Rapid measurement of spatiotemporal contrast sensitivity in behaving macaque monkeys

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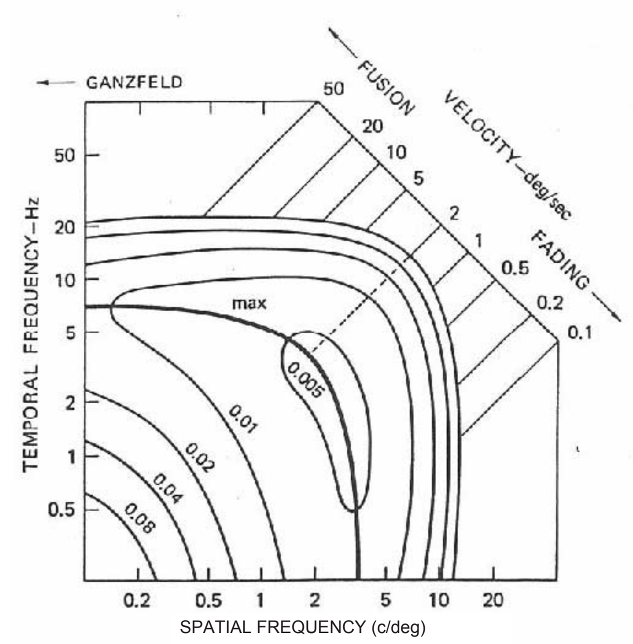
Introduction

The spatiotemporal contrast sensitivity function ("Kelly function") is a large-scale characteristic of visual performance. It consists of contrast thresholds across the visible range of spatial and temporal frequencies of luminance modulation (Kelly, 1979; Nakayama, 1985).

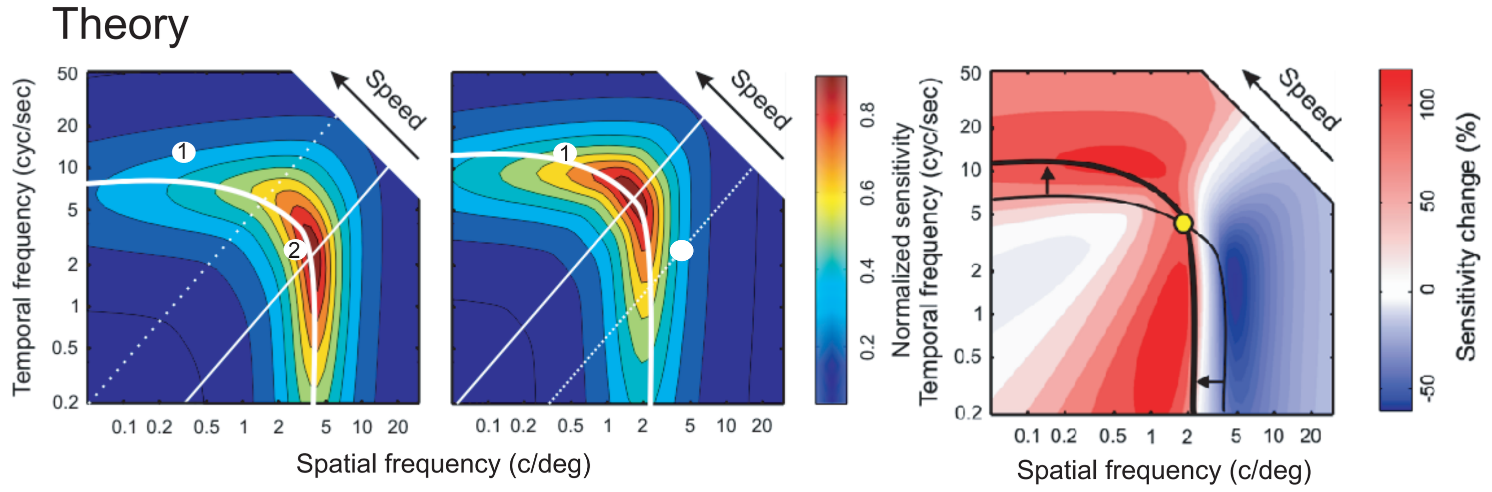
Estimation of the function is important for basic vision research and for evaluating the deficiencies that accompany visual pathology (e.g., Comerford, 1983). Kelly function in humans was previously found to have an invariant shape across tasks and subjects, consistent with a theory of visual sensitivity (Gepshtein et al., 2007).

Changes in speed statistics caused a shift of Kelly function while preserving its shape (Gepshtein et al., 2013). To understand how the large-scale change of sensitivity is mediated by cortical neurons, we need to know where neuronal tunings fall on the Kelly function.

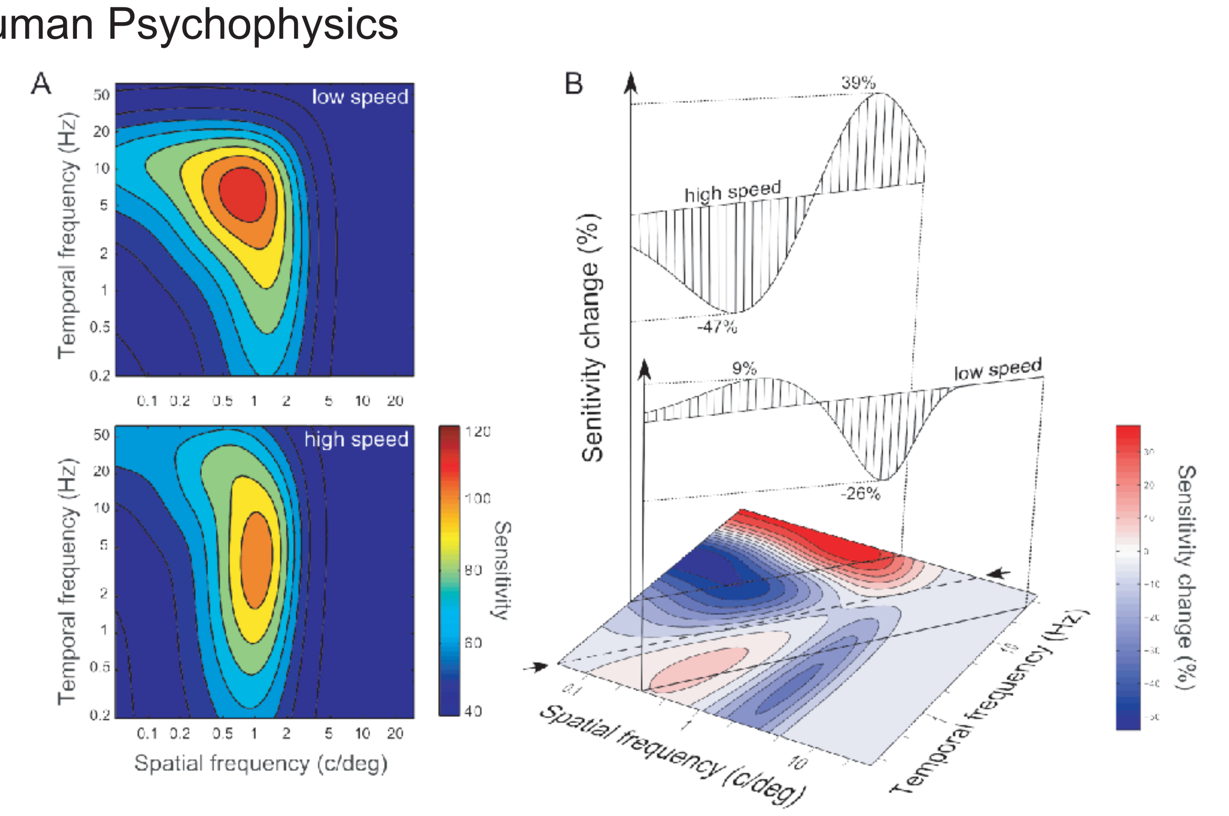


Contour plot of the Kelly function (Kelly 1979). The level curves are isosensitivity contours for five magnitudes of contrast threshold. The ratios of temporal frequency to spatial frequency are stimulus speeds, notated on top right, forming the parallel constant-speed lines. The thick curve labeled "max" is the set of maximal senstivities across speed. The curve is predicted to have an invariant shape under motion adaptation.

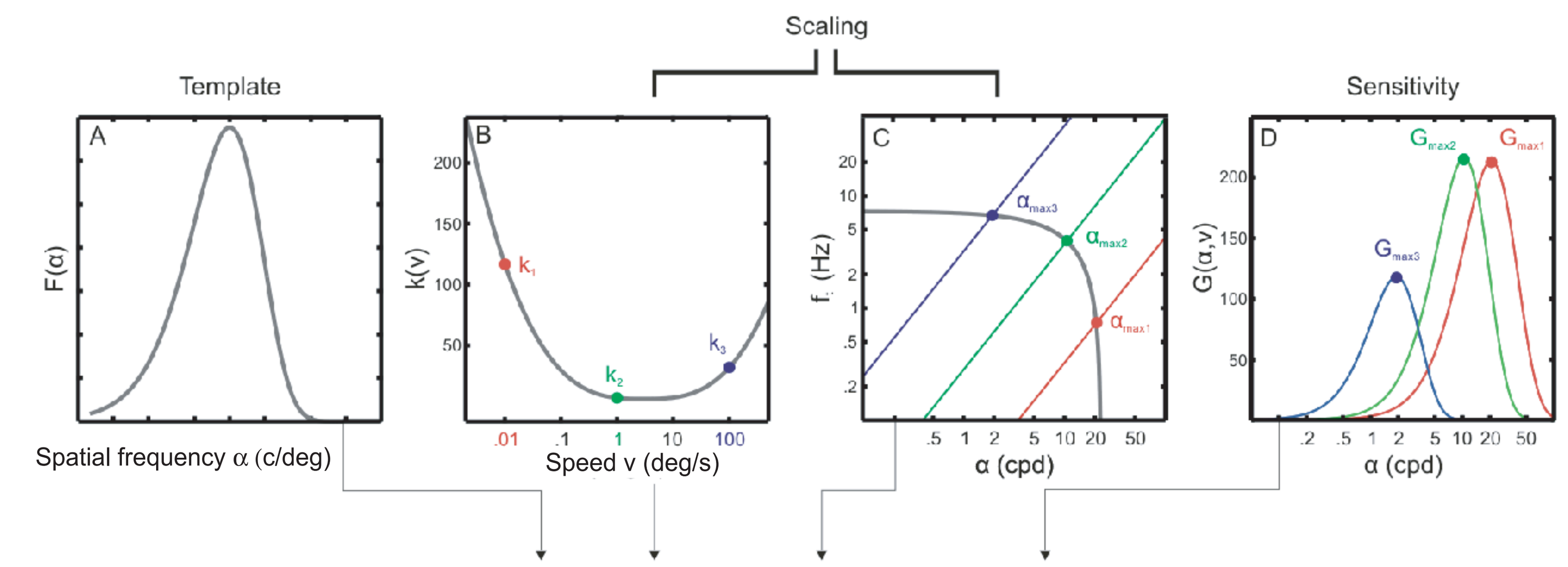
Theory



Human Psychophysics



Sample of results from speed adaptation experiments by Gepshtein et al (2013). Changes in statistics of stimulus speed caused a large-scale reorganization of sensitivity: a shift of the Kelly function predicted by Gepshtein et al. (2010).



$$F(\alpha) \cdot k \cdot v \cdot \alpha_{max}^2 = G_{max}(\alpha,v)$$

Structure of the Kelly function: A generic constant-speed template F(α) is a function of spatial frequency α. α_{max} is the spatial frequency at peak sensitivity. The sensitivity function is generated by scaling F(α) by $k v \alpha^2$, where v is speed, and k is a scaling factor. Both α and k are speed dependant. The maximum value of sensitivity is proportional to $k v \alpha_{max}^2$. The three colors in B-D indicate three corresponding speeds slices.

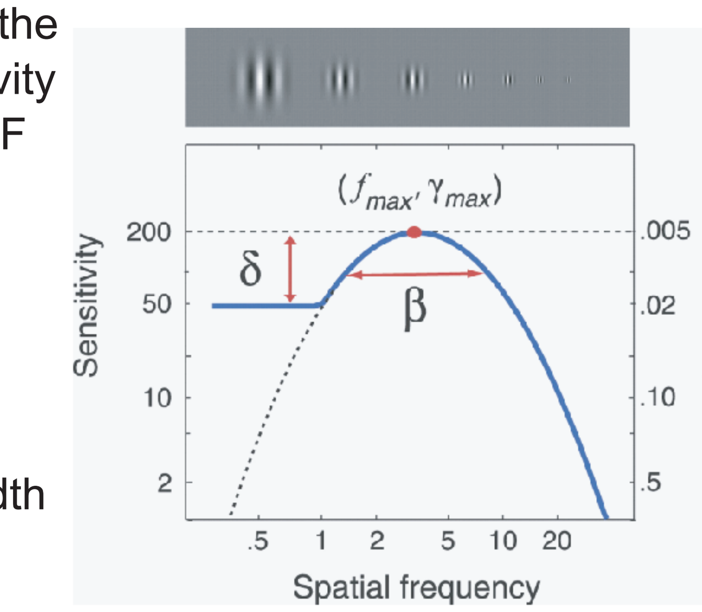
Methods

The Kelly function was measured in two monkeys. The stimuli were drifting Gabor gratings 8° in diameter. The CSF was estimated at seven spatial (from 0.125 to 8 c/deg) and six temporal frequencies (from 0.5 to 32 Hz), i.e., on 42 nodes. Contrast thresholds were estimated on each node while monkeys performed direction discrimination. Two adaptive methods were used: PSI procedure and qCSF.

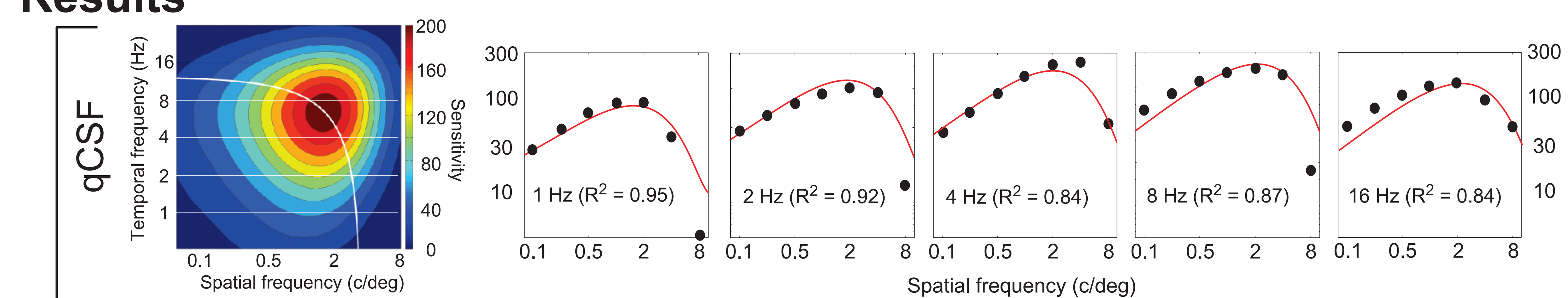
Quick CSF (qCSF)

Parametrization of the 1D contrast sensitivity function in the qCSF procedure.

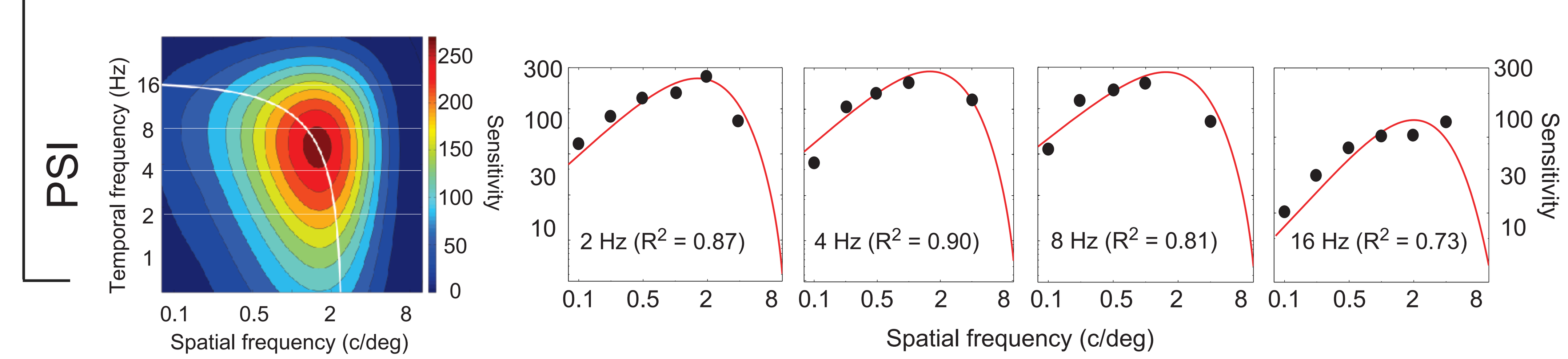
The function is described by four parameters: peak sensitivity, peak frequency, bandwidth (at half-maximum), and truncation (the plateau on the low-frequency end) (Lesmes *et al.* 2010)

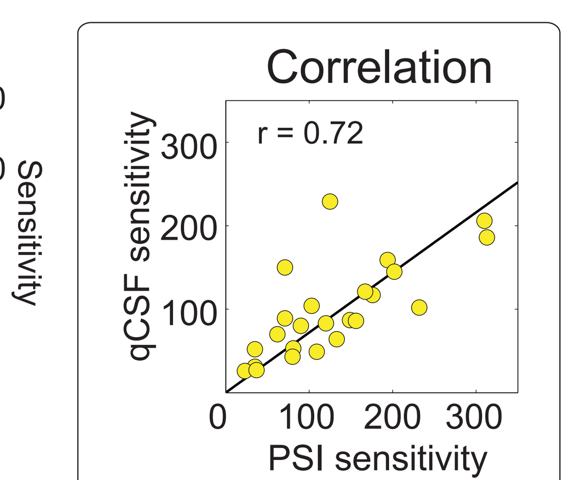


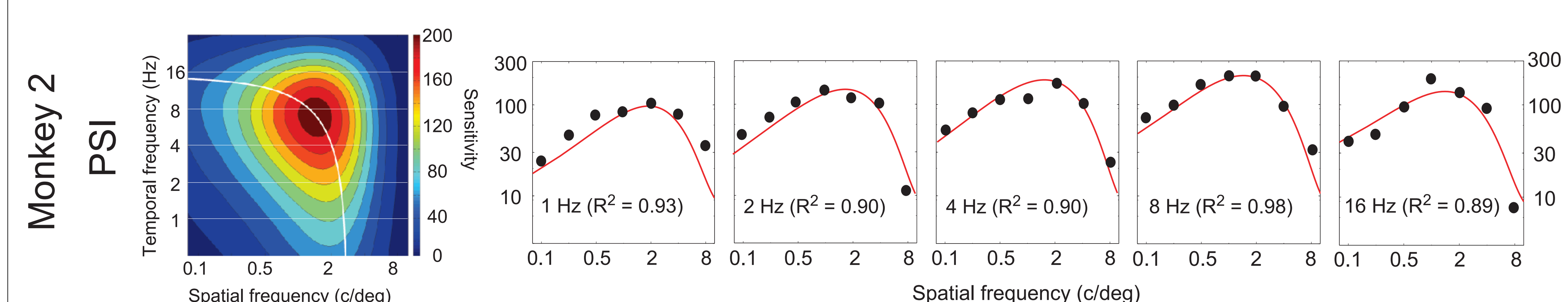
Results



Quick CSF (qCSF) (Lesmes et al., 2010): An adaptive Bayesian procedure that directly estimates the parameters of the slices of the Kelly function using 100 trials per slice by assuming a standard shape of 1D sensitivity function (a "slice"). On every trial, the grating stimulus (defined by frequency and contrast) is selected to maximize the expected information gain about the four parameters of the slice (see qCSF box). (5 slices x 100 trials)







PSI procedure (Kontsevich & Tyler, 1999): An adaptive Bayesian method that directly estimates the threshold and slope of psychometric function. The contrast to be tested on the next trial is selected to maximize the expected information gain about the threshold and slope. This method uses a fraction of trials required by the method of constant stimuli (42 spatiotemporal frequency nodes x 50 trials).

Conclusions and future work

1. We developed and validated methods for rapid measurement of full spatiotemporal contrast sensitivity functions (Kelly functions) in, behaving non-human primates.

2. The Kelly functions in macaque monkeys are similar to the functions in humans and they require comparable trial numbers to measure.

3. We will measure shifts of the sensitivity function induced by adaptation and study how the adaptive changes of sensitivity are mediated in cortical neurons by performing single cell recordings in cortical areas. MT

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