Visualize Behavioral Performance

A key point of the study is to examine the neural processing of sound during perceptual constancy. We must therefore check whether listeners discriminate sounds equally well when vowels are generated with different fundamental frequencies (F0s), sound levels and voicing parameters, as well as when sounds are presented from different locations.

The plots generated here appear in the paper in Figure 1C and cover the four subjects for which we recorded responses of neurons during task performance:

```
% Subject name
ferrets = {'F1201_Florence','F1203_Virginia','F1217_Clio','F1304_Flea'};

% Subject name, first formant of vowels associated with left and right responses on correct tri
contingencies = {'F1201_Florence', 460, 730;
                 'F1203_Virginia', 460, 730;
                 'F1217_Clio',     730, 460;
                 'F1304_Flea',     437, 936};

% Color scheme
colors = [1 0.5 0;      % Florence
          1 0 0;        % Virginia
          0 0.5 1;          % Clio
          0.5 0.25 0.08];   % Flea

% Minimum number of trials for a stimulus condition to be accepted (for
% each subject)
reqTrials = 40;

% Define path to behavioral data
data_dir = 'C:\Users\steph\Documents\GitHub\perceptual_constancy_for_vowels\data\behavior';
```

Fundamental Frequency: Vowels of different pitch

We'll start by comparing vowel discrimination performance of each listener as a function of fundamental frequency. Data is shown as a line plot (lines represent different subjects) and the overall performance of each ferret is also printed to the console. Also reported is the probability of observing that performance if responses followed a binomial distribution with equal probability of correct and error responses (i.e. so we can determine if animals were performing significantly better than chance).

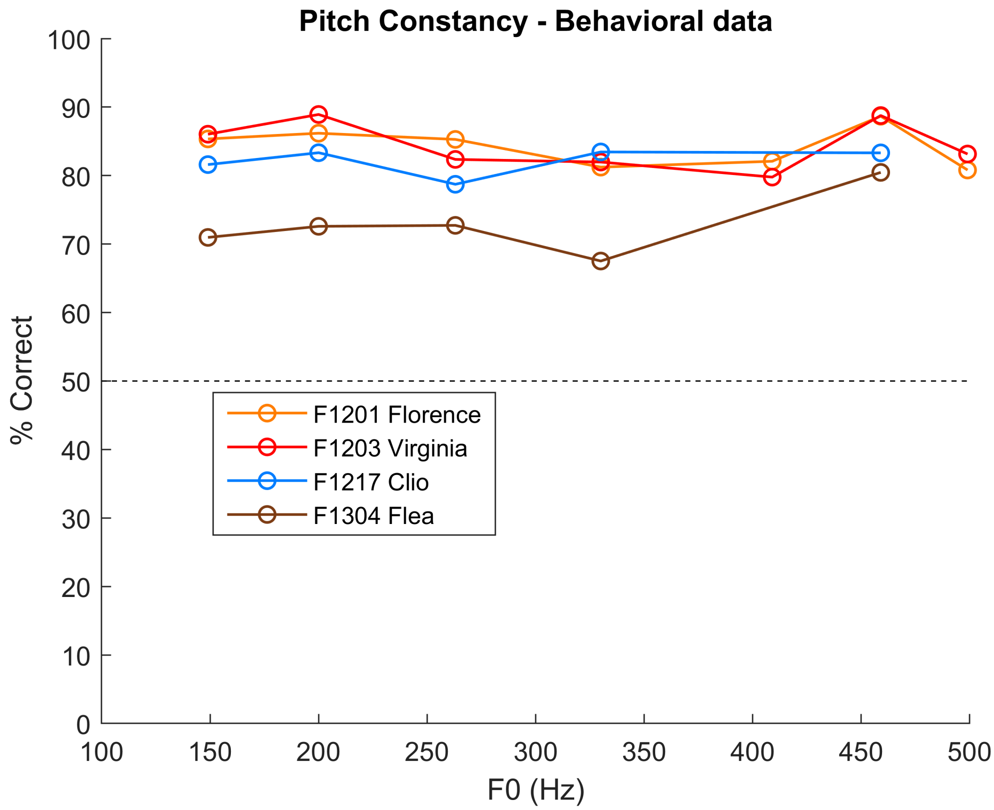
```
% Data directory (change for your machine)
pathname = fullfile(data_dir, 'pitch');

% Define headers for files generated by GoFerret
headers = {'Trial','CorrectionTrial','StartTime','CenterReward',...
             'F1','F2','F3','F4','HoldTime','Atten','Pitch','Side',...
             'Response','RespTime','Correct'};

% Set up figures
figure
axes('nextPlot','add')
```

```
xlabel('F0 (Hz)')
ylabel('% Correct')
ylim([0 100])
title('Pitch Constancy - Behavioral data')

% Set up legend names
[legStr, hp] = deal([]);

% For each ferret
for i = 1 : numel(ferrets)

    % List behavioral files (corrected for calibration
    ferDir = fullfile( pathname, ferrets{i});
    files  = dir( fullfile(ferDir, '*Level*.txt'));
    T = [];

    % Specific continencies
    cIdx  = strcmp(contingencies(:,1), ferrets{i});
    ruleF = cell2mat(contingencies(cIdx,2:3));

    % Build behavioral record
    for j = 1 : numel(files)

        % Skip level 37 files (i.e. sessions where a single vowel token was
        % presented, rather than the two tokens in other sessions)
        if contains(files(j).name,'level37')
            continue
        end

        % Import data
        B = importdata( fullfile( ferDir, files(j).name));

        if isempty(B), continue; end

        % Convert to table
        B = array2table(B.data,'VariableNames',headers);

        % Filter for trial parameters
        B(B.CorrectionTrial == 1,:) = [];   % Remove correction trials
        B(B.Correct == -1,:) = [];          % Remove abort trials

        % Add to all data
        T = [T; B];
    end

    % Escape if no good data
    if isempty(T)
        fprintf('No data for %s\n', ferrets(i).name); continue
    end

    % Run logisitic regression
    mdl = fitglm(T.Pitch, T.Correct,'distribution','binomial');

    % Run binomial test
```

```
    pBinom = myBinomTest(nansum(T.Correct), size(T,1), 0.5);
    fprintf('All data: %s: %d / %d: p = %.5f\n', ferrets{i}, nansum(T.Correct), size(T,1), pBir

    % Get spatial masks
    [nUniqueX, uniqueX, nXUnique] = nUnique(T.Pitch);
    y = nan(nUniqueX,1);

    for j = 1 : nUniqueX
        y(j) = mean(T.Correct(T.Pitch == uniqueX(j)));
    end

    y = y .* 100; % convert proportion to percentage

    % Filter for trial number
    uniqueX = uniqueX( nXUnique >= reqTrials);
    y = y( nXUnique >= reqTrials);

    % Plot performance vs F0
    h = plot(uniqueX, y, '-o',...
           'Color', colors(i,:),...
           'MarkerEdgeColor', colors(i,:),...
           'tag', ferrets{i},...
           'Userdata', nXUnique,...
           'LineWidth', 1);

    % Remember name for legend
   hp = [hp; h];
   legStr = [legStr; {strrep(ferrets{i},'_',' ')}];
end
```

```
All data: F1201_Florence: 10214 / 12032: p = 0.00000
All data: F1203_Virginia: 8502 / 9945: p = 0.00000
All data: F1217_Clio: 3946 / 4792: p = 0.00000
All data: F1304_Flea: 1051 / 1487: p = 0.00000
```

```
plot(xlim,[50 50],'--k')    % Chance performance line

myL = legend(hp, legStr);
set(myL,'position',[0.2298 0.3341 0.2518 0.1698])
```

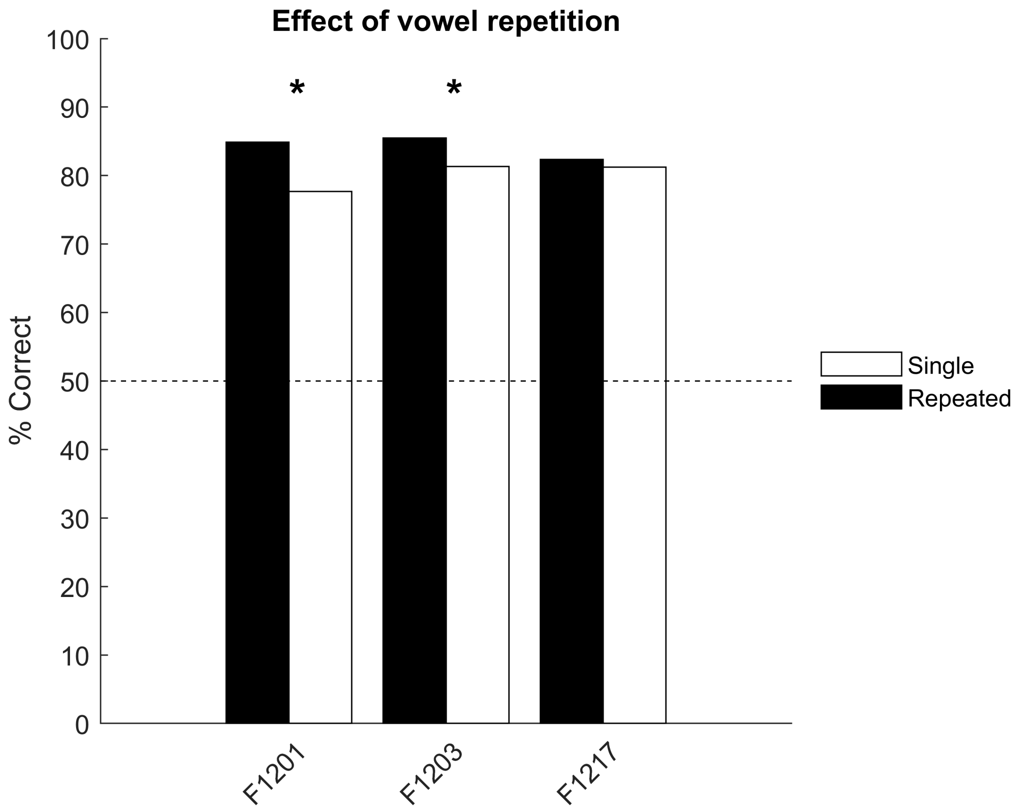


Supplementary Analysis: Effect of vowel repetition

In our behavioral task, we presented listeners with two tokens of a particular vowel on each trial. The motivation for repeating the vowel was to match earlier work in which two repeats were used. However we also conducted some test sessions with only one token of the vowel to check that animals could still perform the task. Here, we plot the performance of the three subjects that were tested in both conditions:

```
% Set up figure
figure
hold on

ylabel('% Correct')
title('Effect of vowel repetition')

xIdx = 0;   % Counter for bar centers
xStr = []; % Containter for xtick labels

% For each ferret
for i = 1 : numel(ferrets)

    % List behavioral files
    ferDir = fullfile( pathname, ferrets{i});
    files  = dir( fullfile(ferDir, '*Level*.txt'));
    T = [];

    % Build behavioral record
    for j = 1 : numel(files)
```

```
        % Note level 37 files
        vowelRep = true;
        if contains(files(j).name,'level37'), vowelRep = false; end

        % Import data
        B = importdata( fullfile( ferDir, files(j).name));

        if isempty(B), continue; end

        % Convert to table
        B = array2table(B.data,'VariableNames',headers);

        % Filter for trial parameters
        B(B.CorrectionTrial == 1,:) = [];   % Remove correction trials
        B(B.Correct == -1,:) = [];          % Remove abort trials

        % Check for weird stimuli
        if any(B.F1 == 595), error('weird stimuli'), end

        % Note condition
        B.VowelRepeated = repmat(vowelRep, size(B,1), 1);

        % Add to all data
        T = [T; B];
    end

    % Skip animals we didn't test single stimulus
    if all(T.VowelRepeated), continue; end
    xIdx = xIdx + 1;
    xStr{xIdx} = ferrets{i}(1:5);

    % Plot performance
    singlePerformance   = nanmean(T.Correct(~T.VowelRepeated)) * 100;
    repeatedPerformance = nanmean(T.Correct(T.VowelRepeated == 1)) * 100;

    b(1) = bar(i+0.2, singlePerformance,'w','BarWidth',0.4);
    b(2) = bar(i-0.2, repeatedPerformance,'k','BarWidth',0.4);

    % Compare performance statistically
    mdl = fitglm(T.Correct, T.VowelRepeated,'distribution','binomial');
    p   =  mdl.Coefficients.pValue(2);

    if p < 0.05
       text(xIdx, 92, '*','FontSize',16,'FontWeight','Bold','UserData',p)
    end
end

plot(xlim,[50 50],'--k')    % Chance performance line

set(gca,'xtick',1:xIdx,'xticklabel',xStr,'XTickLabelRotation',45,'ylim',[0 100])
lh = legend(b,'Single','Repeated');
set(lh,'EdgeColor','none','Location','eastoutside')
```



From this plot, we can see that reducing the number of vowel tokens on each trial from two to oen does have a significant impact on the performance of two animals, but even in those cases, performance was well above chance levels (50%).