OFFICIAL TITLE: Probing the Role of Feature Dimension Maps in Visual Cognition: Expt 1.1 (Behavioral)

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Study protocol and Statistical Analysis Plan

Participants

22 adults recruited from the University of California Santa Barbara (UCSB) community participated in the eyetracking control study (7 female, 19-36 years oldProcedures were approved by the UCSB Institutional Review Board (#5-24-0700) and was registered on ClinicalTrials.gov (NCT06852534). All subjects provided written informed consent before participating and were prorated $20/h for their time in the lab, both for behavioral familiarization/training and scanning sessions.

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Stimuli and Procedure

Stimuli were presented using the Psychophysics toolbox (Brainard, 1997; Pelli, 1997) for MATLAB (The MathWorks, Natick, MA). In the behavioral familiarization session and free viewing eyetracking experiment, we presented stimuli on a contrast-linearized LCD monitor (2,560×1,440, 60 Hz) 62 cm from participants, who were seated in a dimmed room and positioned using a chin rest. For all sessions and tasks (main tasks and mapping task), we presented stimuli on a neutral gray circular aperture (9.5° radius), surrounded by black.

Graded feature salience display

For the main task, participants attended a flashing cross within the fixation circle and ignored any other stimuli presented throughout the scanning session (Thayer & Sprague, 2023b). This task localized goal-directed attention to fixation and was equivalent across all stimulus conditions, allowing us to isolate signals associated with bottom-up salience processing of our peripheral stimuli. Participants monitored the fixation cross throughout the whole run for any increase in length in either the vertical or horizontal bar of the cross and responded to changes with a button press (the left button for a horizontal target, the right button for a vertical target). The vertical and horizontal lines of the fixation cross were 0.25° of visual angle long, were 0.06° wide, and flickered at 3 Hz (10 frames on, 10 frames off at 60 Hz). Whenever the cross was visible, there was a 22.5% chance either line had a small change in length. When a change was detected, participants reported which line increased in length (horizontal or vertical). To ensure participants maintained vigilant attention at fixation throughout the entire experiment, we adjusted the difficulty of the fixation task between runs by altering the degree of size change for vertical/horizontal lines based on behavioral accuracy (range: 0.04° to 0.24°). Participants performed the fixation task continuously throughout both stimulus presentation periods and ITIs to ensure salient events were temporally decoupled from fixation task performance and/or target detection. Feedback for each response to the fixation task was given via the aperture around fixation changing color, with green indicating a correct response, red indicating an incorrect response, and yellow indicating a missed response. A fixation target was never present for the first or last 2 s of a trial, or for 2 s after the presentation of a previous target.

The critical, ignored, stimuli were either a color- or motion-defined salient location presented as a circular disc within random dot arrays spanning the entire stimulus aperture except for a region around fixation (0.75°). We manipulated the contrast of the salient stimulus to be different from the rest of the display at one of six possible steps along a logarithmic scale (0%, 6%, 16%, 33%, 59%, 100%). On color trials, static dots within a disc were presented in a different color (CIE L*a*b* colorspace) as compared to the background dots which was selected as the color with a degree difference from the background based on the log contrast condition (e.g., 59% contrast would be a color ±74° degrees different from the background). The selected color was randomly selected to be +/- the background color (e.g., 59% contrast was randomly 74° clockwise or counterclockwise from the background color) unless it was the maximum contrast condition, in which case there was only a single color that could be selected. On motion trials, moving black and white dots within a disc were presented in a different motion direction as compared to the background dots. Salience was similarly determined along a log scale contrast using a similar degree difference as described for color. For example, if the dot array contained dots moving at 0° (rightward motion), on a 59% contrast trial, the motion-defined salient location would contain dots moving at 74° (to the upper right) or 286° (to the bottom right) depending on the randomly selected ± calculation along a circle. Individual dots occupied 0.05° of visual angle, and dot density was 15 dots/deg^2. In the motion array, dots moved at a speed of 9.5° /s in a randomly selected planar direction and each dot was randomly colored black or white (100% contrast). Dots were randomly replotted every 50 ms or when they exceeded the stimulus bounds. For the color array, all dots remained static and were assigned a random color. Dot locations were updated every 333 ms. Both arrays updated every 333 ms during the 5 s presentation period, such that a new color or motion value was applied to every dot in the updated array three times per second. Trials started with the onset of the peripheral dot array while participants were attending fixation. The salient location appeared throughout the entire stimulus interval, centered 5° from fixation at a random location along an invisible ring from 0°-359° and had a radius of 1.5°.

As a positive control to ensure our image reconstruction and eyetracking procedure was effective in each retinotopic ROI, we presented a flickering checkerboard disc (spatial frequency 0.679 cycles/°) on a gray background at the same size, eccentricity, and duration as the salient discs ('checkerboard' trials; similar to previous reports; Thayer & Sprague, 2023). The checkerboard stimulus flickered at a rate of 6 Hz and was considered to be feature-agnostic with respect to the key manipulations in the study (i.e., color/motion). We also manipulated the checkerboard to be presented in one of 6 levels of contrast along a logarithmic scale. All trials were separated by a randomly selected ITI ranging from 6-9 s with an average ITI of 7.5 s.

Each run had 18 trials. There were 1 trial of each stimulus type (based on color, based on motion, checkerboard) and contrast (0%, 6%, 16%, 33%, 59%, and 100%) combination. Trial order was

shuffled within run. Each run started with a 3 s blank period and ended with a 10.5 s blank period, for a total run duration of 238.5 s. Right eye position in the scanner was monitored throughout the experiment using an Eyelink 1000 eyetracker (SR Research) sampled at 500 Hz. Participants performed 5-point calibration at the start of the session.

The free viewing eye tracking version of the task was nearly identical to the task performed in the scanner aside from the noted changes. Salient stimuli were presented for 1 s (instead of 5 s in the scanner), where features were still updated at a rate of 333 ms. ITIs were changed to be 1 s (instead of 6-9 s). The end wait black period was 3 s. In this version of the task, there were 4 repetitions of each stimulus type and contrast combination, which resulted in a total of 48 trials per run. Each run duration was 294 s. A Eyelink 1000 eyetracker (SR Research) was again used to monitor the right eye position but sampled at 1000 Hz and participants completed a 9-point calibration at the start of each run.

Quantifying eyetracking data

The eyetracking study was meant to assess whether our contrast manipulations differentially captured attention in the absence of an instructed fixation task. We analyzed both the eye position and total time the salient stimulus was fixated using data from this control experiment. We first generated fixation heatmaps for each salience condition and level of contrast. These were the plotted *x* and *y* positions of each fixation, rotated based on the known location of the salient stimulus on each trial, and then smoothed with a 2D Gaussian kernal using the MATLAB function imgaussfilt (kernel $\sigma = 0.33°$). Fixations on each trial that landed within 2° of fixation or outside 9.5° degrees of fixation were excluded from the saccade heatmaps. Eye movements were quantified using two metrics: proportion of all saccades directed to the salient stimulus and the total duration the salient stimulus was fixated. Two areas of interest (AOIs) were used to characterize eye movements to two properties of the stimulus (stimulus center: 5° eccentricity). One AOI corresponding to the stimulus center (0-1° radius from stimulus center), which previous reports have indicated is preferentially fixated (Henderson, 1993; Foulsham & Underwood, 2009). The second AOI corresponded to the stimulus edge, which should be particularly salient in these displays because this is where feature contrast was the strongest (1-2° annulus from stimulus center). Saccades were defined by a velocity threshold of 30°/s, an acceleration threshold of $3800°/s^2$, an amplitude threshold of 0.25°/s, and a minimum post-saccade fixation of at least 20 ms. Only eye movements that were initiated 50 ms after stimulus onset and before stimulus offset (1000 ms) were included in these quantifications.

Statistical analysis

We used parametric statistical tests for all comparisons (repeated-measures ANOVAs and paired-samples T-tests).

For data from the eyetracking control study, we used individual one-way repeated-measures ANOVAs, using either the proportion of saccades or total dwell time, for each feature dimension (color, motion, and checkerboard luminance) with contrast as a factor (6 levels). This was done to test if we were successfully able to manipulate stimulus contrast in a way that meaningfully impacted behavior, which would suggest that neural regions could fluctuate with changes in contrast. Follow-up paired-samples T-tests between contrasts were conducted to determine which contrast level had the greatest impact on behavior.