Distractor Representations in Neural Feature Dimension Maps Depend on Searched Feature Dimension

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Abstract:

The selection of objects in the visual field for attention is based on a combination of image-computable salience and current behavioral relevance. The combination of salience and relevance is reflected by a feature-agnostic priority map that indexes important locations. While attention is ultimately directed based on activation from the aggregate priority map, competition between feature-specific items is reflected within corresponding feature dimension maps (e.g., color or motion map). However, it is unclear how responses within neural feature dimension maps reflect competition between relevant and salient items. Here, we used a visual search task to evaluate how relevant and salient items compete in neural feature dimension maps. We applied a multivariate image reconstruction technique to compute spatial maps from activation patterns in color-selective regions while participants searched for targets among salient distractors, each defined by color or motion. Both targets and distractors were represented in reconstructed spatial maps when items were defined by color. Furthermore, the relevant target feature modulated the distractor strength, consistent with goals prioritizing the entire color dimension map. These results indicate that neural feature dimension maps are crucial for computing attentional priority.

Keywords: Priority Maps, Visual Search, Attentional Capture, fMRI

Introduction

We dynamically attend to items in the environment. For instance, you may be searching for an orange bike helmet as you leave the park, but attention may be captured by a quickly moving football heading in your direction. Relevant items, such as the helmet, and task-irrelevant salient input, like a moving football, compete for attentional selection on a moment-by-moment basis. Priority map theory is often invoked to understand this competition between salience and relevance. A priority map is a feature-agnostic representation of the visual field that indexes the importance of specific locations (Itti & Koch, 2001; Wolfe, 1994). Locations can be prioritized because they contain items that are related to current goals, or because they contain information that stands out due to local feature contrast. While the priority map itself is feature-agnostic, it receives inputs from several 'feature dimension maps' that prioritize locations based on a preferred feature dimension (e.g., motion or color). For example, the moving football will have strong activation in the motion dimension map, but minimal activation in the color dimension map.

Even though interactions between feature-specific salience and relevance is central to priority map theory, minimal research has investigated whether this competition manifests within neural feature dimension maps. Recent studies from our lab have identified motion-selective areas TO1/TO2 and color-selective areas hV4/VO1/VO2 as neural feature dimension maps (Thayer & Sprague, 2023, in prep). These regions tracked the location of stimuli throughout the visual field when salience and relevance were defined by their preferred feature dimension. However, these studies evaluated neural responses to salience/relevance in isolation—it is unclear if neural feature dimension maps track the competition between these priority signals during a complex visual search task.

There are various ways in which relevant and salient information are proposed to interact to guide attention. Some models state that goals sculpt priority corresponding to the exact feature value that is relevant, such that items in the visual field will only be prioritized if they exactly match the target feature value (Folk et al., 1992). Per this account, if one is searching for a red target, only salient red distractors will be prioritized. Other models claim that goals sculpt priority across the entire goal-relevant feature dimension, even when searching for a specific feature value (Found & Muller, 1996). Per this account, all salient color distractors would be prioritized, regardless of color.

To evaluate interactions between salience and relevance within neural feature dimension maps, we utilized a feature visual search task (Fig. 1A). Subjects were cued to search for a specific color or motion direction on each trial in a subsequent search array containing several homogenous colored moving dot arrays. Only the target item contained the feature value cued at the start of the trial and, on most trials, a salient distractor was present which differed from all other items in a single feature dimension (color or motion).

Results

Participants (n = 12) performed a visual search task in the fMRI scanner (Fig. 1A). Color-selective (hV4/VO1/VO2) regions were identified using a separate retinotopic mapping task (Mackey et al., 2017). Inverted encoding models (IEM) were computed using neural activation patterns to reconstruct stimulus representations from neural feature dimension maps (Sprague et al., 2018). Using this approach, we were able to estimate spatial weights for each voxel, which allowed us to reconstruct maps of the visual field in visual field coordinates and quantify target & distractor representations.

Goals Modulate Target Representations

Reconstructed spatial maps were computed for each trial with easily separable target & distractor locations and aligned to either the known target or distractor position and averaged across trials within condition (Fig. 1B/C). Qualitative assessment of reconstructed maps from hV4/VO1/VO2 shows that activation was stronger at the aligned target position when subjects searched for a color-defined target versus a motion-defined target. Distractor-aligned reconstructions were strongest when salience was defined by color.

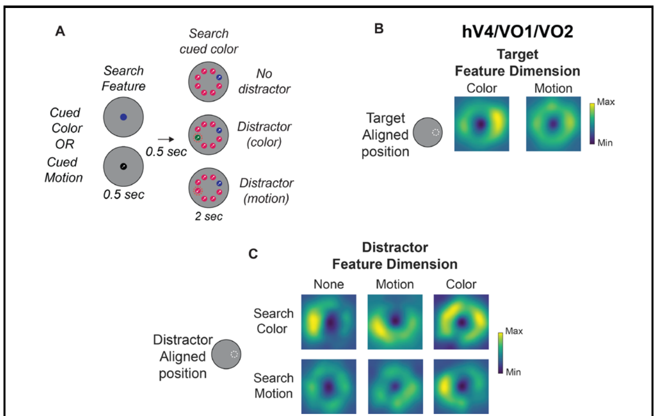

Figure 1: A: Feature visual search task. Subjects were cued to search for a feature-defined target in a search array that could contain a distractor that differed from all other items based on color or motion. B: Target-aligned reconstructed spatial maps using IEM with neural activation patterns in color-selective regions hV4/VO1/VO2. Activation corresponding to the target item was strongest when defined by color. C: Distractor-aligned reconstructed spatial maps. Activation was strongest when the distractor was defined by color and when searching for a color target. Inset shows aligned position in relation to the search array.

Goals Modulate Distractor Representations

To evaluate whether goals prioritize specific target feature values or the entire target feature dimension, we compared salient color distractor activation when participants were searching for color to when they were searching for motion. If goals sculpt priority for the goal-relevant feature value, then the color distractor should never be strongly represented since the distractor was never the same feature value as the target. However, if priority is sculpted across the entire searched feature dimension, then the distractor should be strongest when color is goal-relevant (i.e., color search trials).

Figure 2 shows distractor activation for each type of distractor (none, motion, and color) when either color/motion was goal relevant. Critically, the color distractor had greater activation when color was goal-relevant, indicating that goals sculpt priority across the entire relevant feature dimension.

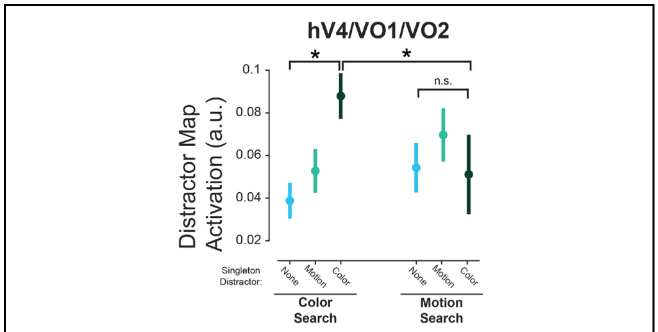

Figure 2: Salient distractor activation in neural color dimension maps depends on current goals. Color-salient distractor activation was greater when searching for color (left dark green) than when searching for motion (right dark green). This indicates that color distractors only evoked a strong response when goals modulate the entire color dimension. Error bars are within-subject SEM.

Our results extend previous findings in two significant ways. First, we show that neural feature dimension maps concurrently track the location of salient and relevant items. Second, goals modulate priority signals across the entire feature dimension, and not for individual feature values. Overall, these findings demonstrate that neural feature dimension maps are critical for computing attentional priority.

Acknowledgments

This work was supported by NIH R01-EY035300, a Sloan Research Fellowship, a UCSB Academic Senate Research Grant, and US Army Research Office Cooperative Agreement W911NF-19-2-0026 for the Institute for Collaborative Biotechnologies.

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