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Modeling the mechanisms underpinning sensory adaptation and gain control

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It is well established that following adaptation, cells adjust their sensitivity to reflect the global stimulus conditions. Post-adaptation, the stimulus-response function (SRF) is often displaced laterally (relative to control), centering the dynamic response region of a cell onto the adapting stimulus (AS). Recent studies in guinea pig inferior colliculus (IC) [1] and barrel cortex [2] using a novel adaptation technique that allowed for the independent manipulation of either stimulus mean or variance also observed a lateral shift in the SRF that was dependent on the mean AS. When stimulus mean was held constant and only the variance of the AS was increased, the SRF was scaled upward, indicating that cells altered the gain of their responses to code for levels of variance in the AS. Gain here refers to neural gain and is quantified as the SRF gradient at the stimulus that elicits half the maximum response. Adaptation to variance was rare in the IC [1] but relatively common in the barrel cortex [2]. However, the direction of gain change was in contradiction to Information Theory [3], which predicts a decrease in neural gain (quantified by the SRF slope) with increased stimulus variance.

We performed a further analysis of the experimental data, from the barrel cortex [2], and found that the adaptive gain changes to AS variance were, in fact, in the direction predicted by Information Theory. To investigate the mechanisms underpinning these variance-related gain changes we implemented, in Matlab, a pulse-based, integrate-and-fire, single neuron model, with Hodgkin-Huxley style dynamics [4]. The introduction of firing rate adaptation [2] resulted in the lateral displacement of the SRF in response to shifts in the mean AS, but did not generate changes in the overall gain of the cell in response to increases in stimulus variance. An extensive literature review has suggested three possible sources of gain control we are currently exploring. (1) Balanced increases in both excitatory and inhibitory random background conductances, in vitro and in modeling studies, can induce changes in gain [5]. We have found that concomitant increases in both background and stimulus variance lead to a scaling downwards of the SRF, in line with the experimental data. (2) Where a non-linear relationship between stimulus and response exists, the addition of excitation or inhibition can increase or decrease gain, respectively [6]. (3) Imbalanced intra-cortical synaptic depression [7] is of most interest as synaptic depression has been proposed as one possible source of contrast-gain control, a well-explored phenomenon of the visual system.

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