

# Ensemble Processing of Color and Shape: Beyond Mean Judgments

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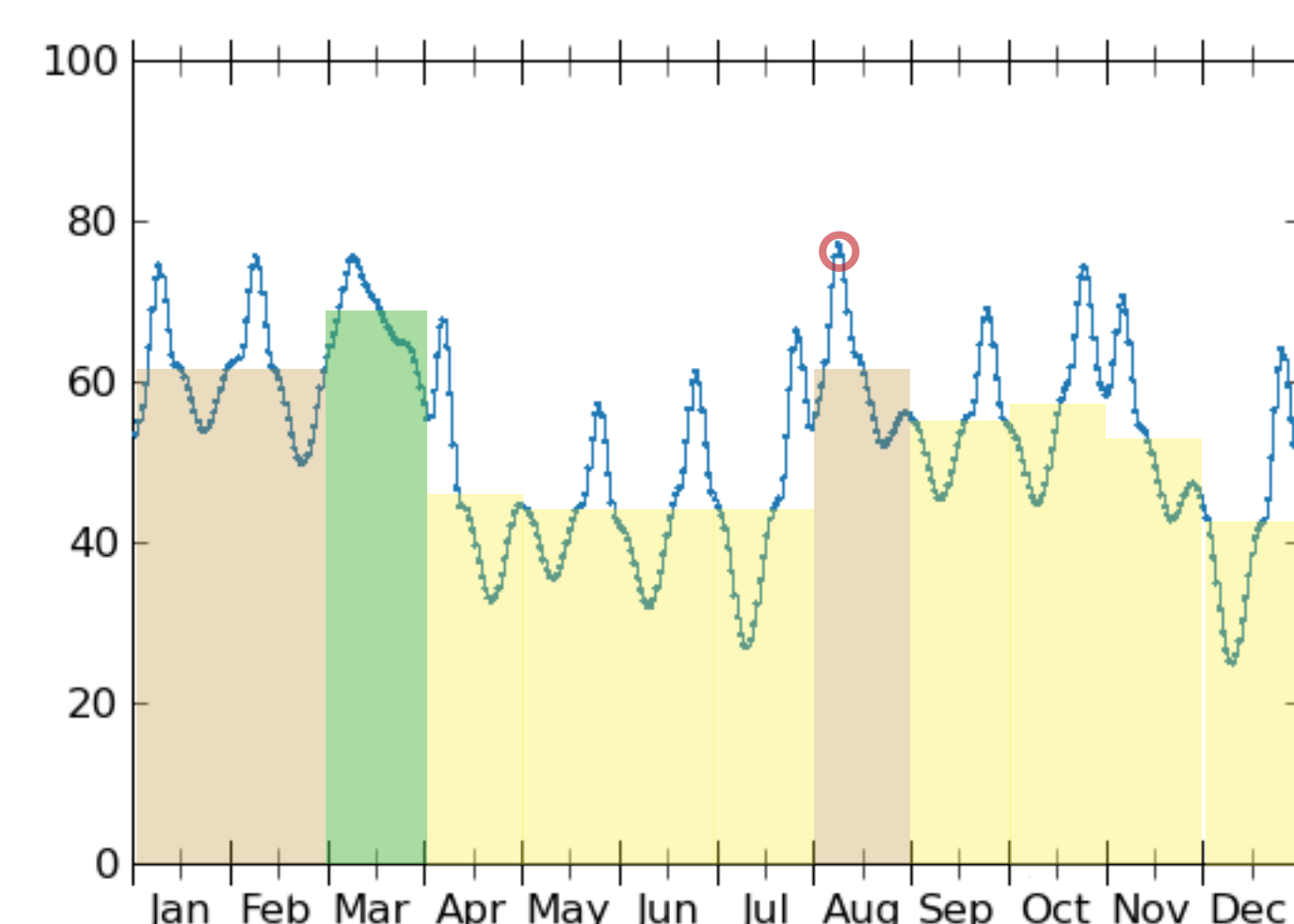
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Our visual system can extract statistical properties of large collections of objects. Most studies of this ability focus on mean value judgments across a constrained set of dimensions<sup>1-3</sup>. We explore how two visual representations of a set, line height and color, influence viewers' abilities to visually extract different properties from the set.

## Model Problem:

What range of values (30 value "months") has the highest value for a given property across the set (12 month "year")?

Measure: Accuracy of participants for 20 second exposures



The target property (e.g. mean) of the **winning range** was a controlled amount better than **n distractor ranges** and explicitly decorrelated from **confounding properties** (e.g. peaks for mean value extraction).

## Judgment Tasks:

**Isolation Statistics** are extracted from unique values in a set.

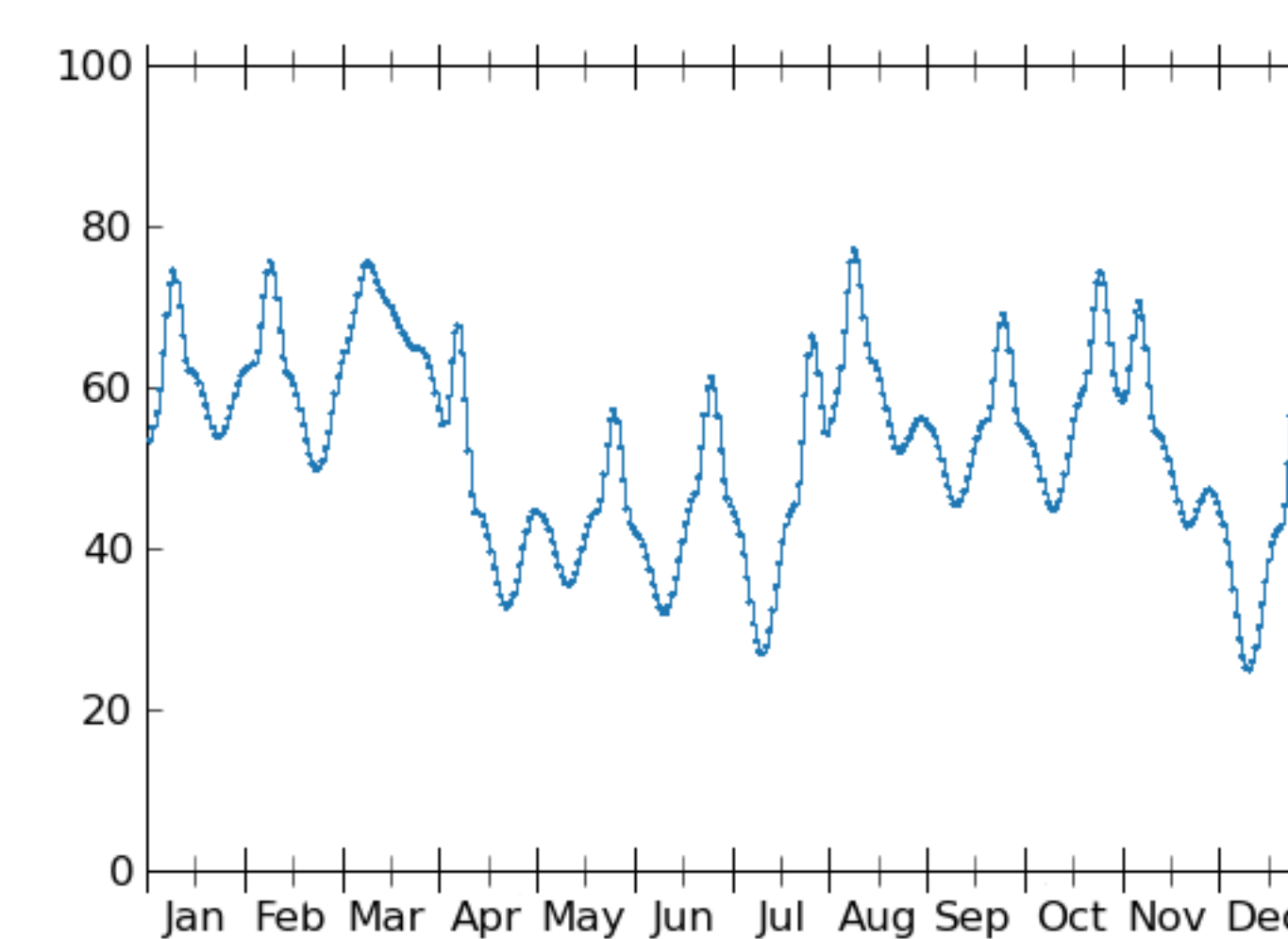
- Extrema — Which month had the day with the highest/lowest sales for the year?
- Range — Which month had the largest range of values?

**Combination Statistics** combine all object values in a set.

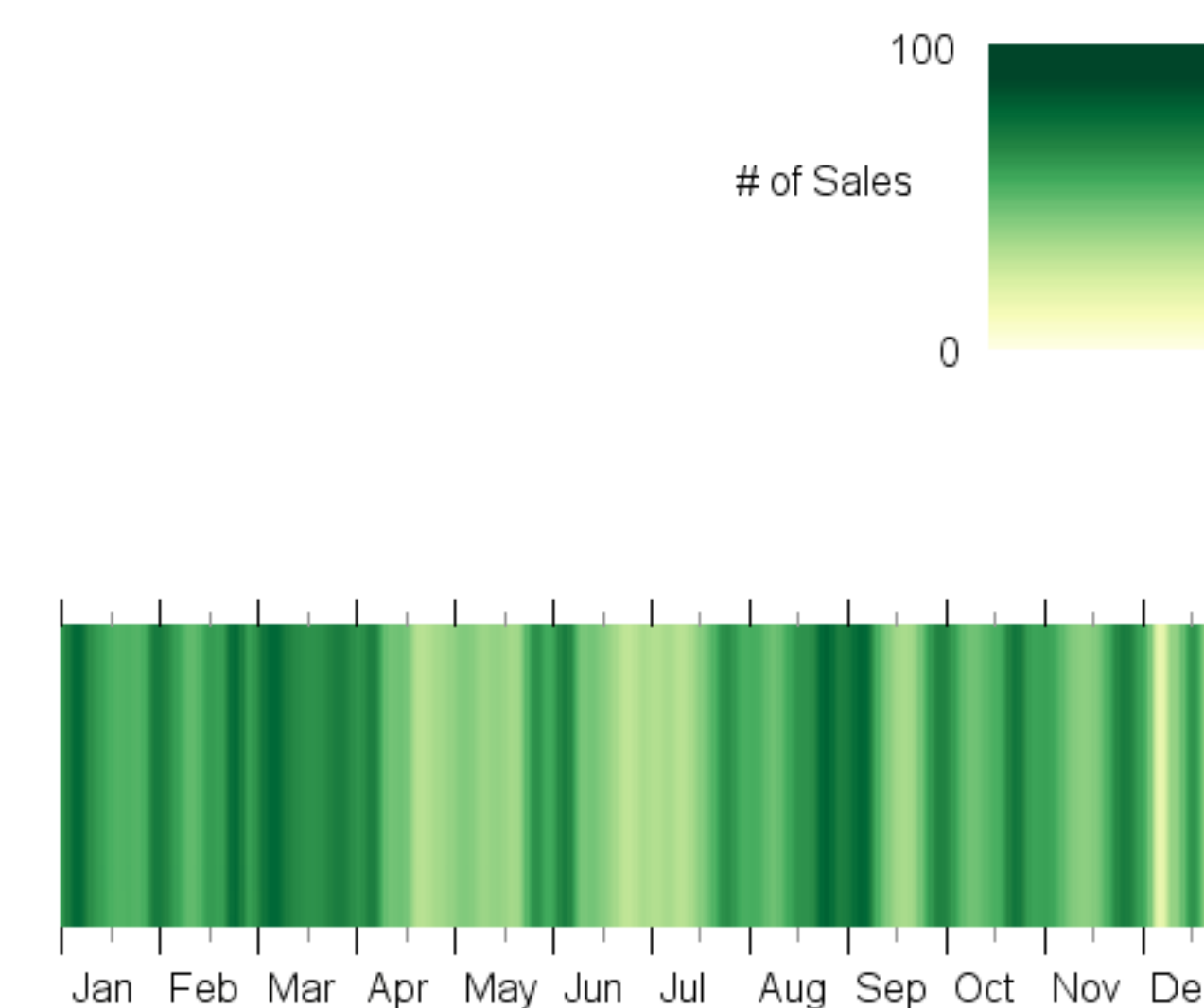
- Mean — Which month had the highest average sales for the year?
- Deviation — Which month had the sales which were the most spread out from their monthly average?

## Experiment One: What visual statistical judgments do color and line height support?

Conditions:

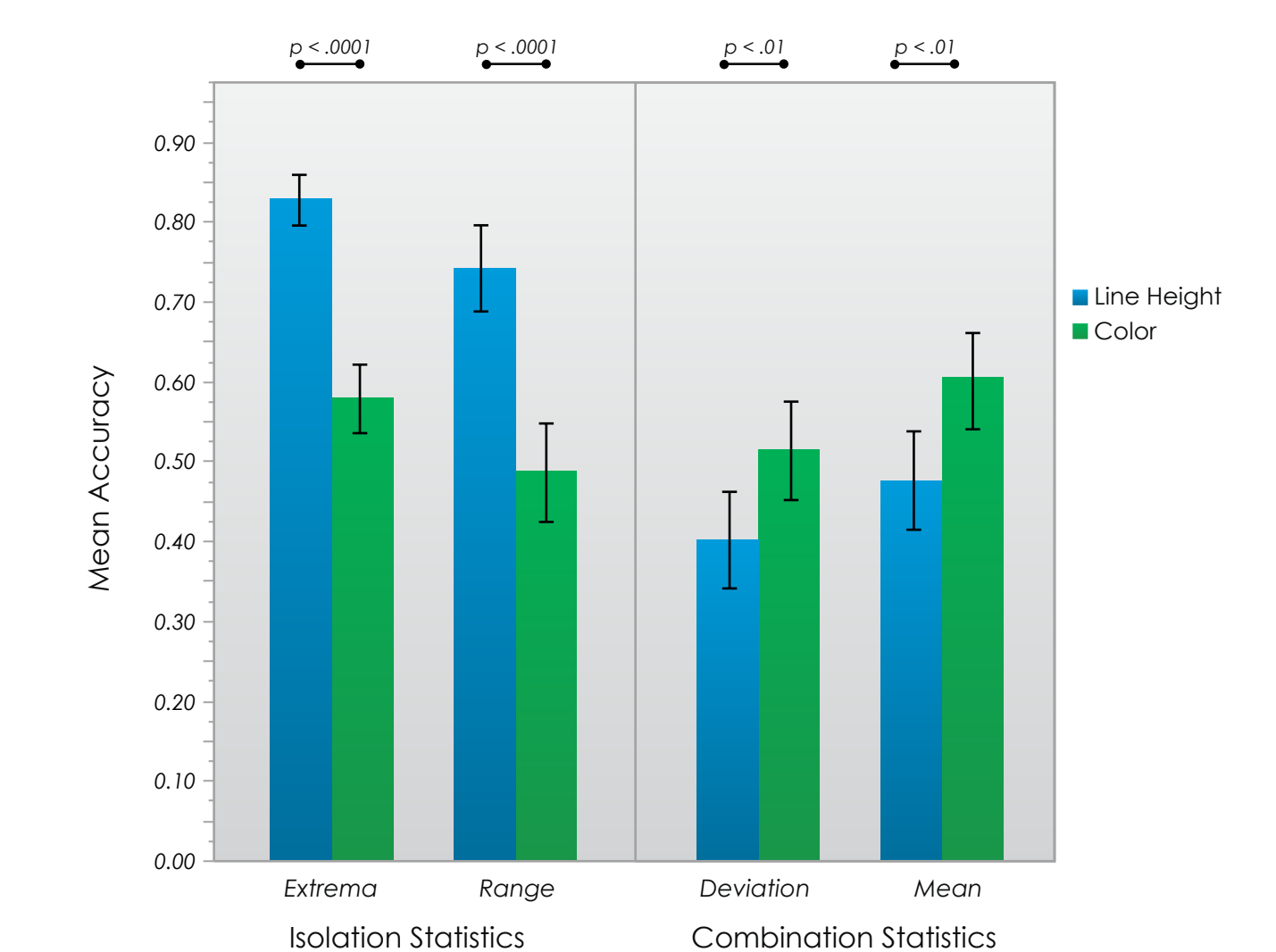


**Line Height:** Each object's value is mapped to a vertical position. Values are connected by a line such that line height corresponds to value.



**Color:** Each object's value is mapped to a colored stripe creating a color gradient representation of the set.

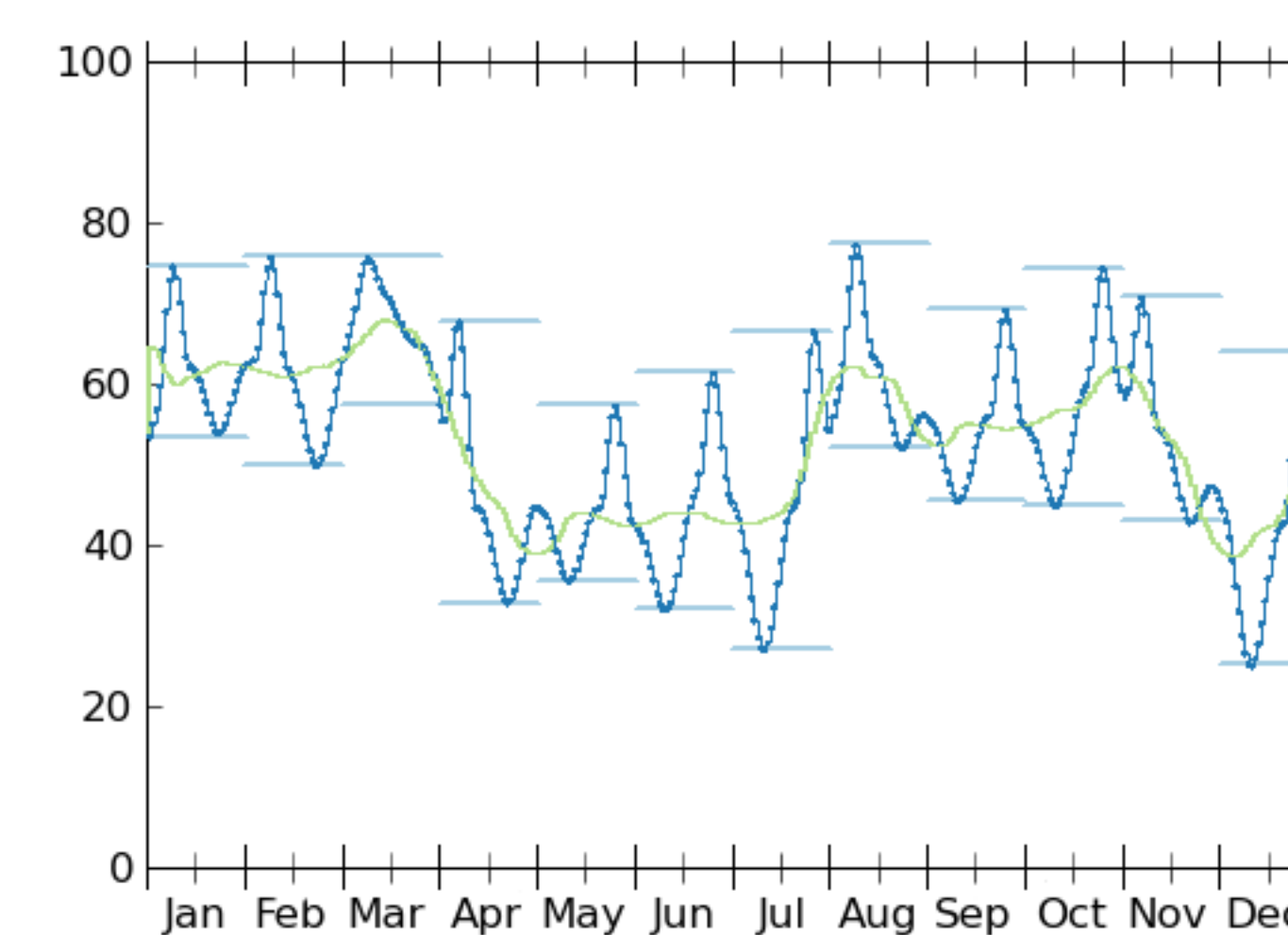
Results:



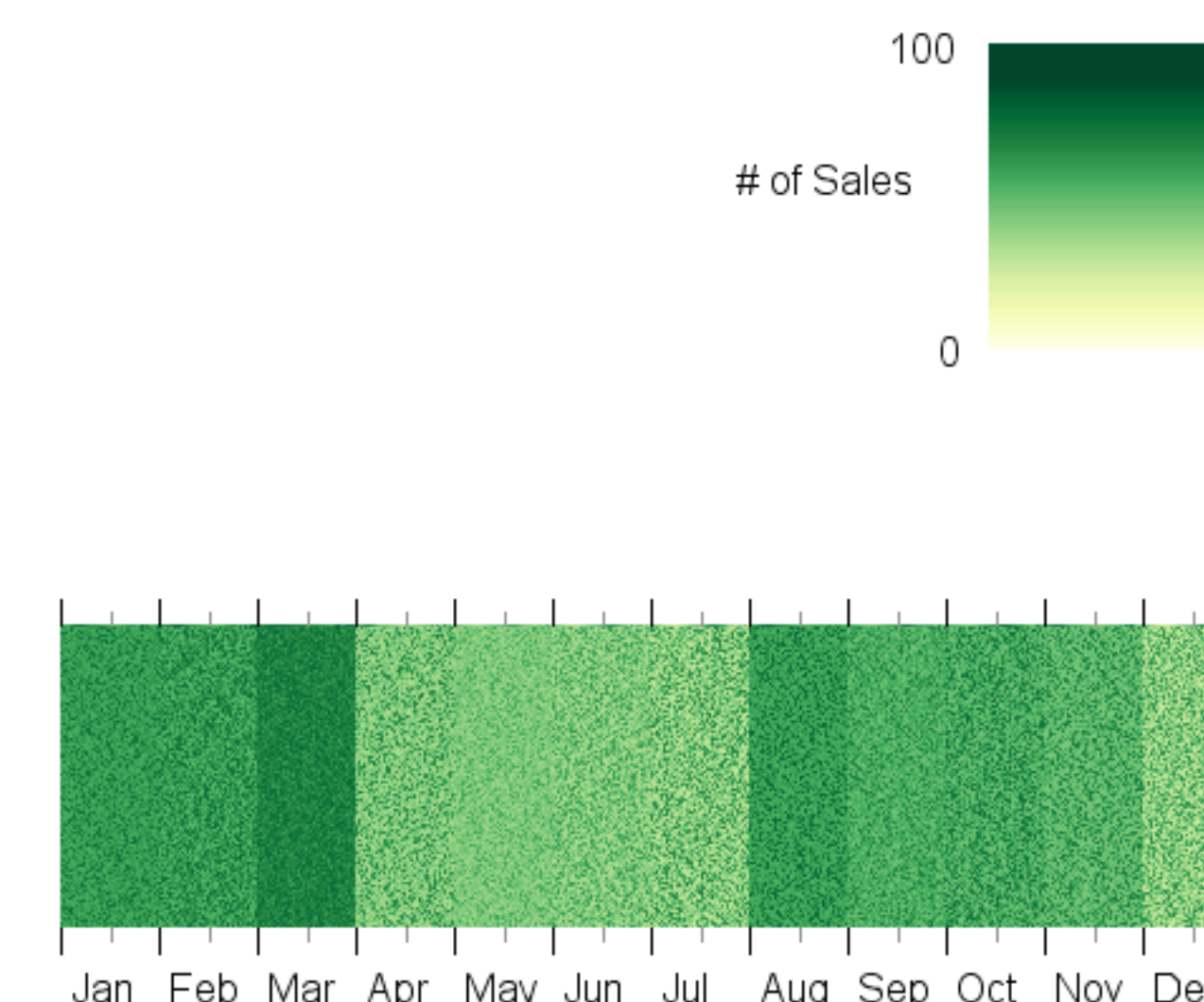
The **line height** condition better supported extracting isolation statistics, while sets represented using **color** better facilitated combination statistics.

## Experiment Two: Can we manipulate set representation to better facilitate ensemble processing?

Conditions:

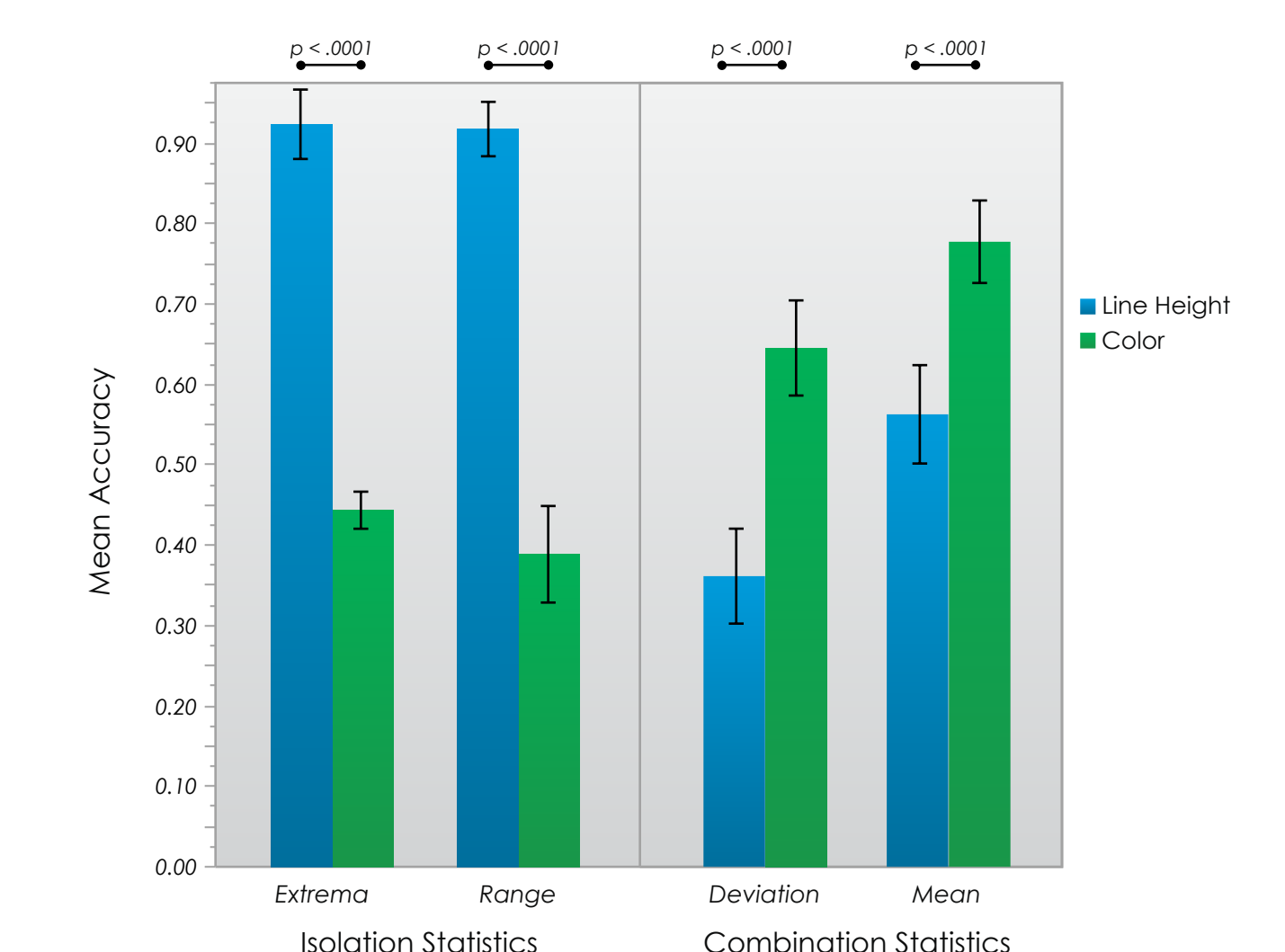


**Line Height:** Extrema are mapped across each range as blue bars and a continuous average of set values as a green line.



**Color:** The pixel values of each object are permuted locally within each range to better facilitate ensemble processing.

Results:



Increasing the saliency of extrema using **line height** improved extrema and range judgments, while permuting local structures in **color gradients** better facilitated mean and deviation judgments.

## Conclusion: Different types of ensemble processing are possible for different types of stimuli

Performance significantly differed across visual set representations within each judgment type. Based on these findings, we hypothesize:

- Line height** facilitates judgments about unique values within a set (isolation statistics) via existing visual biases toward shape boundaries.
- Color** facilitates judgments that combine information across all values in a set (combination statistics) by summing color values at low spatial frequencies.

We plan to further explore these hypotheses in our future work.

	Isolation Statistics		Combination Statistics		
	Extrema	Range	Mean	Deviation	
Line Height	87.5%	74.2%	47.7%	48.8%	Highest Performing
	88.7%	94.8%	56.3%	39.7%	
Color Gradient	59.4%	48.8%	60.5%	57.8%	Lowest Performing
	43.0%	38.7%	77.7%	71.3%	

References:  
1. Alvarez & Oliva. Spatial ensemble statistics are efficient codes that can be represented with reduced attention. *PNAS*, 2009  
2. Ariely. Seeing Sets: Representation by Statistical Properties. *Psychological Science*, 2001.  
3. Parkes et al. Compulsory Averaging of Crowded Orientation Signals in Human Vision. *Nature Neuroscience*, 2001.

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