Cognitive Control in Perceptual Learning: Data and Model

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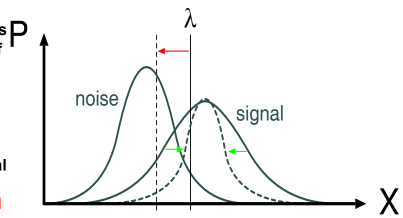
Introduction

Theories of perceptual learning typically concern themselves solely with changes in perceptual sensitivity as a function of experience (see Fahle & Poggio, 2002, for a review): It is generally assumed that practice could lead to either a shift or a narrowing of the distribution of perceptual evidence (as in, e.g., Dosher & Lu, 1999; see green arrows in right figure) and that an observer remains stably biased throughout the experiment. However, it is altogether possible that decisional influences may be at work (e.g., Ahissar & Hochstein, 2002): For example, practice could produce a shift in the decisional criterion (see red arrow in right figure) and thus reflect some sort of cognitive influence. We here report about data supporting this assumption and also present a simple neuronal circuit that captures some of the observed phenomena. The circuit employs a flexible decision criterion that allows for changes in bias.

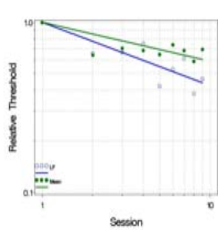


Data

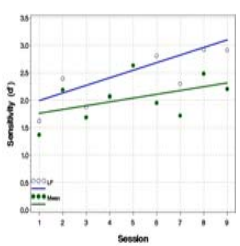
The present study used a contrast *detection task* in which a range of different contrasts was used in each session (method of constant stimuli). The range was shifted to follow changes in observers' performance (Copeland and Wenger 2003; Rasche and Wenger 2004; see right two figures for individual results). A total of nine naïve observers were tested.
From the resulting psychometric functions the following measures were obtained: detection threshold, sensitivity and bias.

Subject 2: the psychometric function rotates counter-clockwise and translates to the left. A liberal shift in bias was observed for this subject!

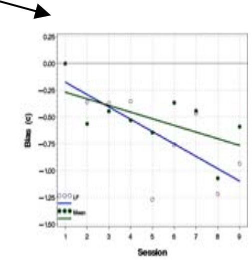
Subject 8: the psychometric function rotates counter-clockwise. The subject showed a liberal shift as well.



5 of 9 observers showed reliable decreases in detection thresholds. Blue: Observer LF. Green: Mean for the five observers.



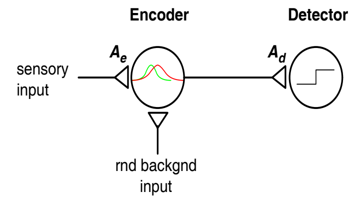
Only 3 of the 5 observers who showed reliable decreases in threshold showed reliable increases in sensitivity. Blue: Observer LF. Green: Mean for the 5 observers.



All of the observers who showed decreases in threshold or increases in hit rates showed reliable liberal shifts in response criterion. Blue: Observer LF. Green: Mean for the 6 observers

Model

The model consists of a two-neuron circuit, an encoder and a detector neuron, which basically mimics the signal detection process for a two-alternative forced choice detection task. The encoder neuron receives continuous random background input and generates a 'noise' interspike-interval (ISI) distribution in the absence of sensory input. In the presence of sensory input, the ISI distribution represents the signal-plus-noise distribution. The detector neuron receives the encoder's spike output and detects ISIs of a certain maximal length.



The example traces show one trial (simulated with integrate-and-fire neurons). The stimulus is a step function. In this specific trial, the encoder produces 3 spikes, of which the first 2 spikes occur close enough in time, such that the detector neuron signals the presence of the stimulus by the integration of the postsynaptic potentials. The detailed correspondence between behavior and circuit is:

hit:	*detector spike during stimulus presence*
false alarm:	*detector spike during stimulus absence*
miss:	*lack of detector spike during stimulus absence*
correct rejection:	*lack of detector spike during stimulus presence*

The synaptic amplitude A_d determines the position of the decision criterion: $\lambda \sim A_d$

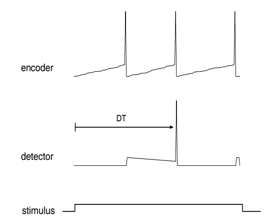
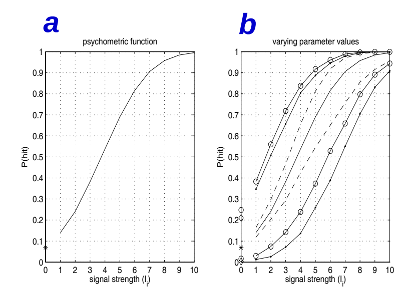


Figure a (left) shows the 'psychometric' function of the circuit. The location and shape of the psychometric function can be modulated by changing the synaptic amplitudes (see b):

decrease in A_e:	clockwise rotation (see stippled right)
increase in A_e:	counter-clockwise rotation (see stippled left)
decrease in A_d:	right-ward translation (see circled right)
increase in A_d:	left-ward translation (see circled left)

Note: a left-ward shift can be induced which looks like perceptual improvement, but which is only a change in bias!

⟶ This allows us to replicate the changes of the psychometric function observed with certain subjects including their liberal shift. For example, the shift of subject 2 (see Data section) can be simulated by increasing A_e (counter-clockwise rotation) and by increasing A_d (left-ward shift), which would result in the same account for the liberal shift. Similar with subject 8.



The input-output relation of the circuit looks akin to a psychometric function.

Changing synaptic amplitudes in the neuron circuit causes changes in the location and shape of the psychometric function.

Summary

1) The data have shown that there exist reliable liberal shifts in response bias for some observers who showed 'improvement' in the contrast detection task. Thus, perceptual learning seems to reflect cognitive as well as perceptual influences.
2) A two-neuron circuit can mimic part of the results by the adjustment of synaptic values in the sensory and decision part of the circuit. This is contrast to other studies like the LAM model (Gold et al. 99) and the PTM model (Dosher and Lu 99), in which the decision criterion remains fixed.

References

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Acknowledgements

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