VSS 2014
36.351

Border salience judgments reveal a curved global geometry of the perceptual space of local image statistics

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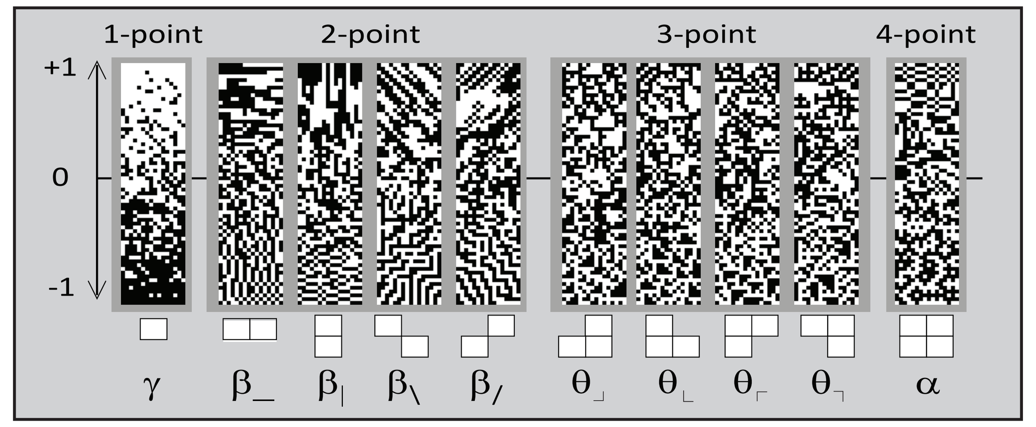
Motivation and Overview

Local features such as lines, edges, and corners are the elements of form vision. Identifying locations that require further attention, segmenting an image, and determining the surface properties of objects, all depend on these features. Thus, these features constitute a perceptual space that is crucial to visual processing. The perceptual distances in this space – i.e., the perceptual dissimilarities between collections of these local features making up a visual texture – determines the extent to which such differences can support the direction of attention, image segmentation, and discrimination of surface properties. Here, we use a border salience task to measure suprathreshold perceptual distances – i.e., the global geometry -- of this perceptual space.



The 10 axes of the perceptual space. Each axis corresponds local image statistic that quantifies the black/white balance, pairwise correlations, or higher-order correlations within a 2x2 neighborhood. The "sliders" indicate the gamut of each axis: 0 is random, and -1 and +1 represent the extremes of correlation. Here, we measure perceptual distances along individual axes, and in planes corresponding to pairs of axes.

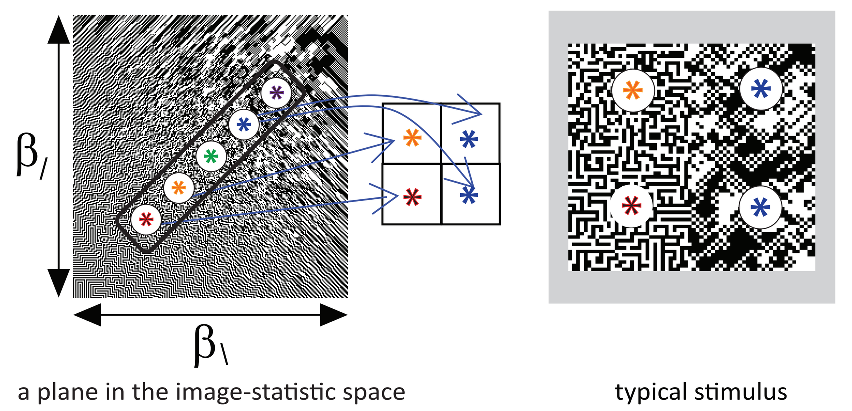
Methods

SUBJECTS
- 4 subjects
- VA: 20/20, with correction if needed
- Practice: approx. 50 trials

STIMULI
- Pixel size: 7 min
- Display size: 14.8 deg^2
- Binocular viewing at 1 m
- Contrast: 1.0
- Duration: 120 ms, followed by 300 ms mask

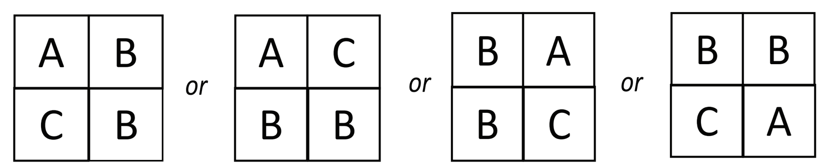
CONDITIONS
- 5 points along each direction
- Stimuli constructed from three points, with one point repeated in each map
- 240 trials per block, random order
- 10 or 20 blocks = 2400 or 4800 trials per direction
- 11 directions tested

TASK
Find the most salient border.
(4-AFC, top, right, bottom, left)



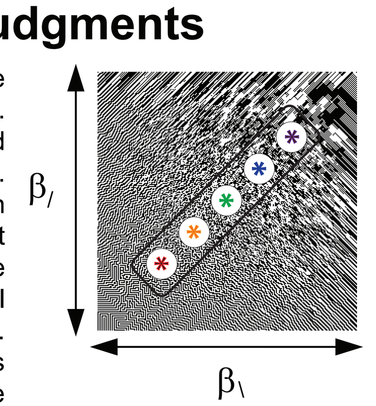
Construction of stimuli to determine perceptual distances in the ($\beta_\backslash$, $\beta_/$)-plane. Points along a line in image-statistic space (left) specify the four quadrants of a stimulus (right).

The four quadrants contain samples of only three different points in the space, so every stimulus contains one null border, and three real borders.

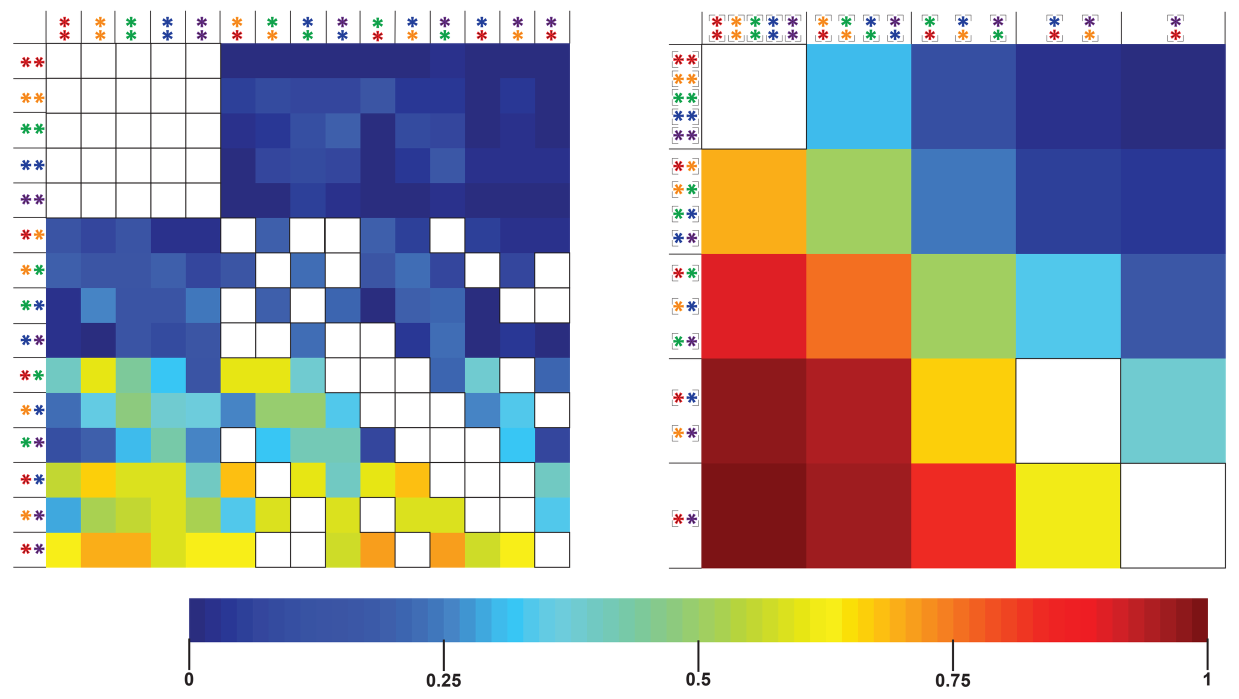


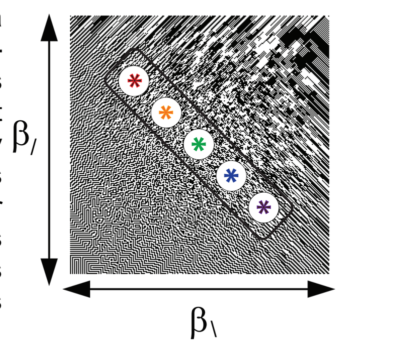
The subject's task is to determine which of the four potential borders is the most salient. Because every stimulus contains one null border, we can use the extent to which the subject chooses the null border as an internal control that the subject understands the task.

Border salience judgments



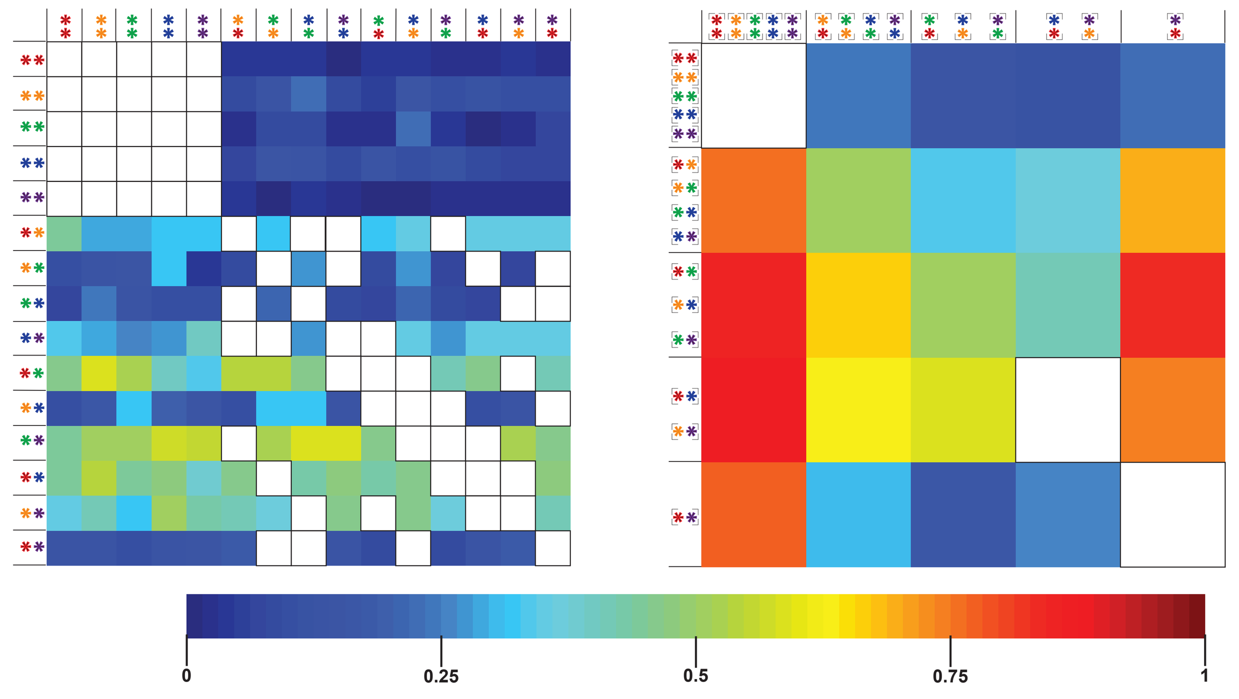
Border salience data along one diagonal in the ($\beta_\backslash$, $\beta_/$)-plane. Above, the five points sampled along a diagonal in that plane. Near right, frequency that each kind of border is judged the most salient. Far right, border salience judgments grouped by veridical distances within the plane. Borders defined by pairs of points that had a large veridical distance were seen as more salient than borders defined by a pair of points that had a small or zero veridical distance. **That is, veridical distances and perceptual distances covaried.** Subject: KP





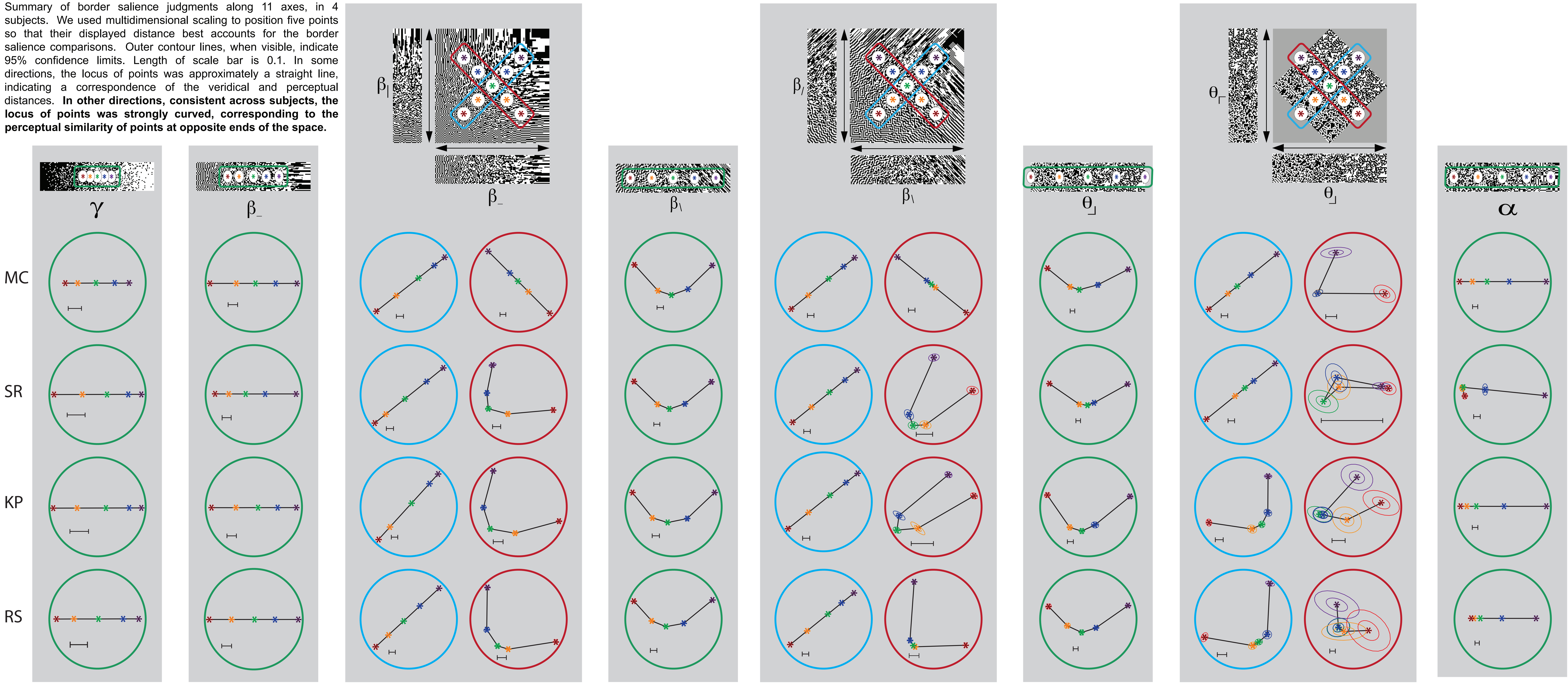
Border salience data along a second diagonal in the ($\beta_\backslash$, $\beta_/$)-plane. Above, the five points sampled along a diagonal in that plane. Near right, frequency that each kind of border is judged the most salient. Far right, border salience judgments grouped by veridical distances within the plane. Borders defined by pairs of points that had the largest veridical distances were less salient than borders defined by pairs of points that had a small veridical distance, and were near the origin. **That is, some points at opposite ends of the space appeared more similar to each other than points at smaller distances from each other, but near the origin.** Subject: KP

Color scale indicates the fraction of the time that the border indicated by the row label was seen as more salient than the border indicated by the column label. A white square indicates that this condition was not tested, because it involved four separate points in the plane and was therefore not part of the stimulus design

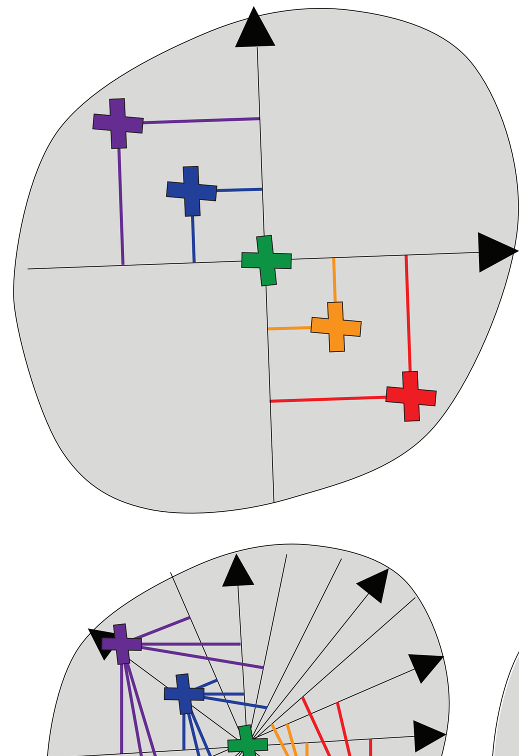


Multidimensional scaling of border salience judgments

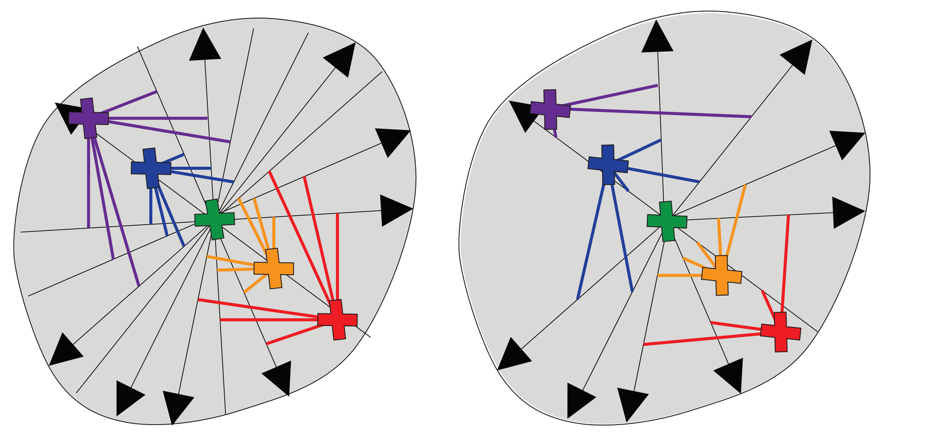
Summary of border salience judgments along 11 axes, in 4 subjects. We used multidimensional scaling to position five points so that their displayed distance best accounts for the border salience comparisons. Outer contour lines, when visible, indicate 95% confidence limits. Length of scale bar is 0.1. In some directions, the locus of points was approximately a straight line, indicating a correspondence of the veridical and perceptual distances. **In other directions, consistent across subjects, the locus of points was strongly curved, indicating a correspondence of the perceptual similarity of points at opposite ends of the space.**



Models for the representation of a perceptual space

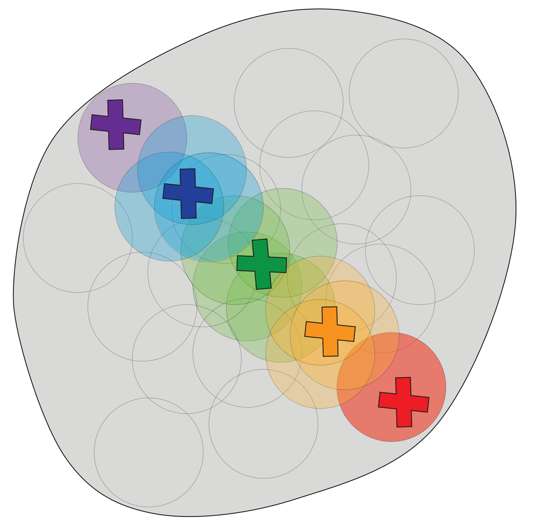


Representation of a perceptual space via projection onto coordinate axes. Here, the perceptual distance between two points is determined by the difference in their coordinate values. This model cannot account for perceptual similarity between points that are at opposite ends of the space, since their coordinate values will be very different.



Alternative coordinate-based representations. Left: a representation via projections onto multiple coordinate axes, rather than just a minimal set of orthogonal axes. Right: A representation via projections onto rays, rather than axes that run in both directions from the origin. As with a standard coordinate representation (top), these models cannot account for perceptual similarity between points that are at opposite ends of the space.

A distributed representation, in which points in the space are represented by the pattern of activity across broadly-tuned coding units. The perceptual distance between two points is determined by the number of units that respond differently to them. If these units are concentrated near the origin of the space, then perceptual distances between points in the periphery will appear small.



Conclusions

- We used border salience comparisons to determine the global geometry of a perceptual space.
- In some directions, points that were on opposite sides of the origin and in the periphery of the space appeared closer together than points that were *near* the origin.
- This finding is inconsistent with a representation based on coordinate axes, but can be explained by a distributed representation by broadly-tuned coding elements.

Supported by EY7977