CCN Exercise Sheet 1: Encoding, Decoding and Sensory Adaptation

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1 Introduction

Visual adaptation[1] is known to induce a lot of changes in perception. For example, if you stare at a waterfall for a long time, then look away, it will seem as if the world is suddenly moving up.

Similarly, adaptation to a moving stimulus (thereafter called the 'adaptor') modulates the perception of the direction of subsequent moving stimuli (the 'test'). This effect depends on the direction of the test compared to the adaptor (Fig. 1). When the angle between the adaptor and the test is less than about 90 deg, the direction of the test appears to be repelled away from that of the adaptor ('direction after-effect'). For larger angles (>90 deg or <-90 deg), the estimation bias disappears or reverses slighly (the 'indirect effect'). This phenomenon has been widely studied in psychophysics.

Aim of this assignment

The aim of this assignment is to understand the relationship between the neural basis of adaptation and these perceptual effects. We will design a very simple model of physiological adaptation, use a decoder to relate the neural responses and the psychophysical performance and explore whether this provides a good model for the perceptual effects of adaptation.

[1] In this context, visual adaptation is the fact of staring at an image for at long time, at least 15 seconds.

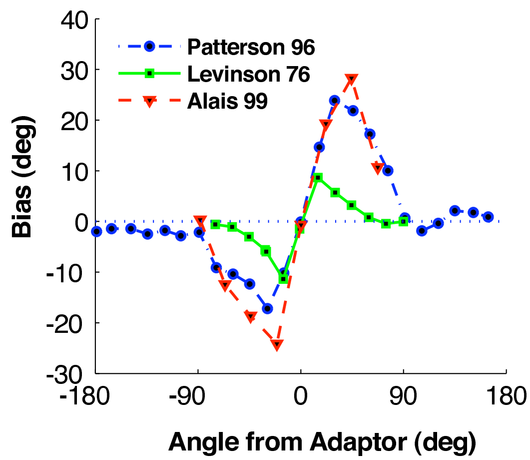

Figure 1: Motion After Effect: Psychophysical measurements. Shift in perceived direction as a function of the stimulus direction, after adaptation to a direction of 0 deg. Directions close to the adaptor are repelled away from the adaptor. Data are replotted from [2] (squares), [3] (circles) and [1] (triangles).

2 Exercise

2.1 Model of the population of neurons

We consider a population of $N = 50$ neurons with tuning curves $f_i(\theta)$ describing the mean spike count of each neuron in 1 second as a function of the stimulus direction θ. The cells have preferred directions θ_i equally spaced between -180 deg and 180 deg. The tuning curves are circular normal distributions[2]:

$$f_i(\theta) = G.\exp(\beta(\cos(\theta - \theta_i) - 1)) + K \tag{1}$$

where G is the maximal firing rate ($G = 50$ spikes), $\beta = 3$ controls the width of the tuning curves and K denotes spontaneous activity ($K = 5$ spikes). The variability of the spike count is Poisson. We denote by $\mathbf{r}(\theta) = \{r_1(\theta), .., r_N(\theta)\}$ the response of the population of neurons on a given trial of 1 sec for a stimulus θ.

- Plot the mean response $\mathbf{f}(\theta_0)$ of the population of neurons to stimulus $\theta_0 = 0°$.
- Plot an example of the population response $\mathbf{r}(\boldsymbol{\theta_0})$ to stimulus $\theta_0 = 0°$ for one trial.
  Tip: You will need to use a Poisson random number generator in matlab, for eg. `http://homepages.inf.ed.ac.uk/pseries/CCN/poirv.m`

[2]These functions are similar to Gaussian functions but they are periodic, so that they wrap around the circle of stimulus directions naturally.

2.2 Decoding the direction of the stimulus

To decode the direction of the stimulus based on the responses of the neurons, we will first use the winner-take-all decoder. On each trial, the estimate of the stimulus is thus given by the preferred direction of the neuron which fires most.

- Vary the stimulus direction θ from -180 to 180 deg and for each stimulus direction, compute the stimulus estimate for 100 repetitions of the stimulus.
- Plot the bias as a function of θ (i.e. the difference between the estimate and the stimulus, averaged over all repetitions).

2.3 Effect of Adaptation

We assume that adaptation operates by decreasing the gain of neurons, G_i . The gain is decreased by a factor that depends on the difference between the preferred direction of each neuron and the direction of the adaptor so that the cells that are most selective to the adapting stimulus are maximally suppressed:

$$G_i = G\left[1 - \alpha_a \exp\left[-\frac{(\theta_i - \theta_{adapt})^2}{2\sigma_a^2}\right]\right] \tag{2}$$

The parameter α_a quantifies the amount of suppression; σ_a quantifies the spatial extent of the response suppression in the direction domain and G is the gain before adaptation. The adaptor is $\theta_{adapt} = 0$ deg. We use $\alpha_a = 0.85$ and $\sigma_a = 22.5$ deg. After adaptation, test stimuli covering the whole range of directions are presented[3] and we decode again the direction of the stimulus based on the responses of the model population.

- Adapt your code to include this adaptation model. Plot the bias as a function of θ.
- Compare these figures with the psychophysical results (Fig 1). Is it a good model of the perceptual effects of adaptation ? Comment.

2.4 Optimal decoding

It is known that the winner-take-all method is a very suboptimal method for decoding. We decide to use a maximum-likelihood decoder instead. The estimate of the stimulus direction is now the one that maximizes the log-likelihood: $\hat{\theta} = \text{argmax}_\theta \ln P[\mathbf{r}|\theta]$.

[3] We assume that the level of adaptation of the cell is constant during the whole procedure.

- Write the mathematical expression of the log likelihood, $ln(P[\mathbf{r}|\theta])$, for the present model, as a function of the stimulus direction θ.
- Implement the maximum likelihood decoder algorithm (Tip: matlab optimization functions such as $fminsearch$ can be useful) and try it out on a few trials.
- Plot the bias with this decoder before adaptation.
- In which sense is this decoder more 'optimal'? If you were to quantify it, how would you do?
- Plot the bias with this decoder after adaptation (assuming that the decoder is still based on the likelihood defined *before* adaptation). Comment.
- What would happen if the decoder after adaptation was based on the likelihood defined *after* adaptation?

References

[1] D. Alais and R. Blake. Neural strength of visual attention gauged by motion adaptation. *Nat Neurosci*, 2(11):1015–1018, Nov 1999.

[2] E. Levinson and R. Sekuler. Adaptation alters perceived direction of motion. *Vision Res*, 16(7):779–781, 1976.

[3] R. Patterson and S. Becker. Direction-selective adaptation and simultaneous contrast induced by stereoscopic (cyclopean) motion. *Vision Res*, 36(12):1773–1781, Jun 1996.