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Contrast masking and facilitation in human psychophysical experiments using natural scene stimuli

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It has repeatedly been observed (e.g. Foley 1994) that the minimum detectable contrast difference of a sinusoidal grating is a function of the base contrast of the grating. For low contrast gratings, the discrimination threshold drops below the detection threshold (facilitation effect) and rises as base contrast increases (masking effect). This pattern of results is known as the dipper function. We present the results of two observers for psychophysical contrast discrimination experiments that used natural images, rather than sinusoidal stimuli.

Stimuli were two digitised, linearised black-and-white photographs of natural scenes, and two random dot patterns that were filtered to have the same second order statistics as natural images. Experiments (following local guidelines) used a 2-alternative-forced-choice procedure in which the observer had to indicate which interval showed the base stimulus combined with contrast increment, as opposed to the base alone. The base stimulus was the full sized photograph, measuring 6 deg × 6 deg. The increment was a small, central, Gaussian-weighted patch of the photograph. Simultaneous staircases adjusted increment contrast for 8 base contrast values; performance converged on the 75 % correct, threshold rate.

For all 4 stimulus images, and for both observers, the plot of threshold increment contrast against base contrast showed both facilitation at low contrasts and high-contrast masking, but the amount of facilitation was less than obtained when we used sinusoidal gratings as base and increment. Facilitation was greatest for the random dot images, with discrimination threshold falling 8.0 dB below detection threshold for one observer, 6.0 dB for the other. Of the photographs, a street scene produced more facilitation than a garden scene (7.0 *vs.* 2.5dB for one observer, 4.5 *vs.* 3.5 dB for the other).

These data were compared with the predictions of a simple-cell computer model, based on the model of Foley (1994) and first developed for contrast discrimination experiments using sinusoidal stimuli. Good fits are achieved for the photograph experiments, but the model consistently underestimates the amount of facilitation that occurs in the random dot experiments. The results of the psychophysical and computational study suggest that similar neuronal mechanisms underlie the processing of contrast differences in sinusoidal and natural stimuli, and that understanding the experiments using sinusoidal stimuli can indeed shed some light on the processing of natural images. However, the differences between the data for the photographs and random dot images suggest that the natural scene data cannot be explained by reference to second-order statistics alone.

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A Poisson decoder performs near-optimally at extracting motion signals from the temporally structured onset transients of MT neurons

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Neurons in cortical area MT respond to step changes in visual motion with a transient pulse of high firing rate activity before settling down to their sustained level of response (Lisberger & Movshon 1999). These onset transients, unlike the sustained response, show fine-grained temporal structure.

To investigate MT transient dynamics, we recorded extracellularly from area MT of anaesthetised macaque monkeys using methods described in detail in (Kohn & Movshon, 2003). After induction with Ketamine HCl (10 mg kg^{-1}), anaesthesia was continued during surgery with 1.5–3.5 % isoflurane in a 98 % O_2/2 % CO_2 mixture. Experiments typically lasted 4–5 days, during which anaesthesia and neuromuscular blockade were maintained with sufentanil citrate (4–8 μg kg^{-1} h^{-1}) and vecuronium bromide (0.1 mg kg^{-1} h^{-1}) in Ringer's solution containing dextrose (2.5 %). Experiments conformed to local and national guidelines. The adequacy of anaesthesia was monitored continuously (EEG, ECG etc., see Kohn & Movshon (2003) for further details). Animals were humanely killed at the end of experiments.

Using an information theoretic approach (Panzeri & Schultz 2001), we found that the temporal structure in the onset transients can lead to either synergy or redundancy in the information content of spikes nearby in time, with a large variation from cell to cell. However, not all encoded information may be useful, so we compared the amount of information encoded about motion direction with that extracted by two maximum likelihood (ML) decoding strategies. The first strategy utilised complete knowledge of the probability of responses (spike trains) given stimuli, as determined from a training dataset. The second strategy, which we refer to as Poisson decoding, ignored correlations, instead assuming all time bins to be conditionally independent, and the response probability therefore obtained by the product of the spike probability distributions at each point in time. Neither decoder necessarily extracted all of the encoded information, some of which must therefore relate to differences in responses to non-preferred stimuli. The Poisson decoder performed almost as well as the ideal ML decoder, indicating that temporal structure in the onset transients neither helps nor hinders the extraction of motion signals from the spike train.

An adaptive filter implementation of Poisson decoding can be made using such well known mechanisms as synaptic depression and postsynaptic gain control; its near-optimal performance, together with the ubiquity of transient responses, is suggestive of a general mechanism present at each level of visual processing.

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