Crowding in peripheral vision: an explanation from cortical geometry & natural image statistics

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Visual crowding, the marked inability to identify shapes in peripheral vision when targets are flanked by other objects, has been widely studied; however, the mechanism of crowding remains unsettled. In this study, we provide a computational model that accounts for the development of several widely accepted signatures of the zone of crowding: (a) the spatial extent of crowding scales to half the target eccentricity (Bouma, 1970); (b) the zone of crowding exhibits a marked radial-tangential anisotropy (Toet & Levi, 1992), and (c) crowding is asymmetric in that an outward flanker (away from the fovea) is more effective at crowding a target than is an inward flanker (Bouma, 1973). Our model assumes a columnar architecture of the cortex, with columns packed hexagonally in cortical space. We assume that the receptive field sizes of V1 columns increase with eccentricity with a slope of 0.1 (Motter, 2002). We further assume that the lateral (horizontal) connections within V1 are isotropic in cortical space and have a radial extent of 6 hypercolumns (Bosking et. al., 1997, Stettler et. al., 2002). The geometry of this basic architecture already exhibits the properties of spatial scaling (Bouma's Law) and the inward-outward asymmetry. To account for the radial-tangential anisotropy, we propose that the statistics of natural scenes that shape the weights of the lateral connections are gated by spatial attention. As such, the attention-gated image statistics in the periphery are fundamentally different from those in the fovea in one respect: the statistics in the periphery are "corrupted" by the image motion due to radial saccadic eye movements which bring attended peripheral targets to the center of gaze. We showed with simulation that the interactions between saccade induced image motion and an attention-mediated Hebbian learning scheme can lead to a radial bias in the weight adjustments. Hebbian learning modifies and sharpens the initially homogeneous synaptic weights and is assumed to be active during development. Our simulations showed that connection weights are pruned along the tangential direction while being strengthened along the radial direction. The end result is that the zone of feature integration and competition for a higher-level neuron has the size and shape that exhibits the radial-tangential anisotropy while preserving the other two properties.

Support: NIH EY016391, EY017707