The human visual system is optimised for discriminating the spatial structure of scenes with natural second-order statistics

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It is often argued that the visual system must be optimized (by evolution and by neonatal adaptation) to encode the information in the natural visual environment. We have tried to test this proposition psychophysically by comparing people's discrimination thresholds for small spatial changes in natural and unnatural visual stimuli.

Systematic sequences of natural visual stimuli were made by 'morphing' one monochrome digitized photograph step-by-step into another. For instance, a sequence of slightly different faces could be made in which the shape, contrast and texture of each spatial feature in successive stimuli differed by less than 1 %. People with normal vision measured their thresholds for discriminating between morphed stimuli in a two-alternative forced-choice experiment; a staircase procedure sought how large a morphing change was needed for the observer to discriminate between a reference and a test stimulus on 75 % of trials (Tolhurst et al. 1998).

In the control condition, each stimulus in the experiment could potentially have been a photograph of a truly natural scene, and people were able to discriminate spatial changes in the scenes of about 0Â·5-15 %. The stimuli were made unnatural in a systematic way by changing the slopes of their power spectra, which determine the second-order statistics or autocorrelation functions of the stimuli (the correlations between the luminances of pairs of pixels in the images). When the spectral slopes were made shallower than normal (image whitening) or steeper than normal (blurring), the discrimination thresholds increased. This seems to be a direct confirmation, at least in the domain of second-order statistics, that the human visual system is optimized for dealing with natural as opposed to unnatural stimuli.

A preliminary computational model of the discrimination process was based on the fact that the visual cortex contains simple cells that have a spatial-frequency bandwidth of about 1-1Â·5 octaves. It was presumed that simple cells in several independent spatial-frequency bands sample the reference and test stimuli point-by-point, and that each cell then signals any local differences in the spatial structure of the two stimuli in the same way that it would signal that the contrast of its preferred sinusoidal grating had changed. This simple model of low-level processes in the visual system was surprisingly effective at explaining the forms of the relationships between discrimination threshold and spectral slope, and the ways that these differed between picture sets and observers.

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