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## Table of Contents

Introduction and Data description .....	1
replicate Feng's spectral results (PS of velocity) .....	2
PS of oculomotor activity .....	4
estimate how eye movement redistributes power in space-time .....	5
what is the mouse retina sensitive to? .....	9
compute temporal power in retinal input .....	10

## Introduction and Data description

This script analyzes the spectral content of micro-tremor in the mouse eye and its impact on the spatiotemporal structure of the retinal input. Data provided by Guanping Feng and Jesse Schallek.

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date created: December 14, 2020

```
clear all;

FONTSIZE = 14;

load(fullfile('..', 'Data', 'EyeMotions_03397_ch1_20200304_bs_001_08hr.mat'));
% The data is a structure with 3 fields: 1. 'EyeMotions.Time' is the
% time
% axis. 2. 'EyeMotions.X' is the eye motion trace in unit of microns.
% 3. 'EyeMotions.X_angle' is the eye motion trace in unit of visual
% angle
% (arcmin).

t = EyeMotions.Time; % seconds
x = EyeMotions.X_angle; % arcmin

Fs = 1 ./ mean(diff(t)); % sampling rate of data

winsize = round(41/1000 * Fs);
if rem(winsize, 2) == 0
    winsize = winsize + 1;
end

vel = sgfilt(x, 3, winsize, 1) * Fs; % arcmin / s
speed = abs(vel); % arcmin / s

figure(1); clf;
ax(1) = subplot(2, 1, 1);
plot(t, x, 'b.-', 'MarkerSize', 3);
ylabel('(arcmin)');
title(sprintf('horizontal eye movement (sampling rate %ikHz)',
    round(Fs/1000)));
```

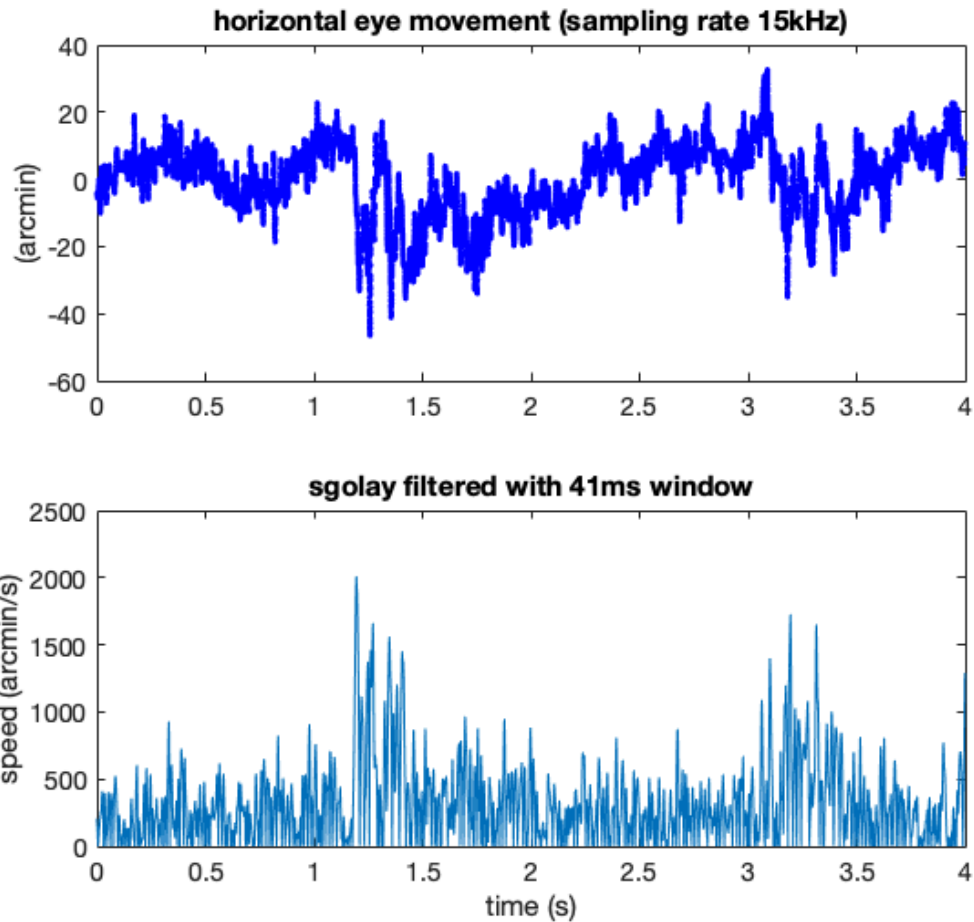
---

```

ax(2) = subplot(2, 1, 2);
plot(t, speed);
xlabel('time (s)');
ylabel('speed (arcmin/s)');
title('sgolay filtered with 41ms window');
linkaxes(ax, 'x');

set(ax, 'FontSize', FONTSIZE);

```



## replicate Feng's spectral results (PS of velocity)

First replicate Feng's result showing that power of the velocity trace is contained in the 30-200Hz band.

```

df = diff(x);
ps = abs(fft(df)).^2;

freq = (0:length(df)-1) / length(df) * Fs;
n2 = floor(length(freq)/2);

```

```

% welch's power spectrum
nfft = 2^14;
[pxx,f] = pwelch(df, hann(nfft), nfft/2, nfft, Fs);

figure(2); clf;
ax(1) = subplot(2, 1, 1);
plot(freq(1:n2), ps(1:n2), 'k-');
ylabel('|FFT|^2 (a.u.)');
xticks([10, 30, 100, 300, 500]);
title('PSD of eye velocity');

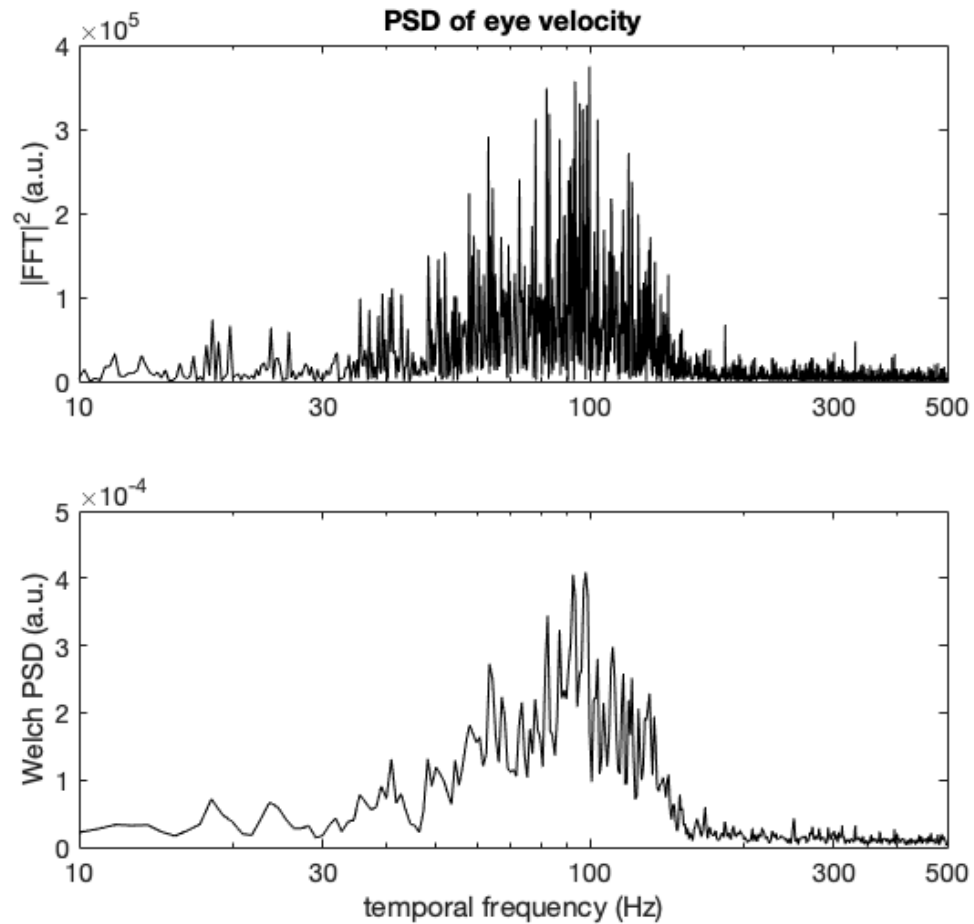
ax(2) = subplot(2, 1, 2);
plot(f, pxx, 'k-');
ylabel('Welch PSD (a.u.)');
xlabel('temporal frequency (Hz)');

linkaxes(ax, 'x');
set(ax, 'XScale', 'log', 'XLim', [10, 500]);

xticks([10, 30, 100, 300, 500]);

set(ax, 'FontSize', FONTSIZE);

```



---

# PS of oculomotor activity

Here we estimate the power spectrum of the oculomotor activity. A similar analysis for humans is in Rucci & Poletti (2015) - Figure 2a <http://aplab.bcs.rochester.edu/assets/download/PDFs/articles/RucciPoletti15.pdf> In humans, intersaccadic eye movements consist of low temporal frequencies (low pass up to ~30Hz) with a prominent peak around 60Hz for tremor.

As shown by the power of the velocity signal, there is a clear deviation between the PSD of oculomotor activity and  $1/f^2$  (dashed blue lines) in the 30-200Hz band.

```
ps = abs(fft(x)).^2;

freq = (0:length(x)-1) / length(x) * Fs;
n2 = floor(length(freq)/2);

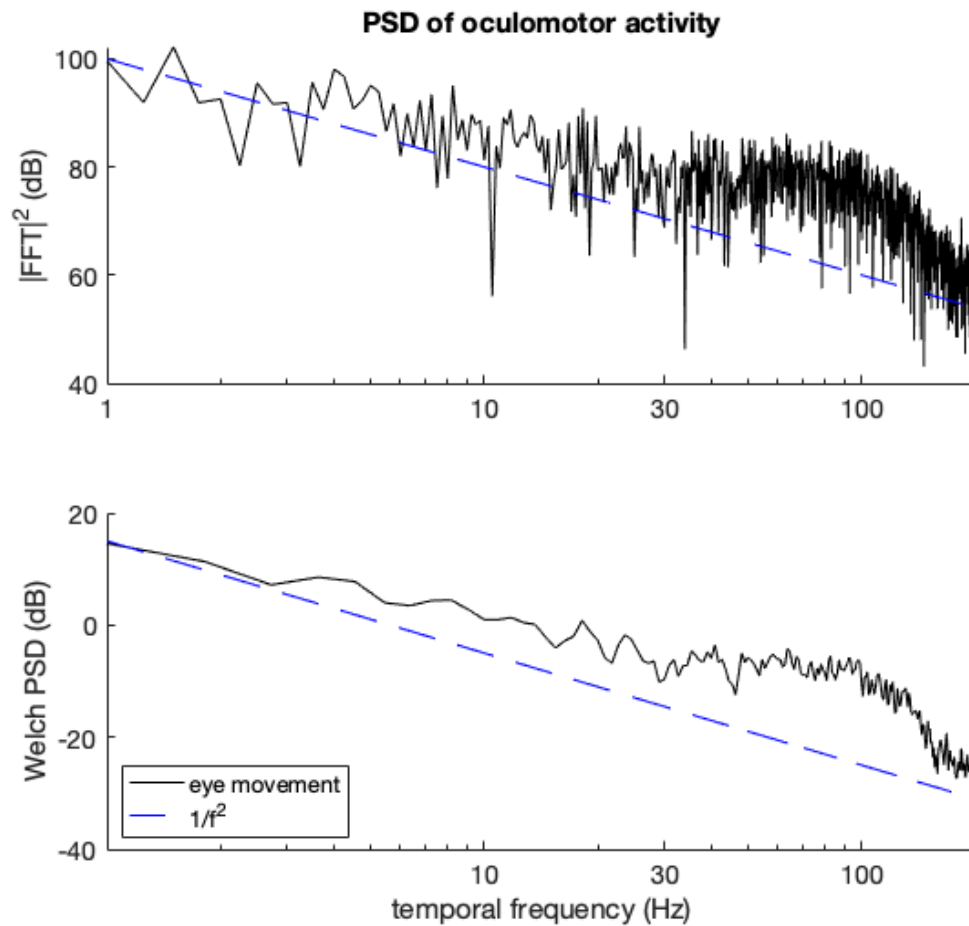
% welch's power spectrum
nfft = 2^14;
[pxx,f] = pwelch(x, hann(nfft), nfft/2, nfft, Fs);

figure(3); clf;
ax(1) = subplot(2, 1, 1); hold on;
plot(freq(1:n2), pow2db(ps(1:n2)), 'k-');
plot(freq(1:n2), pow2db(10^10 ./ freq(1:n2).^2), 'b--');
ylabel('|FFT|^2 (dB)');
xticks([1, 10, 30, 100, 300, 500]);
title('PSD of oculomotor activity');

ax(2) = subplot(2, 1, 2); hold on;
plot(f, pow2db(pxx), 'k-');
plot(freq(1:n2), pow2db(10^1.5 ./ freq(1:n2).^2), 'b--');
ylabel('Welch PSD (dB)');
xlabel('temporal frequency (Hz)');
legend({'eye movement', '1/f^2'}, 'Location', 'southwest');

linkaxes(ax, 'x');
set(ax, 'XScale', 'log', 'XLim', [1, 200], 'FontSize', FONTSIZE);

xticks([10, 30, 100]);
```



## estimate how eye movement redistributes power in space-time

Intuitively, this describes the spectral content of the spatiotemporal retinal input when the mouse is looking at a white noise image. method described in Kuang et al, 2012 for drift and Mostofi, Zhao et al, 2020.

Similar to human drift, as spatial frequency increases, spatial power is distributed across a larger range of temporal frequencies. This becomes more clear when plotting slices at several spatial frequencies.

```
nfft = 2^14;

k = logspace(-1, 1.5, 100); % spatial frequencies (cpd)
PS2 = nan(length(k), nfft);
for ki = 1:length(k)
    ss = exp(-1i*2*pi*(k(ki)*x)/60);
    [ps_trace, f] =
    pwelch(ss,hann(nfft),round(nfft/4),nfft,Fs, 'twosided');
    PS2(ki, :) = ps_trace;
end
```

---

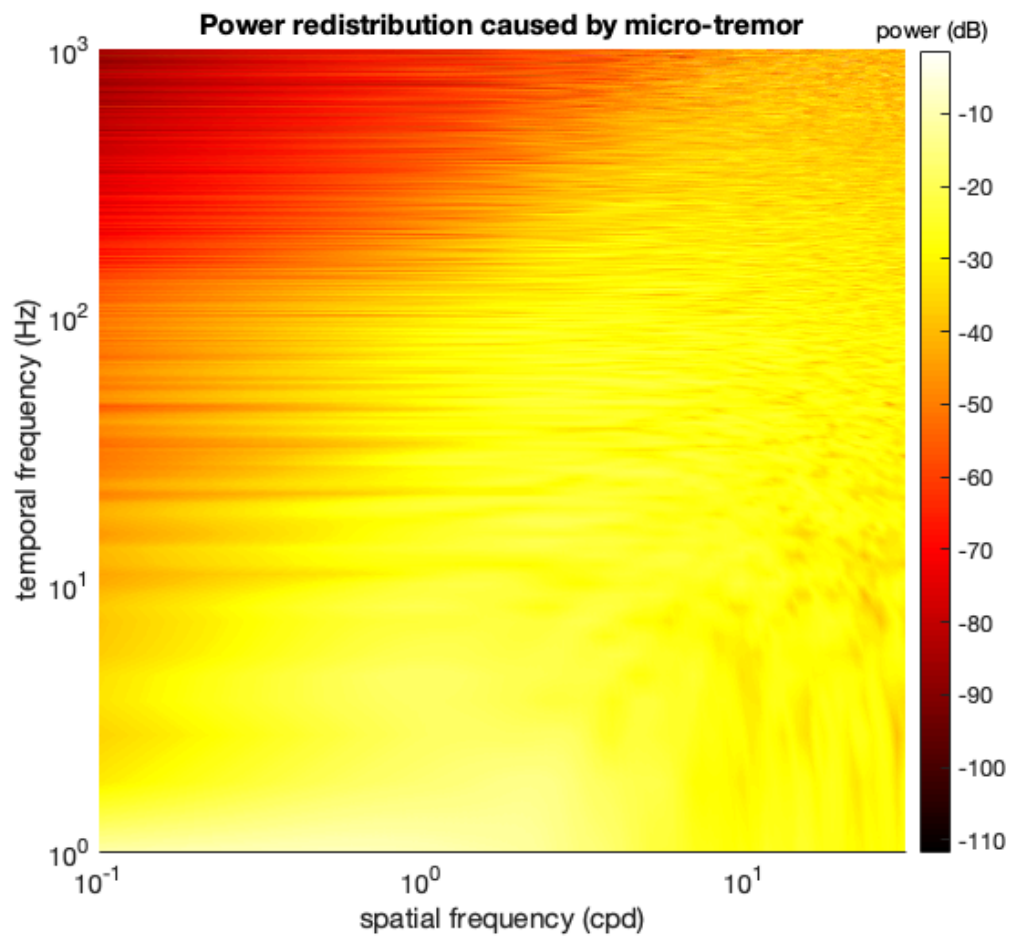
```

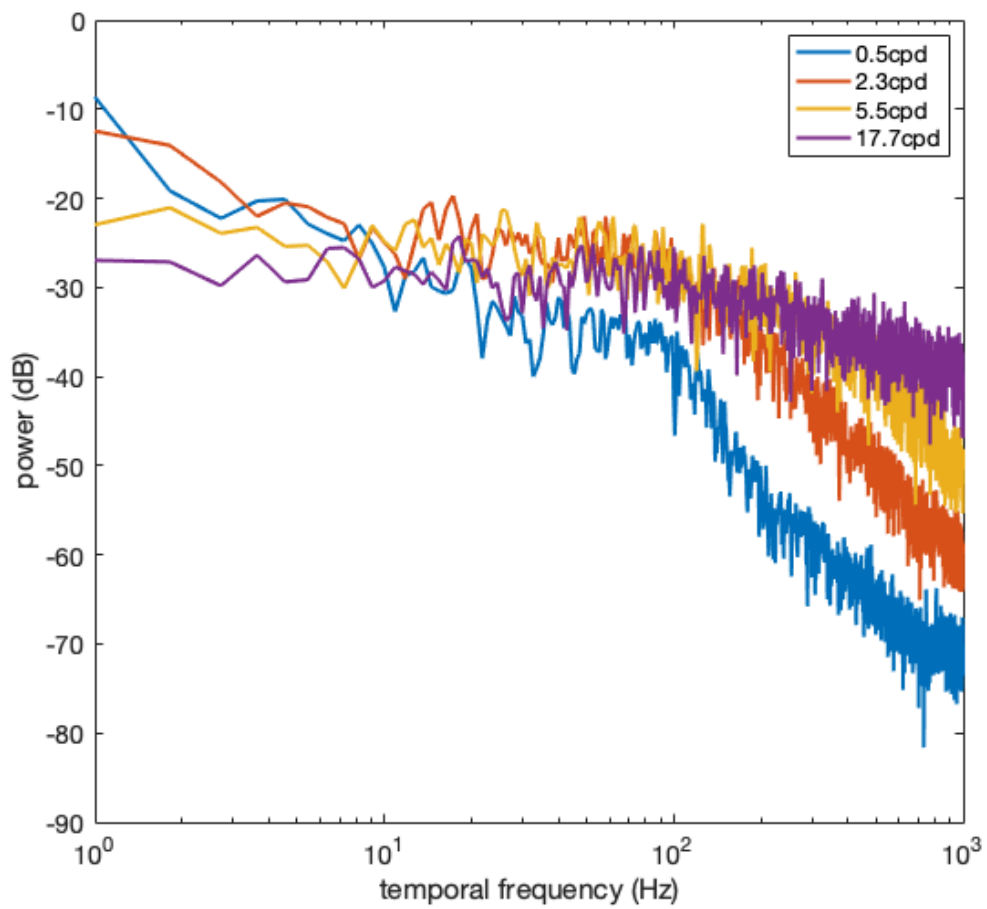
figure(4); clf; hold on;
pcolor(k, f(1:nfft/2), pow2db(PS2(:, 1:nfft/2)));
xlim(k([1, end]));
shading interp;
colormap hot;
set(gca, 'XScale', 'log', 'YScale', 'log', 'FontSize', FONTSIZE);
ylim([1, 1000]);
xlabel('spatial frequency (cpd)');
ylabel('temporal frequency (Hz)');
hcb = colorbar;
set(get(hcb, 'Title'), 'String', 'power (dB)');
title('Power redistribution caused by micro-tremor');

%%%%%%%%%%%%%% slices through temporal frequencies
kplot = [30, 55, 70, 90];
figure(5); clf;
plot(f(1:nfft/2), pow2db(PS2(kplot, 1:nfft/2)), 'linewidth', 2);
set(gca, 'XScale', 'log', 'XLim', [1, 1000], 'FontSize', FONTSIZE);
legend(cellfun(@(x) sprintf('%1.1fcpd', x),
    num2cell(k(kplot)), 'UniformOutput', false));
xlabel('temporal frequency (Hz)');
ylabel('power (dB)');

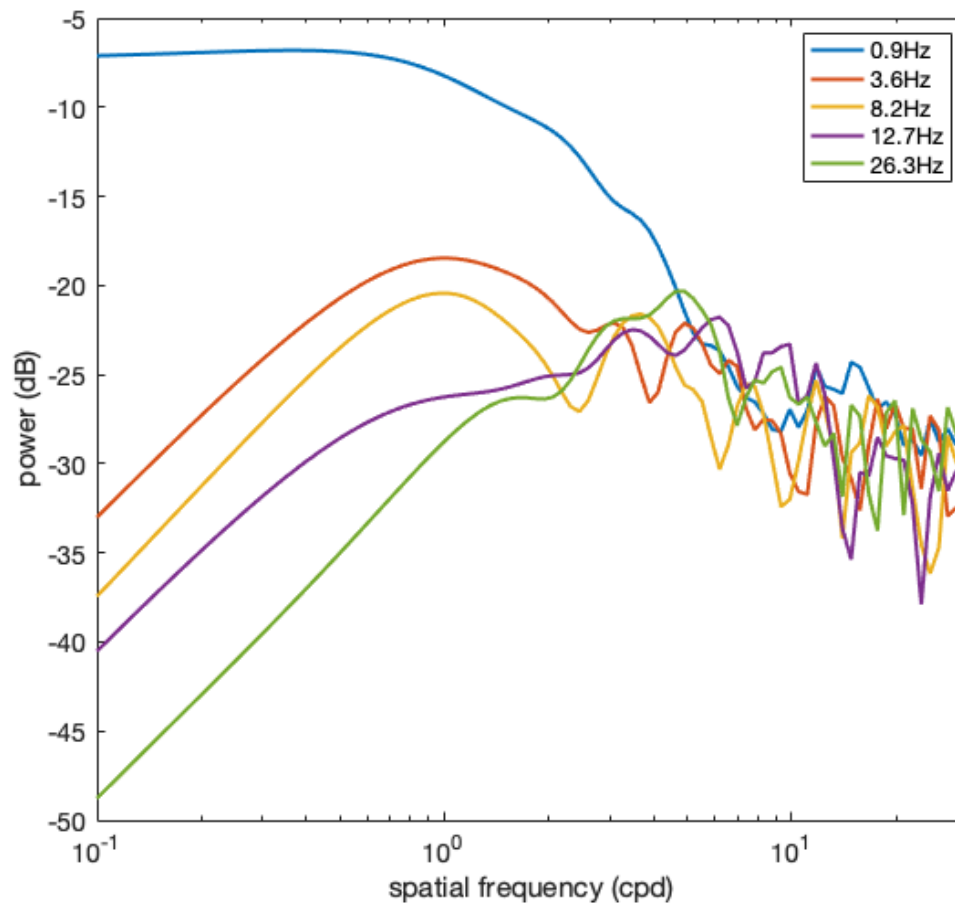
%%%%%%%%%%%%%% slices through spatial frequencies
fplot = [2, 5, 10, 15, 30];
figure(6); clf;
plot(k, pow2db(PS2(:, fplot)), 'linewidth', 2);
set(gca, 'XScale', 'log', 'XLim', k([1, end]), 'FontSize', FONTSIZE);
legend(cellfun(@(x) sprintf('%1.1fHz', x),
    num2cell(f(fplot)), 'UniformOutput', false));
xlabel('spatial frequency (cpd)');
ylabel('power (dB)');

```









## what is the mouse retina sensitive to?

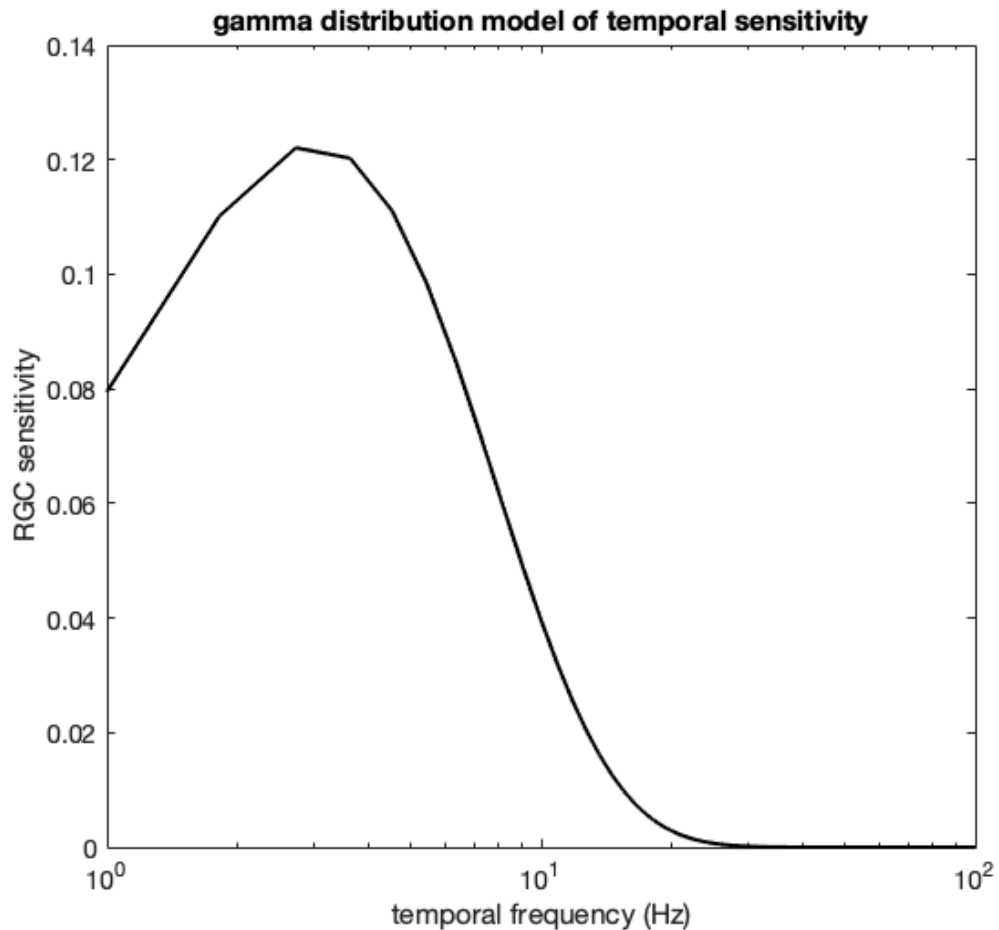
A more comprehensive literature review is needed, but RGC seem to be sensitive to temporal frequencies up to 30Hz with sensitivity peaking between 2 and 5Hz (Weng, Weick, Demb, 2011) <https://www.jneurosci.org/content/31/21/7670>

For now model this with a gamma distribution that captures these two characteristics. Note that this model assumes that sensitivity is 0 at 0Hz.

```
rgc_temporal = gampdf(f,2,3);

figure(7); clf;
plot(f, rgc_temporal, 'k-', 'linewidth', 2);
xlim([1, 100]);
set(gca, 'XScale', 'log');
ylabel('RGC sensitivity');
xlabel('temporal frequency (Hz)');
title('gamma distribution model of temporal sensitivity');

set(gca, 'FontSize', FONTSIZE);
```



## compute temporal power in retinal input

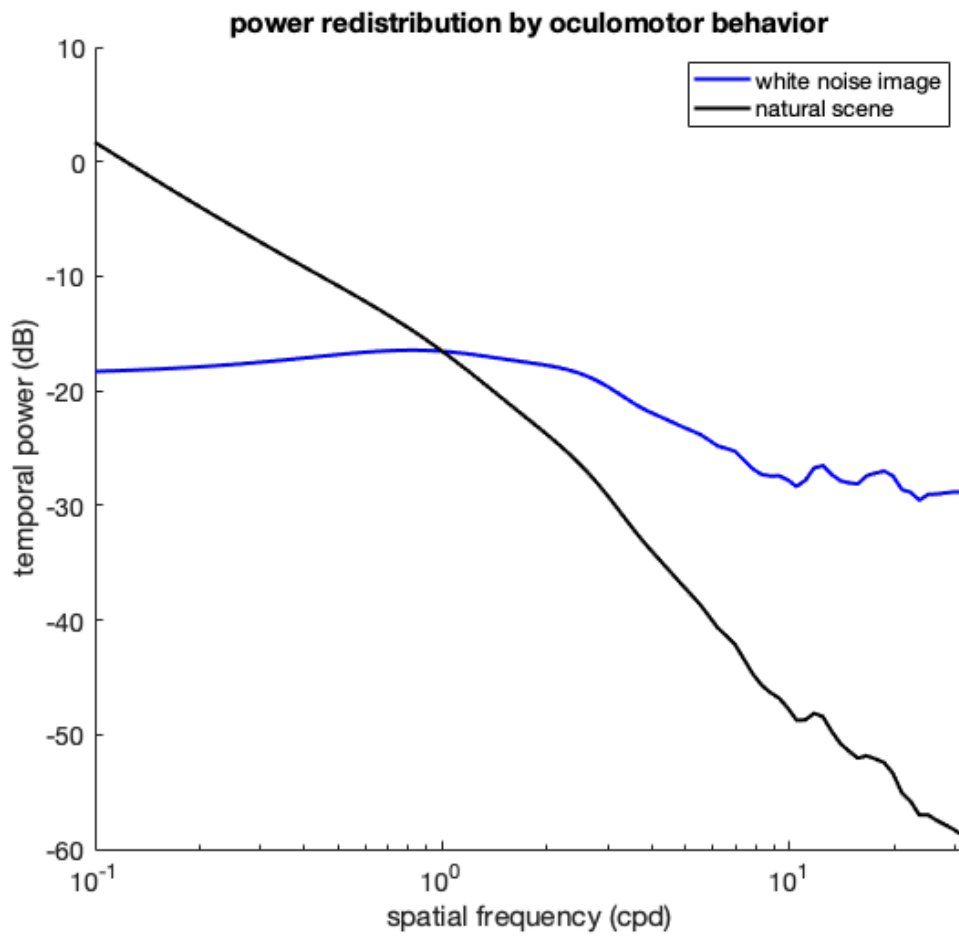
Temporal power is the power of the modulations that are effective in driving retinal ganglion cells. It is computed by averaging PS2 across temporal frequencies weighted by RGC sensitivity

```
temporalPower = PS2 *rgc_temporal(:);

figure(8); clf; hold on;
plot(k, pow2db(temporalPower), 'b-', 'linewidth', 2);
plot(k, pow2db(temporalPower(:) ./ k(:).^2), 'k-', 'linewidth', 2);
legend({'white noise image', 'natural scene'});
xlabel('spatial frequency (cpd)');
ylabel('temporal power (dB)');
set(gca, 'XScale', 'log');
xlim(k([1, end]));

set(gca, 'FontSize', FONTSIZE);

title('power redistribution by oculomotor behavior');
```



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