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Structure of the neuronal interactions underlying human contour integration

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Contour integration is believed to be an important step in human image processing and object recognition, and has been shown to be performed very efficiently by the visual system. However, its neuronal mechanisms are still not well understood. Most contour integration models propose lateral connections between distant orientation columns of similar orientation preference for establishing a so-called 'association field', which links colinearly aligned edge elements into a single contour. However, these models differ both in their dynamics and structure. In some models, afferent input from visual stimuli and lateral input are summed up, in other models these quantities are multiplied. In addition, one finds different assumptions on the range, geometry, and symmetry of the lateral connectivity. It is often assumed that long-range horizontal interactions in V1 serve as the neuronal substrate for the association field. Probabilistic models require unidirectional lateral interactions, linking orientation columns in only one direction, in order to get optimal contour detection performance. In contrast, experimental findings in monkeys rather suggest isotropic connections, spreading symmetrically into all directions from an orientation column.

In order to analyze the range and symmetry of lateral interactions underlying contour integration in the human brain, we compared simulations of multiplicative and additive model dynamics with psychophysical contour detection data. For these investigations we used stimuli generated from association fields with different geometries. As expected, models detect contours exceedingly well when using the same association field for contour generation and contour detection. However, analyzing the correlations between human behavior and model prediction on a trial-by-trial basis showed that human behavior is reproduced best, when using the same association field for all contour geometries. Furthermore it turned out that a bidirectional association field reaching only to the nearest neighboring edge elements can not explain the correlations found among the responses of different subjects, while a single unidirectional association field can do so. However, when assuming connections up to the next to-nearest-neighbor elements, a bidirectional association field also explains the correlations between human subjects.

The stimuli were designed such that the distance between two neighboring elements lies within the range of long-range connections found in V1. Hence our results allow two possible conclusions: If contour integration relies on horizontal interactions of the spatial range like in V1, a so far unknown unidirectional linking mechanism between neuronal columns is required. If such a unidirectional mechanism does not exist, our results suggest that contour integration is based on interactions on a larger spatial scale as found in higher cortical areas.