MODELING ATTENTIONAL EFFECTS IN CORTICAL AREAS MT AND MST OF THE MACAQUE MONKEY THROUGH FEEDBACK LOOPS

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Introduction

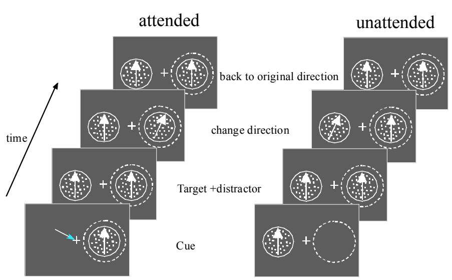
It has been shown that attention can increase the response of visual neurons to behaviorally relevant stimuli. Two general features of this attentional modulation are 1) it is stronger for areas located higher up in the hierarchy of visual processing (Treue and Maunsell, 1996; McAdams and Maunsell, 1999) and 2) its intensity increases over time (McAdams and Maunsell, 1999).

Hypothesis

Attentional effects on cell responses in visual cortex are consequence of a common mechanism that modulates the gain of negative feedback loops in visual neurons. We hypothesize that a reduction in the magnitude of spike frequency adaptation can explain the attentional effects at the level of single neurons.

Methods

We recorded the responses of 167 direction-selective cells in area MT and 46 in area MST of two macaques monkeys while the animals detected a direction change in a moving random dot pattern (the target) and ignored another change in a second random dot pattern (the distractor) moving in the cells' preferred direction. In one attentional condition (attended) the target appeared inside the cells' receptive field and the distractor outside. In the second condition (unattended) the target appeared outside and the distractor inside.

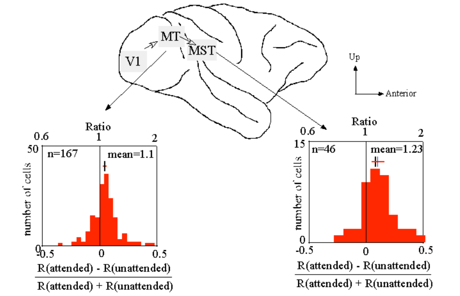


Cells were classified as MT or MST according to the electrode position within the recording chamber and their direction selectivity for linear and spiral motion. For each unit, spike density functions (SDF) in the two attentional conditions were obtained. These SDF were pooled across units to obtain average SDF for both (MT and MST) samples in the two conditions.

Model: We modeled the attentional feedback loops by connecting 4 hypothetical neurons, two MT units (U,V) projecting via feed-forward to each one of another two MST units (U,V). Each unit possesses one or two negative feedback loops that modulate the strength of its own inputs.

Physiology

Magnitude of attentional effects in areas MT/MST

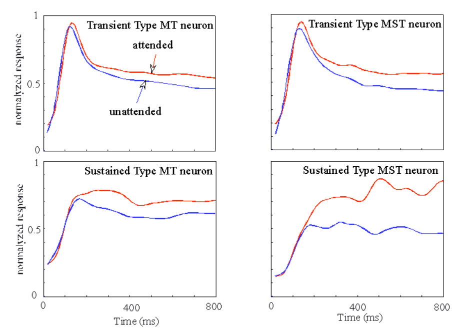


mean increase in MT=1.1

mean increase in MST=1.23

I) $\text{mean increase in MST} = \left[\text{mean increase in MT}\right]^2$

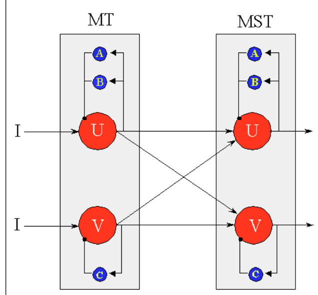
Time course of attentional effects in areas MT and MST



II) The attentional modulation of responses grows linearly over time.

'I' and 'II' suggest that attentional effects on MT/MST could be generated by inhibiting a negative feedback loop that would otherwise decrease the response of the unit at a constant rate over time.

Modelling



Model

Two MT neurons, one transient (U) and one sustained (V) projecting toward two MST neurons (U, V). Each neuron possesses a negative feedback loop(s) than causes response adaptation. Attention acts in the same way in each neuron by regulating the intensity of the negative feedback.

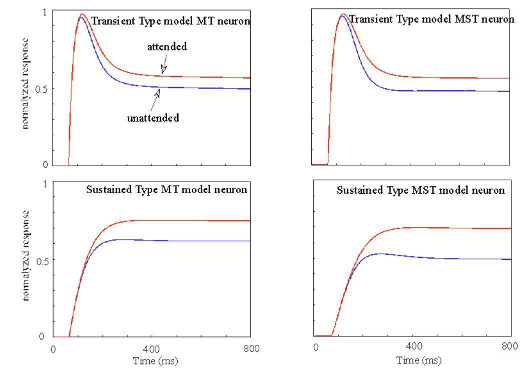
$$\frac{dU}{dt} = \frac{1}{18} \cdot \left[-U + \frac{100 \cdot I^2}{(C50 + 0.6 \cdot A + 0.3 \cdot B)^2 + I^2} \right] \qquad \frac{dA}{dt} = \frac{1}{200} \cdot \left[-A + G \cdot U + G \cdot U^2 \right]$$

$$\frac{dB}{dt} = \frac{1}{4000} \cdot \left[-B + G \cdot U \right]$$

$$\frac{dV}{dt} = \frac{1}{18} \cdot \left[-V + \frac{100 \cdot I^2}{(C50_F + C)^2} \right] \qquad \frac{dC}{dt} = \frac{1}{200} \cdot \left[-C + G \cdot V \right]$$

A, B, C: Negative feedback loops with gains (G) that are modulated by attention.

Model Simulations



The model simulations closely match the physiological results. The gain effect in MT and MST is about 1.10 and 1.21 respectively. The effect of attention on each individual feedback loop is the same in the two areas. The stronger effect in MST is due to the effect of attention in the signal already modulated coming from MT.

Conclusions

The attentional feedback loops hypothesis offers a quantitative and biologically plausible explanation of the mechanism by which attention modulates the responses of visual neurons. We proposed that attentional effects across different cortical areas are the result of a common mechanism that inhibits spike frequency adaptation at the level of single neurons. An increase in the modulatory power of attention in cortical areas located higher in the hierarchy of processing is the result of a chain of modulatory effects across lower level areas.