Characterization of local and global statistics in three kinds of medical images, and an example of their role in a clinical judgment

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Barlow's efficient coding principle, that a sensory system deploys its resources in a manner that takes advantage of the statistical properties of its natural inputs, is a cornerstone for understanding principles of sensory processing and visual perception. However, there are important settings in which humans make perceptual decisions based on visual analysis of images that do not result from viewing natural scenes, such as radiologic diagnosis. With this motivation in mind, we examine the extent to which the statistics of natural scenes, for which the visual system is arguably optimized, are shared by various classes of medical images: digital mammograms, brain MRI (T1- and T2-weighted), and carotid ultrasound, and, for digital mammograms, investigated the impact of image statistics on a common clinical decision.

To characterize global statistics, we used the spatial power spectrum. As is well-known, natural images have $1/f^2$ power law behavior over a wide range and are largely isotropic. We found that the spatial power spectra of medical images typically have a steeper slope, often deviate from power law behavior, and may manifest substantial anisotropy. To characterize local statistics, we used multipoint correlations, as determined by Hermundstad et al. (eLife, 2014). In natural images, fourth-order correlations are more informative than third-order correlations; correspondingly, human perceptual sensitivity is higher for fourth-order than for third-order local image statistics. But in medical images, especially mammograms and brain MRI, third-order correlations are as informative as fourth-order correlations. Finally, we investigated the importance of global and local image statistics in a clinical judgment. To do this, we built general linear models to predict radiologists' breast density scores (BIRADS fatty/scattered vs. heterogeneous/dense). A model based on spectral statistics alone yielded an area under the curve of 0.89; this increased to 0.93 ($p<0.04$) when local image statistics were included. Second- and fourth-order statistics contributed most to this improvement. The signs and magnitudes of their model weights suggested that these statistics were used to estimate the Minkowski functional associated with porosity.

Differences between the statistics of natural images and medical images likely have many origins. Medical images differ from natural images in the physics of image formation, the source and nature of image noise, and in standardized viewing conventions. However, the human visual system – which is extensively shaped by the statistics of natural images – is used to analyze them. Thus, whatever the origin of these differences, they are likely to have implications for understanding human expertise and, ultimately, improving diagnostic technology.

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