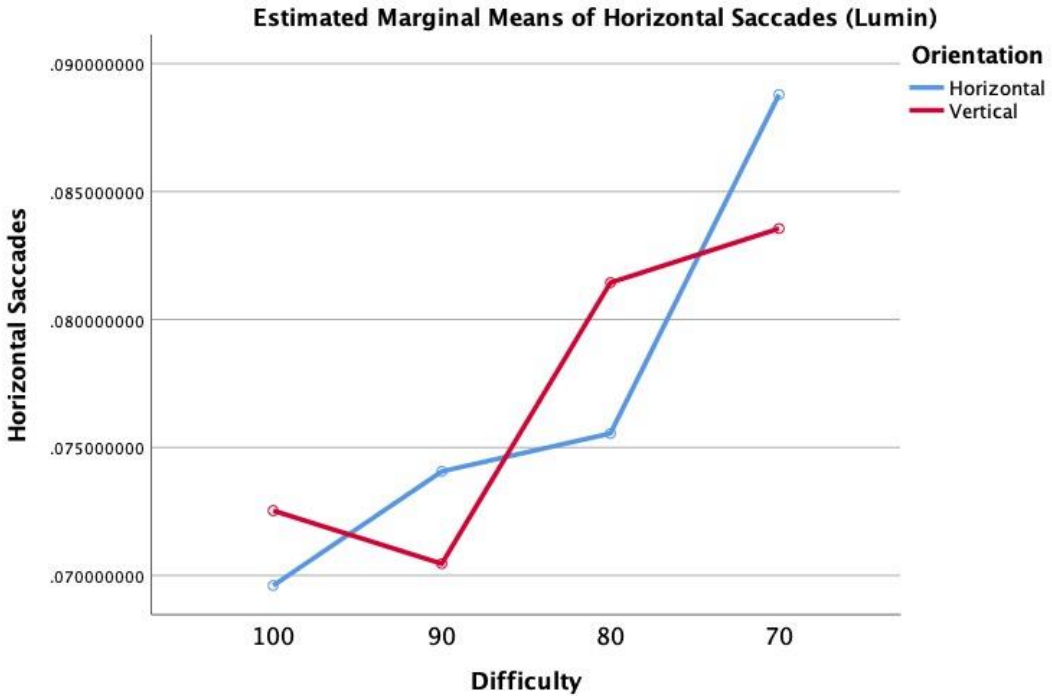


- Eye movement on y axis for a sample trial: Dots are highlighted in green if their velocity exceeds 80th percentile.
- If abs (tan (Vy/Vx)) > tan (60) → Vertical Movement; If abs (tan (Vy/Vx)) < tan (30) → Horizontal Movement (*velocity-based threshold algorithm: Salvucci & Goldberg, 2000*).

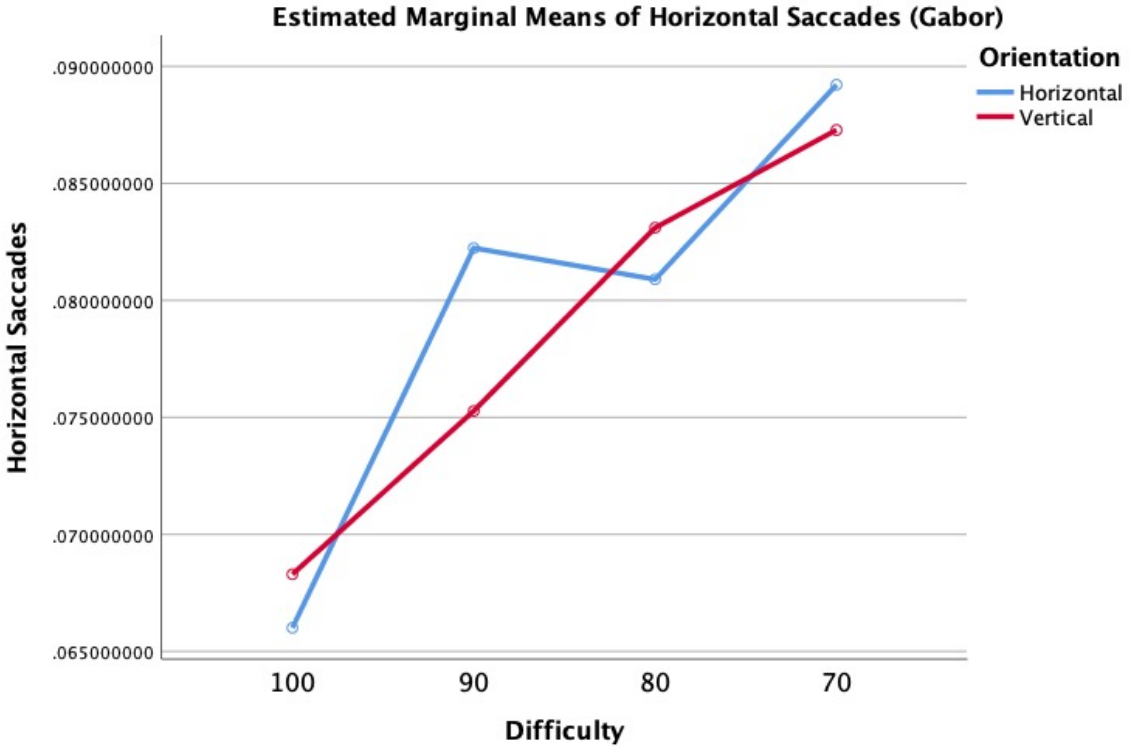
Horizontal Saccades: Color Stimuli by Difficulty Level



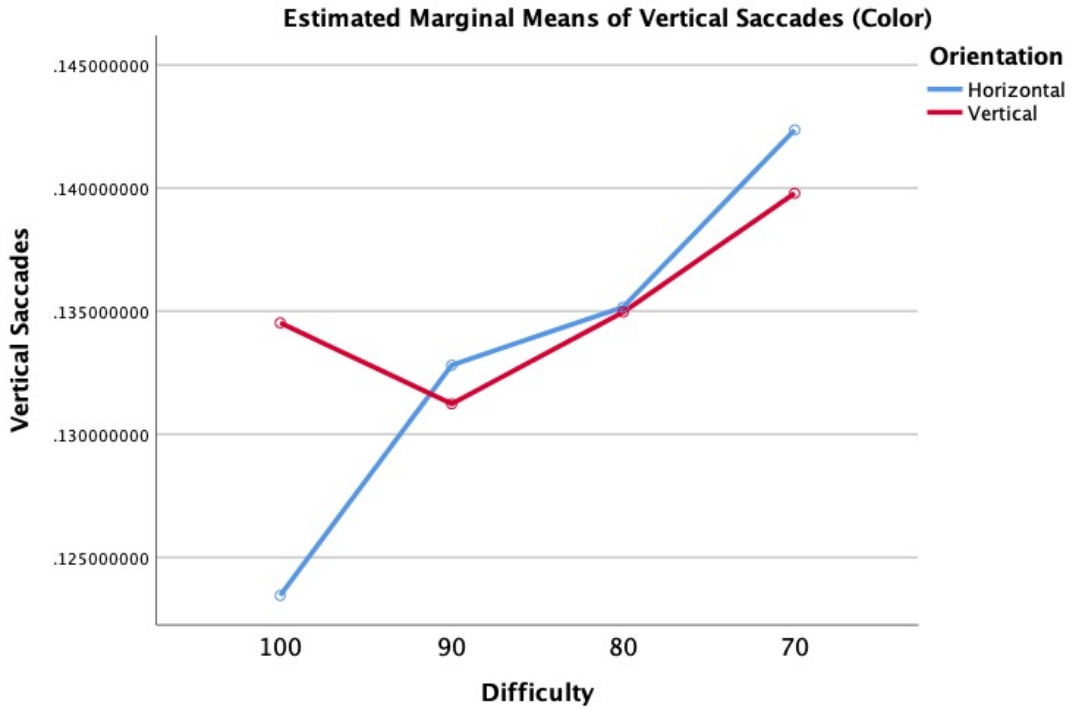
Horizontal Saccades: Luminance Stimuli by Difficulty Level



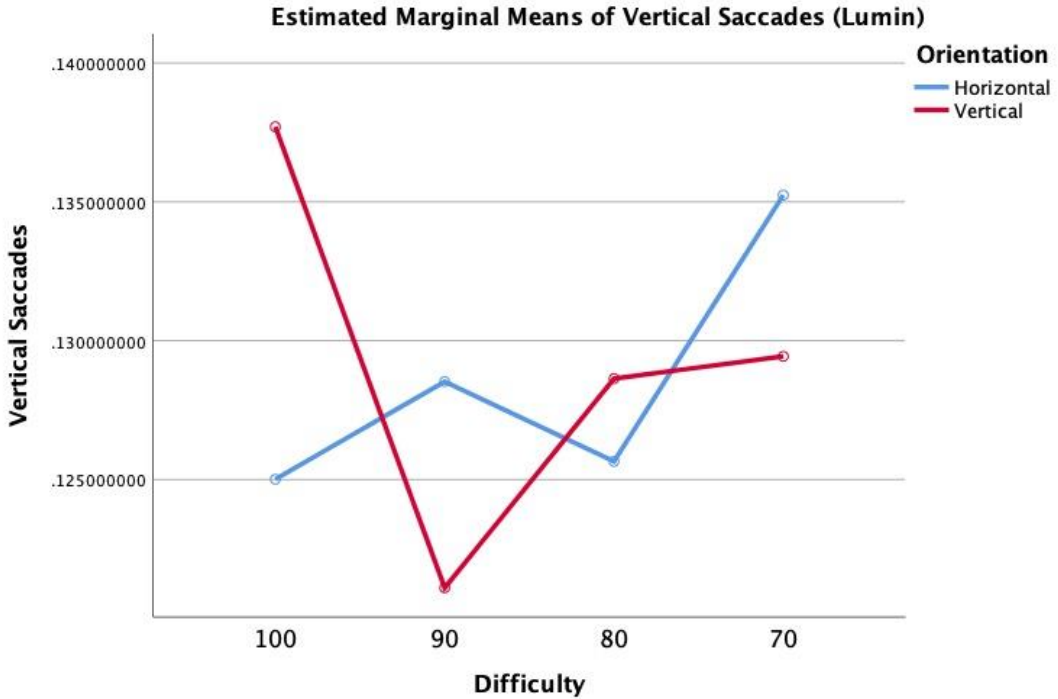
Horizontal Saccades: Gabor Stimuli by Difficulty Level



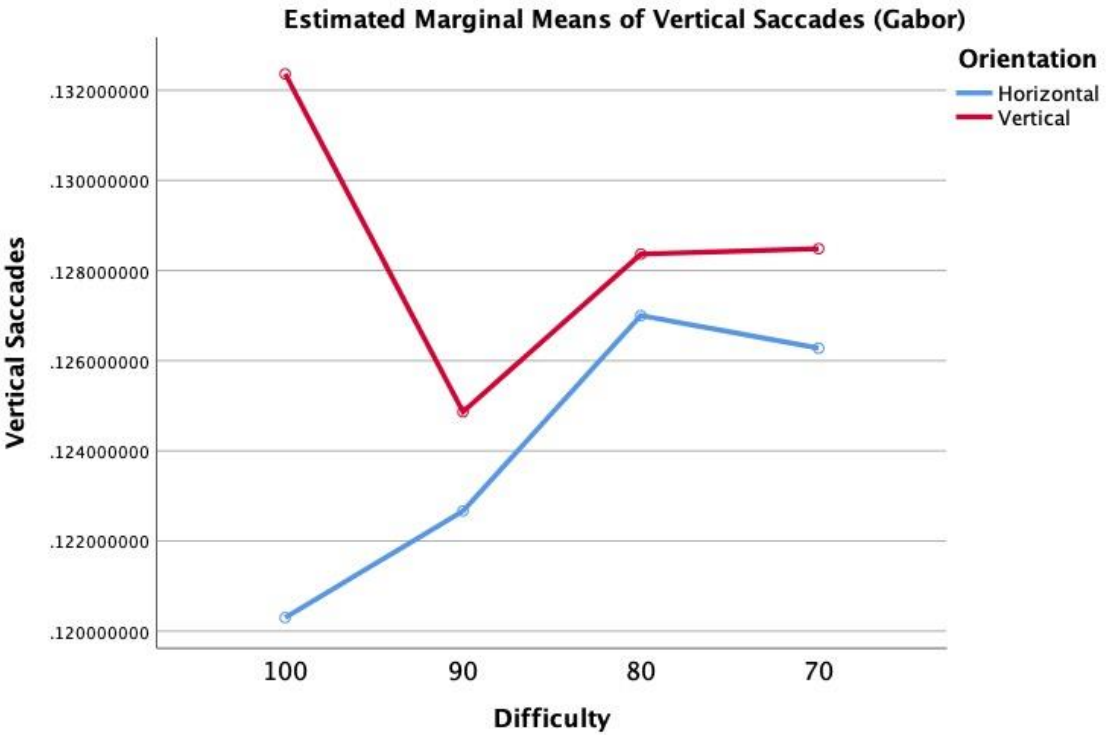
Vertical Saccades: Color Stimuli by Difficulty Level



Vertical Saccades: Luminance Stimuli by Difficulty Level



Vertical Saccades: Gabor 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).
- Thus, only horizontal saccadic activity is a reliable biomarker of visual processing in this task.

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 (PO) Task.
- These results confirm that there are reliable biomarkers of visual processing in PO that could be used to segregate component processes to identify the locus of PO deficits in populations with visual disorders, such as schizophrenia, dyslexia, autism, TBI patients, etc.
- Our current findings are being supplemented with an ERP study using similar stimuli and an MMN protocol

References

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