Equalization of ocular dominance columns induced by an activity dependent learning rule and the maturation of inhibition

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In cat primary visual cortex (V1), responses early in development are dominated by the contralateral eye [1]. Both physiologically and anatomically [1,2], inputs from the ipsilateral eye are restricted to patches within a continuous sea of contralateral-eye inputs. Then, beginning approximately at the onset of the critical period for plasticity in response to monocular deprivation, the inputs from the two eyes become roughly equalized and segregate into alternating ocular dominance columns [1]. This equalization and segregation does not occur if the eyes are not opened [1]. It was argued [1] that this equalization was unlikely to arise simply from Hebbian rules of synaptic plasticity. This was presumably based on the intuition that, in a Hebbian competition between two inputs with similar activities, the initially stronger input should win. In mouse V1, the onset of the critical period for monocular deprivation plasticity has been shown to coincide with, and depend upon, a sufficient maturation of intracortical inhibition [3,4]. The maturation of inhibition and the associated onset of the critical period does not occur if the eyes are not opened.

Here we show how these observations can be united: sufficiently strong inhibition forces equalization of the two eyes under a Hebbian rule. If intracortical connections are inhibition-dominated, then activation of some cortical cells by one eyes' inputs evokes net inhibition that suppresses the activation of other cortical cells. This suppresses patterns in which a majority of cortex is driven by a single eye, leaving only those in which the two eyes equally share cortex. A periodically alternating ocular dominance pattern results if excitation and inhibition are organized in a "Mexican hat" pattern. In semi-linear models of plasticity, this solution is too inflexible: even after simulated monocular deprivation, the two eyes remain equal. We show that a nonlinear model that incorporates homeostatic as well as correlation-based plasticity can replicate the entire developmental sequence. If, on average, contralateral synapses are initially stronger, ipsilateral-eye dominant patches emerge in a continuous sea of contralateral-eye input. After maturation of inhibition, an equalized, periodically alternating ocular dominance pattern emerges, but monocular deprivation still causes an ocular dominance shift. Thus, if the onset of the critical period in cats coincides with a maturation of inhibition that depends on the eyes being open, as in mice, this suffices to explain the interocular equalization observed at the onset of the critical period in cats and its failure to occur under binocular deprivation [1].

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