Supplementary materials for: A mechanistic cortical microcircuit of attention for amplification, normalization and suppression

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Results with standard parameters

In the following, we will verify that the basic model characteristics and not the free model parameters explain the vast range of data sets. For this, we fixed all model parameters to the standard values outlined in Tab. 1 (Section 2) and re-simulated all experiments. We only treat the input tuning curve as free parameter. This curve determines the feature tuning of neurons in layer 4 and layer 2/3. As the data were recorded from different brain areas, the feature tuning can be expected to be variable. We decided to treat it still as free parameter, as the width of the curve differs strongly among data sets, e.g. narrow in V1 (Fig. 3f) versus broad in MT (Fig. 8a). Likewise the baseline, i.e. the activity to anti-preferred features, deviates as well, e.g. weak in V4 (Fig. 7) versus average in MT (Fig. 8a).

As the data stems from different brain areas, neurons, and monkeys, a perfect fit cannot be expected with a single set of parameters. For example, feature-based attention amplifies the response in a range from +10% in V1 to +35% in MT (Fig. 2E, Saenz et al. (2002)).

The simulation results show that the model can replicate the main effects in all data sets, with the exception of minor deviations in the surround suppression experiment of Cavanaugh et al. (2002) and Sundberg et al. (2009) (Fig. S3c, S3d). The results are grouped similar as in Section 3 into biased competition (Fig. S1), attentional modulation of the neuronal tuning curve (Fig. S2), contrast response function (Fig. S3a,b), and surround suppression (Fig. S3c-g).

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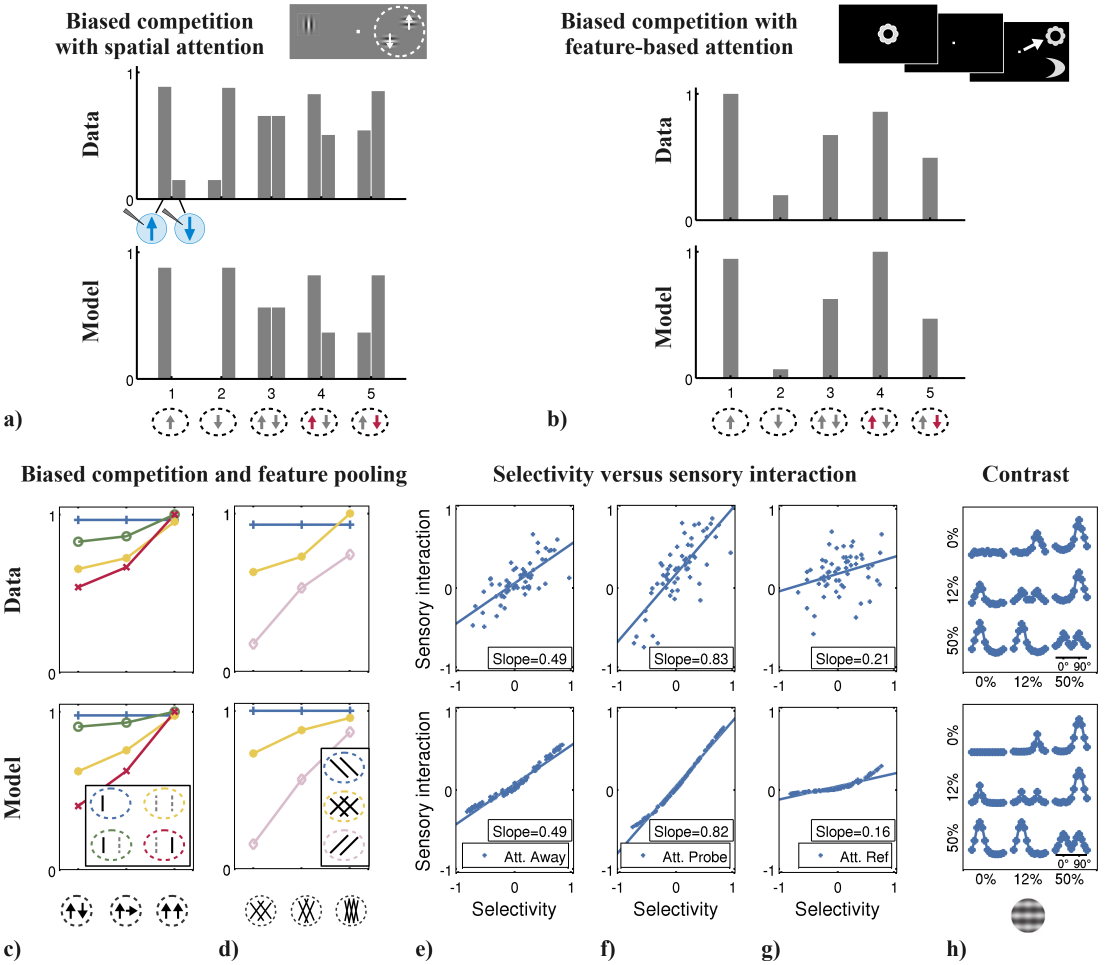

Figure S1: Biased competition can be fully replicated with standard parameters. Neurophysiological data (top row) is shown in relation to simulation results (bottom row). The figure refers to Fig. 2 - 4. **a)** Biased competition with spatial attention: A neuron preferring upward motion shows a lower response to the pair (condition 3) compared to a stimulus alone (condition 1). The response increases if the preferring stimulus is attended (condition 4) or decreases if the anti-preferred is attended (condition 5). **b)** Biased competition with feature-based attention results in the same effects. **c)** The competitive interactions depend on the similarity of the two spatially disjunctive stimuli. Biased competition occurs with two different stimuli (left) and feature pooling with two equal stimuli (right). **d)** The same similarity dependency as in c) can be observed for overlapping gratings in data from V1 and the model. **e-g)** Effect of attention on the relationship between selectivity (probe - reference) and sensory-interaction (pair - reference). Significant effects are: the slope does not differ from 0.5 in the attend away condition (e), is greater than 0.5 in attend probe condition (f), and is less than 0.5 in a attend reference condition (g). **h)** Contrast dependency of cross-orientation suppression. The response to a pair of stimuli is lower as to a single stimulus, illustrating cross-orientation suppression. In data from V1 and model the suppression and the population response depends on the contrast differences between the two stimuli. For similar contrasts, the population response shows two peaks, whereby it shows only a single peak for large differences (i.e. 50% and 12%), as the response to the lower contrasted stimulus is completely suppressed..

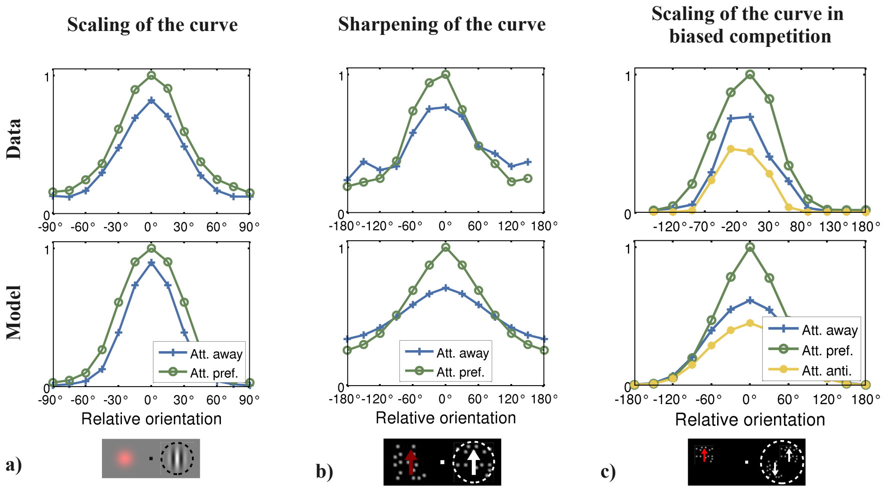

Figure S2: Attention modulation of neuronal tuning curves can be fully replicated with standard parameters. Neurophysiological data (top row) is shown in relation to simulation results (bottom row). The figure is illustrated identical as Fig. 7 - 8. **a)** Scaling of a tuning curve by spatial attention. The authors reported two significant results which are also present in our results: The whole tuning curve is scaled, and is slightly, but significantly shifted upwards by attention. The width and the preferred tuning direction are not affected by attention. **b)** Sharpening of the tuning curve is caused by feature-based attention, resulting in a significantly increased response at the preferred feature (0°) and in a significantly decreased response at anti-preferred ones (±180°). c) Contrary in biased competition, feature-based attention leads to a scaling of the tuning curve and sharpening cannot be observed.

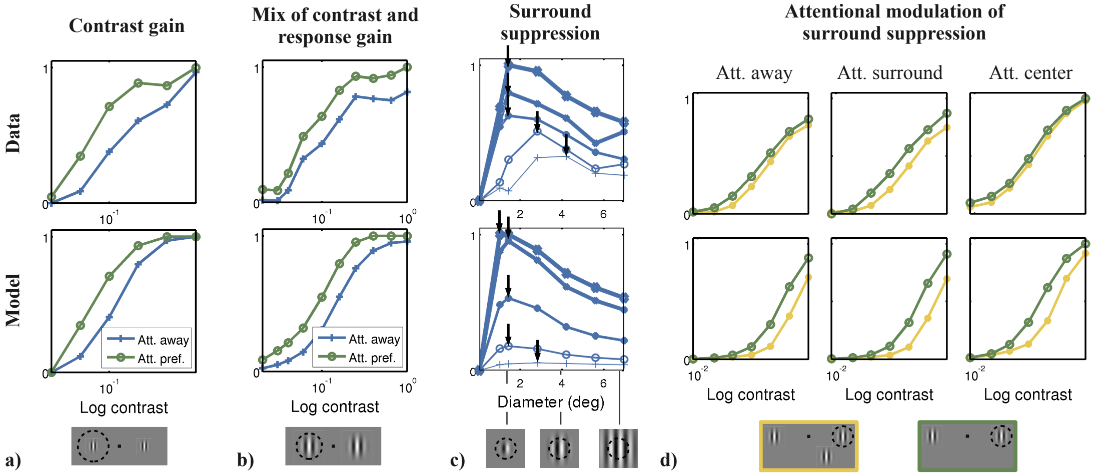

Figure S3: Attentional modulation of the contrast response function (a, b) and of surround suppression (c, d). Effects in a), b) can be nearly replicated with standard parameters, effects in c) and d) partly. Neurophysiological data (top row) is shown in relation to simulation results (bottom row). The figure refers to Fig. 5, 6, 9a, 9b. **a)** Contrast gain denotes the effect that the response at lower contrasts is significantly stronger increased by attention, resulting in a left-wards shift of the contrast response function (cRF). **b)** A mix of response and contrast gain results in an leftwards and upwards shift of the cRF. The response gain at high contrasts observable in the data is only partially replicated in the model due to a too weak suppression from neurons in the close surround. This suppression is calibrated based on the data of Cavanaugh et al. (2002) (S3c), which is optimally fitted by a scaling factor $v^{\mathrm{SUR}} = 0.5$, whereby the free parameter model uses $v^{\mathrm{SUR}} = 1.0$ to fit the response gain data. In the Cavanaugh et al. (2002) data, such a stronger suppression from the close surround would result in a too swift decrease of the response after the stimulus exceeds the receptive field, i.e. after the peak of the response curve. **c)** Surround suppression without attention: The response to increased gratings shows significant surround suppression after the stimulus exceeds the receptive field border (black arrows). The peak amplitude differs dependent on the stimulus contrast (thickest line denotes highest contrast), which is roughly replicated by the standard parameter model. Furthermore, the receptive field size increases significantly with lower contrasts. Our results show this effect only marginally. The main reason for this deviation is the change of p^{SUR} from 2.0 to 1.0. This parameter controls non-linearly the influence of the presynaptic firing rate on the surround suppression. A value of 2.0 decreases the surround suppression for lower rates induced by lower contrasts, which explains our data fits (Section 3.4). Contrary, the non-linearity was disabled by setting p^{SUR} to 1.0 in the standard parameter set as it fits optimally four other data sets (Fig. 3b, 6, 7, 8a). The difference between these data sets and the current one is the large regular stimulus in the current one. This stimulus would drive optimally contour linkage effects (Gilbert, 1998), which would enhance the response and so decrease suppression. Therefore, we speculate that the increase of receptive fields is due to contour linkage effects which is beyond the grasp of the attention mechanisms in our model. **d)** Attentional modulation of surround suppression: In attend away, adding the surround stimulus suppresses the response over all contrasts, whereby the suppression is proportionally larger at lower contrasts. Attention to the surround increases this suppression, whereby attention to the center decreases it. All these significant effects can be replicated. Yet, our result deviates notable from the data because the surround suppression is too strong (yellow curves). The model with free parameters fits the data via a weak suppression $v^{\mathrm{SUR}} = 0.55$, $p^{\mathrm{SUR}} = 2.5$, contrary the standard model uses $v^{\mathrm{SUR}} = 0.5$, $p^{\mathrm{SUR}} = 1.0$. The non-linearity ($p^{\mathrm{SUR}} = 2.5$) has the side effect to weaken the suppression, so it is much weaker than in the standard model with disabled non-linearity ($p^{\mathrm{SUR}} = 1.0$). The non-linearity is disabled in it as it allows to fit more data sets (Fig. 3b, 6, 7, 8a).

References

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