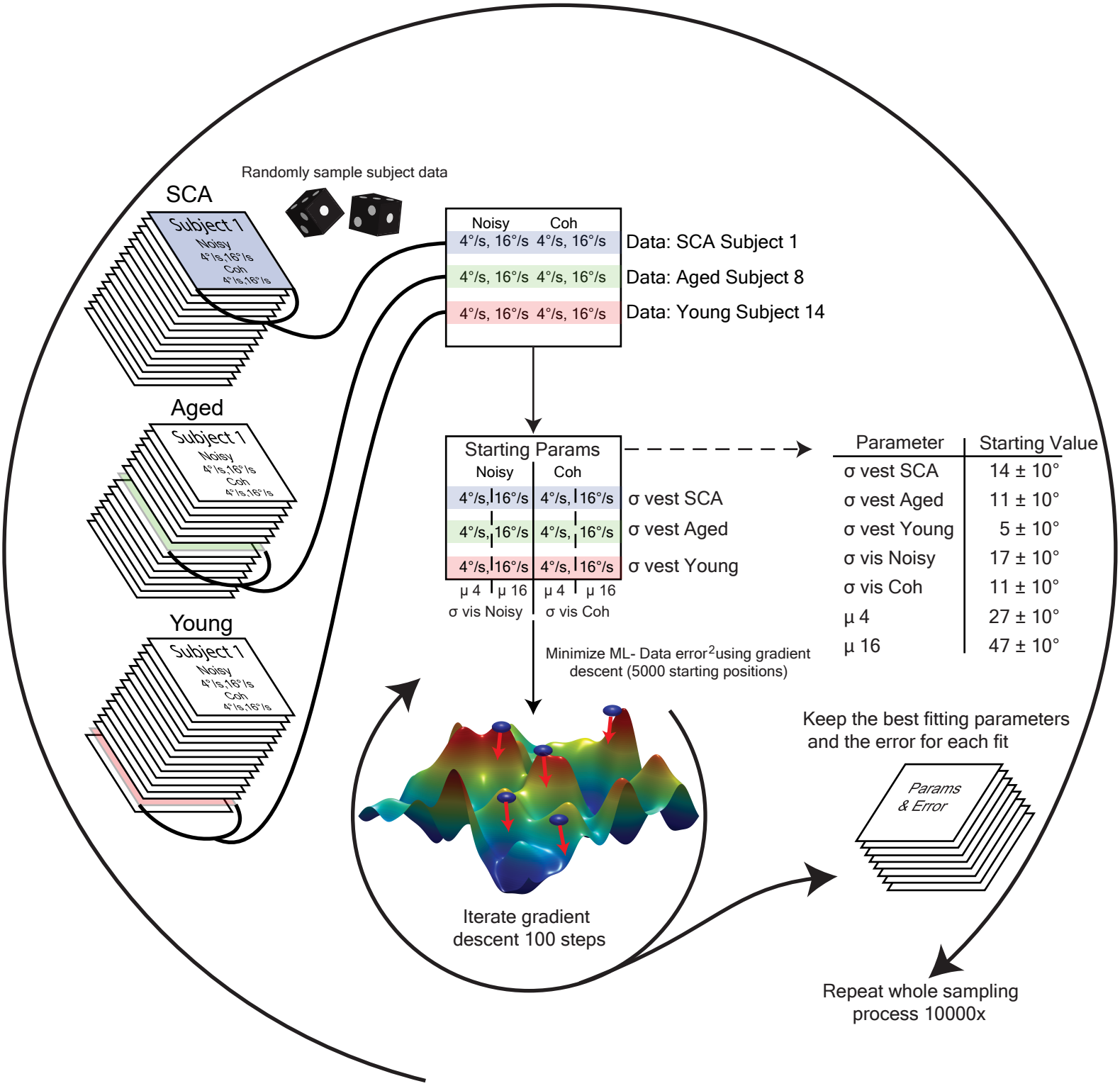
Figure S1. Schematic describing the maximum likelihood estimation procedure, related to the Quantification and Statistical Analysis section in the STAR methods. Starting on the left, first trial data from one subject in each group was randomly drawn. Using this data we estimated 7 parameters: the vestibular likelihood distribution standard deviations for the SCA (σ vest SCA), Aged (σ vest Aged) and Young (σ vest Young) groups, the visual likelihood standard deviations for the noisy (σ vis Noisy) and coherent (σ vis Coh) conditions, and the mean of the visual bar angle likelihood distribution for both velocities (μ 4 = 4 ˚/s, μ 16 = 16 ˚/s). All twelve conditions were fit at once (3 subjects x 4 Conditions) using overlapping parameters (seen in the center of the figure). The starting parameters for the squared error minimization procedure, summarized in the table on the right of the figure, were drawn randomly from a distribution whose mean was adjusted based on convergence of the model and plausibility (e.g. a mean visual bar angle of 180˚ is implausible given the empirical data). To fit the model five-thousand sets of starting parameters were drawn to avoid non-convergence and local minima (blue balls on the topography, which for illustrative purposes represents the error function, in the bottom center of the image), and the maximum likelihood estimate was calculated for each set of parameters. The goal was to find the best fitting parameters or the 'global error minimum' given the parameter restrictions. The parameters were then adjusted in the direction that reduces the squared error between the maximum likelihood estimate and the sampled data using a gradient descent algorithm with a learning rate of 0.05 (blue spheres follow the error gradient, moving towards the bottom of the valley that is the local region with the lowest error). During this process the visual noise parameters were restricted to prevent them

becoming negative. We iterated this process one-hundred times and then the parameters and the error of the best fitting model were stored. One-hundred iterations tended to be sufficient to reach local minima (the valleys the spheres are moving towards in the center bottom image) or cause model divergence. The sampling and gradient descent procedure was then repeated ten-thousand times to determine the confidence intervals on the parameters.


Randomly sample subject data
SCA
Subject 1
Noisy
4°/s,16°/s
Coh
4°/s,16°/s
Aged
Subject 1
Noisy
4°/s,16°/s
Coh
4°/s,16°/s
Young
Subject 1
Noisy
4°/s,16°/s
Coh
4°/s,16°/s
Noisy Coh
4°/s, 16°/s 4°/s, 16°/s
Data: SCA Subject 1
4°/s, 16°/s 4°/s, 16°/s
Data: Aged Subject 8
4°/s, 16°/s 4°/s, 16°/s
Data: Young Subject 14
Starting Params
Noisy Coh
4°/s, 16°/s 4°/s, 16°/s
σ vest SCA
4°/s, 16°/s 4°/s, 16°/s
σ vest Aged
4°/s, 16°/s 4°/s, 16°/s
σ vest Young
μ 4 μ 16 μ 4 μ 16
σ vis Noisy σ vis Coh
Parameter Starting Value
σ vest SCA 14 ± 10°
σ vest Aged 11 ± 10°
σ vest Young 5 ± 10°
σ vis Noisy 17 ± 10°
σ vis Coh 11 ± 10°
μ 4 27 ± 10°
μ 16 47 ± 10°
Minimize ML- Data error2using gradient descent (5000 starting positions)
Iterate gradient descent 100 steps
Keep the best fitting parameters and the error for each fit
Params & Error
Repeat whole sampling process 10000x

This code accompanies the manuscript: Cerebellar degeneration increases visual influence on dynamic estimates of verticality

This code accompanies the manuscript: Cerebellar degeneration increases visual influence on dynamic estimates of verticality

```
% Functions needed:
% shadedErrorBar
% keep
% hline and vline

% Labview data:
% Col 1 time at each sample (30Hz)
% Col 2 trial code - starts at motion and ends with motion
% Col 3 Wobble data - But it is transformed when added to the bar
% Col 4 Bar Angle (degrees)
% Col 5 Not Used

% Matlab Data:
% Col 1 Trial code - should correspond to col 2 in the labview data
% Col 2 Rotation Direction -1 = clockwise 1 = anticlockwise
% Col 3 Dot velocity ()
% Col 4 Dot noise/Coherence level

% Condition order:
% Condition 1 = 4 deg/s noise
% Condition 2 = 4 deg/s coh
% Condition 3 = 16 deg/s noise
% Condition 4 = 16 deg/s coh

clear all;
clc;
close all;
```

Set Initial Parameters

```
    General_Params.Fs = 30; % labview sampling rate
    General_Params.Start_Point = 27; % Start of averaging period
    General_Params.End_Point = 40; % End of averaging period
    General_Params.N_Total = 45; % Total number of subjects
    General_Params.Total_Different_Trials = 32; % Total # of trials
    General_Params.Total_Conditions = 4; % Total number of conditions
    General_Params.Total_Trials = 8; % Total # of trials in each condition
    General_Params.Trial_Length = 1533; % Longest data collection length
    General_Params.N_YOUNG = 15; % Number of Young participants
    General_Params.N_AGED = 15; % Number of Aged participants
    General_Params.N_SCA = 15; % Number of SCA participants
    General_Params.SARA_Scores =...
        [2;9;4;5.5;22;8;22;9.5;5.5;9.5;9;10;19;22;24]; % SARA SCORES

% Run the gradient descent to fit the Maximum Likelihood model 1 = run,
% 0 = dont run *** Takes a significant amount of time to run ***
    Run_CI_model = 0;
```

```
% Participants 1 to 15 are Young Controls, Participants 16 to 30 are Aged
% Controls, Participants 31 to 45 are SCA
    General_Params.Participant_List = {'01';'02';'03';'04';'05';'06';'07';...
        '08';'09';'10';'11';'12';'13';'14';'15';'16';'17';'18';'19';'20';...
        '21';'22';'23';'24';'25';'26';'27';'28';'29';'30';'31';'32';'33';...
        '34';'35';'36';'37';'38';'39';'40';'41';'42';'43';'44';'45'};

%Trial names array
    General_Params.trials={'00';'01';'02';'03';'04';'05';'06';'07';'08';...
        '09';'10';'11';'12';'13';'14';'15';'16';'17';'18';'19';'20'; ...
            '21';'22';'23';'24';'25';'26';'27';'28';'29';'30';'31'};

%Initialization
    Labview_data = zeros(General_Params.Trial_Length ,5,...
        General_Params.Total_Different_Trials,General_Params.N_Total);

    Matlab_data = zeros(General_Params.Total_Different_Trials,...
        General_Params.Total_Conditions,General_Params.N_Total);

    Condition = 1 : General_Params.Total_Conditions; % Four conditions

    DATA.ALL_DATA_Unsorted = nan(1533, General_Params.Total_Trials,...
        General_Params.Total_Conditions, General_Params.N_Total);

    DATA.ALL_DATA_Sorted = nan(1533, General_Params.Total_Trials,...
        General_Params.Total_Conditions, General_Params.N_Total);
```

Load in Data

```
for Participant = 1 : General_Params.N_Total

    %load labview data from all text files
    for q = 1:General_Params.Total_Different_Trials
        load(['InsertPathHere\P',...
        General_Params.Participant_List{Participant,:},...
        '\P',General_Params.Participant_List{Participant,:},...
        '_Labview_File\P',General_Params.Participant_List{Participant,:},...
        '_',General_Params.trials{q,:},'.mat'])

        Labview_data(:,:,q,Participant) = Data;
        clear Data
    end

    %load the matlab file
    load(['InsertPathHere\P',...
        General_Params.Participant_List{Participant,:},...
        '\P',General_Params.Participant_List{Participant,:},...
        '_Matlab_File\P',General_Params.Participant_List{Participant,:},...
        '_TrialkeyCohVelmap.mat'])

    Matlab_data(:,:,Participant) = trialkey;
```

```
% Loop through trials and get the control program trial code
%by averaging and rounding between 30 - 40 secs
control_key = nan(General_Params.Total_Different_Trials,1);

for loop = 1 : General_Params.Total_Different_Trials
    control_key(loop,1) = round(mean(Labview_data...
        (30*30:30*40,2,loop,Participant))*10);
end

TEMP_DATA = nan(General_Params.Trial_Length,...
    General_Params.Total_Different_Trials,...
    General_Params.Total_Conditions, General_Params.N_Total);

for loop = 1:General_Params.Total_Conditions

    % Index condition (loop) based on motion direction
    Ipos = find(Matlab_data(:,1,Participant) == loop &...
        Matlab_data(:,2,Participant) == 1);  % counter-clockwise

    Ineg = find(Matlab_data(:,1,Participant) == loop &...
        Matlab_data(:,2,Participant) == -1); % clockwise

    % add all conditions with the mean removed (calc from 5-10secs)
    % to a new variable DATA with
    % conditions in the 3rd dimension. Should be datalength by 8 trials
    % by 4 conditions and both positive and negative directed trials
    % SIZE: DATA.ALL_DATA_Unsorted(1533,8,4,45)
    DATA.ALL_DATA_Unsorted(:,1:4,Condition(loop),Participant) =...
        -(Labview_data(:,4,Ipos,Participant)-repmat(nanmean...
        (Labview_data(150:300,4,Ipos,Participant))...
        ,length(Labview_data(:,4,Ipos,Participant)),1));

    DATA.ALL_DATA_Unsorted(:,5:8,Condition(loop),Participant) =...
        Labview_data(:,4,Ineg,Participant)-repmat(nanmean...
        (Labview_data(150:300,4,Ineg,Participant))...
        ,length(Labview_data(:,4,Ineg,Participant)),1);

    % Sort and flip data and remove mean
    TEMP_DATA(1:length(Labview_data(:,4,1)),Ipos,loop,Participant)...
        = -(Labview_data(:,4,Ipos,Participant) - repmat(nanmean...
        (Labview_data(150:300,4,Ipos,Participant))...
        ,length(Labview_data(:,4,Ipos,Participant)),1));

    TEMP_DATA(1:length(Labview_data(:,4,1)),Ineg,loop,Participant)...
        = Labview_data(:,4,Ineg,Participant) - repmat(nanmean...
        (Labview_data(150:300,4,Ineg,Participant))...
        ,length(Labview_data(:,4,Ineg,Participant)),1);

    %Extract data for each condition so that sequential trials
    %of a particular condition are in consecutive columns
    % SIZE: DATA.ALL_DATA_Sorted(1533,8,4,45)
    DATA.ALL_DATA_Sorted(:,:,loop,Participant) = TEMP_DATA(:,~all...
        (isnan(TEMP_DATA(:,:,loop,Participant))),loop,Participant);
```

```
        clear  Ipos Ineg
    end
    clear TEMP_DATA
end
```

T-Test to compare motion directions

```
%   t-test to compare clockwise motion vs counterclockwise motion
%   SIZES: DATA.ALL_DATA_Sorted(1533,8,4,45) to DATA.t_test_Clock(45,4);
DATA.t_test_Clock = permute(nanmean(nanmean(nanmean...
    (DATA.ALL_DATA_Unsorted(General_Params.Start_Point*...
    General_Params.Fs:General_Params.End_Point*General_Params.Fs,...
    1:4,:,:),1),2),3),[4 3 2 1]);

DATA.t_test_Anti_Clock = permute(nanmean(nanmean(nanmean...
    (DATA.ALL_DATA_Unsorted(General_Params.Start_Point*...
    General_Params.Fs:General_Params.End_Point*General_Params.Fs,...
    5:8,:,:),1),2),3),[4 3 2 1]);

[~,DATA.Reported_Measures_Stim_Direction_ttest_pvals(1,1)] =...
    ttest(DATA.t_test_Clock(1:15,1),DATA.t_test_Anti_Clock(1:15,1),...
    'tail','both');

[~,DATA.Reported_Measures_Stim_Direction_ttest_pvals(2,1)] =...
    ttest(DATA.t_test_Clock(16:30,1),DATA.t_test_Anti_Clock(16:30,1),...
    'tail','both');

[~,DATA.Reported_Measures_Stim_Direction_ttest_pvals(3,1)] =...
    ttest(DATA.t_test_Clock(31:45,1),DATA.t_test_Anti_Clock(31:45,1),...
    'tail','both');
```

In paper Means and stdev: grandmean and stdev of means across subjects

```
% Mean baseline across participants for the first 10s of the trial
% DATA.Reported_Measures_PreStim_Mean_and_Stdev(3,3), where col 1
% are the grand means and col 2 are the grand mean stdev.
% Rows are ordered Young, AGED, SCA
DATA.Reported_Measures_PreStim_Mean_and_Stdev(1,1) = nanmean(nanmean...
    (nanmean(nanmean(DATA.ALL_DATA_Sorted(241:300,:,:,1:15),1),2),3),4);

DATA.Reported_Measures_PreStim_Mean_and_Stdev(2,1) = nanmean(nanmean...
    (nanmean(nanmean(DATA.ALL_DATA_Sorted(241:300,:,:,16:30),1),2),3),4);

DATA.Reported_Measures_PreStim_Mean_and_Stdev(3,1) = nanmean(nanmean...
    (nanmean(nanmean(DATA.ALL_DATA_Sorted(241:300,:,:,31:45),1),2),3),4);


DATA.Reported_Measures_PreStim_Mean_and_Stdev(1,2) = nanmean(nanmean...
    (nanmean(nanstd(DATA.ALL_DATA_Sorted(241:300,:,:,1:15),0,1),2),3),4);

DATA.Reported_Measures_PreStim_Mean_and_Stdev(2,2) = nanmean(nanmean...
```

```
    (nanmean(nanstd(DATA.ALL_DATA_Sorted(241:300,:,:,16:30),0,1),2),3),4);

DATA.Reported_Measures_PreStim_Mean_and_Stdev(3,2) = nanmean(nanmean...
    (nanmean(nanstd(DATA.ALL_DATA_Sorted(241:300,:,:,31:45),0,1),2),3),4);
```

Mean deviation from 27s to 40s for trial

```
%   SIZES: DATA.ALL_DATA_Unsorted(1533,8,4,45)
%   to DATA.ALL_DATA_Mean_27s_to_40s(8,4,45)
DATA.ALL_DATA_Mean_27s_to_40s(1:4,1:4,1:45) = reshape...
    (nanmean(DATA.ALL_DATA_Unsorted(General_Params.Start_Point*...
    General_Params.Fs:General_Params.End_Point*General_Params.Fs,1:4,:,:)),...
    4,4,45);

DATA.ALL_DATA_Mean_27s_to_40s(5:8,1:4,1:45) = reshape...
    (nanmean(DATA.ALL_DATA_Unsorted(General_Params.Start_Point*...
    General_Params.Fs:General_Params.End_Point*General_Params.Fs,5:8,:,:)),...
    4,4,45);

%   SIZES: DATA.ALL_DATA_Sorted(1533,8,4,45) to DATA.ALL_DATA_Mean_27s_to_40s_Sorted(8,4,45)
DATA.ALL_DATA_Mean_27s_to_40s_Sorted = reshape...
    (nanmean(DATA.ALL_DATA_Sorted(General_Params.Start_Point*...
    General_Params.Fs:General_Params.End_Point*General_Params.Fs,:,:,:)),...
    General_Params.Total_Trials, General_Params.Total_Conditions,...
    General_Params.N_Total);
```

Average Time Series within each subject for each condition

```
%   SIZES: DATA.ALL_DATA_Sorted(1533,8,4,45) to DATA.WITHIN_SUBJECT_Mean_Time_Series(1533,1,4,45)
    DATA.WITHIN_SUBJECT_Mean_Time_Series = nanmean(DATA.ALL_DATA_Sorted,2);
```

Time Constant Calculation for the average trial (individual trials have lots of noise due to the 'wobble' noise added to the bar angle)

**Time Constants may vary a little bit each time due to the curve being refit from a random starting position each time

```
%   SIZES: DATA.WITHIN_SUBJECT_Mean_Time_Series(1533,1,4,45) to
DATA.ACROSS_SUBJECT_Mean_Time_Series_Young (1533,1,4)
    DATA.ACROSS_SUBJECT_Mean_Time_Series_Young = nanmean(...
        DATA.WITHIN_SUBJECT_Mean_Time_Series(:,:,:,1:15),4);

    DATA.ACROSS_SUBJECT_Mean_Time_Series_Aged = nanmean(...
        DATA.WITHIN_SUBJECT_Mean_Time_Series(:,:,:,16:30),4);

    DATA.ACROSS_SUBJECT_Mean_Time_Series_SCA = nanmean(...
        DATA.WITHIN_SUBJECT_Mean_Time_Series(:,:,:,31:45),4);

    Xaxis(:,1) = 1/General_Params.Fs : 1/General_Params.Fs :...
        1/General_Params.Fs*1500;
```

```
    X_Trunkated(:,1) = Xaxis(1:901,1);
    Projected_Time = 0:1/30:1000;

    fo = fitoptions('Method','nonlinearLeastSquares',...
                'MaxIter',200,'DiffMaxChange',0.1);

    ft = fittype('a*(1-exp(-b*x))+c','independent','x','options',fo);

% plots the fit over the grand mean data when fitplot is equal to 1
    fitplot = 0;
    for Group = 1:3
        for j = 1:General_Params.Total_Conditions
            G.rsquare = 0;
            GPrev.rsquare = 0;
            k=1;
            while 0.96 > G.rsquare

                if Group == 1
                    try
                        [F, G] = fit(X_Trunkated(:,1),...
                            DATA.ACROSS_SUBJECT_Mean_Time_Series_Young...
                            (300:1200,1,j),ft);
                    catch
                    end
                elseif Group == 2
                    try
                        [F, G] = fit(X_Trunkated(:,1),...
                            DATA.ACROSS_SUBJECT_Mean_Time_Series_Aged...
                            (300:1200,1,j),ft);
                    catch
                    end
                elseif Group == 3
                    try
                        [F, G] = fit(X_Trunkated(:,1),...
                            DATA.ACROSS_SUBJECT_Mean_Time_Series_SCA...
                            (300:1200,1,j),ft);
                    catch
                    end
                end

                if G.rsquare > GPrev.rsquare
                    Model.Coef{j} = coeffvalues(F);
                    Model.Fit{j} = G;
                    Fit_Test.function = Model.Coef{j}(1)*...
                        (1-exp(-Model.Coef{j}(2)*(Projected_Time))) + ...
                        Model.Coef{j}(3);
                    Peak_Exp = max(Fit_Test.function);
                    index = min(find(Fit_Test.function >=...
                        (1-0.37)*Peak_Exp));

                    if isempty(index) == 1
                       DATA.Time_Constants(Group,j) = nan;
```

```
                    else
                       DATA.Time_Constants(Group,j) =...
                           Projected_Time(index) - Projected_Time(1);
                    end
                end

                GPrev = G;

                if k > 300
                    break
                end
                k=k+1;
            end

        if fitplot == 1
        % plot the curve fits
        figure
        plot(Projected_Time,Model.Coef{j}(1)*(1-exp(-Model.Coef{j}(2)* ...
            (Projected_Time))) + Model.Coef{j}(3),'r')% 4 deg/s noise
        hold on;plot(Projected_Time(index),Fit_Test.function(index),'ro')
            if Group == 1
                hold on;plot(Xaxis(300:1200,1)-10,...
                    DATA.ACROSS_SUBJECT_Mean_Time_Series_Young...
                    (300:1200,1,j),'g');xlim([-10 100])
            elseif Group == 2
                hold on;plot(Xaxis(300:1200,1)-10,...
                    DATA.ACROSS_SUBJECT_Mean_Time_Series_Aged...
                    (300:1200,1,j),'g');xlim([-10 100])
            elseif Group == 3
                hold on;plot(Xaxis(300:1200,1)-10,...
                    DATA.ACROSS_SUBJECT_Mean_Time_Series_SCA...
                    (300:1200,1,j),'g');xlim([-10 100])
            end
            else
            end

        end
    end

DATA.Reported_Measures_Mean_Time_Constant(:,1) =...
    mean(DATA.Time_Constants,2);

DATA.Reported_Measures_Mean_Time_Constant(:,2) =...
    std(DATA.Time_Constants,0,2);
```

Mean deviation of the bar for the period from 27s to 40s from the average trial

```
DATA.WITHIN_SUBJECT_Mean_27s_to_40s = reshape(nanmean...
    (DATA.WITHIN_SUBJECT_Mean_Time_Series(General_Params.Start_Point*...
    General_Params.Fs:General_Params.End_Point*...
    General_Params.Fs,:,:,:),1),4,45);
```

95% confidence interval for the 'mean within subjects time series' across subjects

```
DATA.Young_Timeseries_95CI = (nanstd...
    (DATA.WITHIN_SUBJECT_Mean_Time_Series(:,:,:,1:15),0,4)./...
    sqrt(General_Params.N_YOUNG)).*1.96;

DATA.Cont_Timeseries_95CI = (nanstd...
    (DATA.WITHIN_SUBJECT_Mean_Time_Series(:,:,:,16:30),0,4)./...
    sqrt(General_Params.N_AGED)).*1.96;

DATA.SCA_Timeseries_95CI = (nanstd...
    (DATA.WITHIN_SUBJECT_Mean_Time_Series(:,:,:,31:45),0,4)./...
    sqrt(General_Params.N_SCA)).*1.96;
```

95% confidence interval for the mean of the 'mean within subjects bar angle for the period between 27 and 40 s' across subjects

```
DATA.Young_Mean_27s_to_40s_95CI = (nanstd...
    (DATA.WITHIN_SUBJECT_Mean_27s_to_40s(:,1:15),0,2)./...
    sqrt(General_Params.N_YOUNG)).*1.96;

DATA.Cont_Mean_27s_to_40s_95CI = (nanstd...
    (DATA.WITHIN_SUBJECT_Mean_27s_to_40s(:,16:30),0,2)./...
    sqrt(General_Params.N_AGED)).*1.96;

DATA.SCA_Mean_27s_to_40s_95CI = (nanstd...
    (DATA.WITHIN_SUBJECT_Mean_27s_to_40s(:,31:45),0,2)./...
    sqrt(General_Params.N_SCA)).*1.96;
```

----------Figure 1b ----------

```
figure
    subplot(3,1,1);plot(Xaxis,Labview_data(1:1500,4,11,6)-...
        mean(Labview_data(150:300,4,11,6)),'k');
    hold on;hline(0,'--k');title('Example Subject 16deg/s');
    ylim([-5 40]);ylabel('Degrees');

    % Noise was summed before being presented to subjects
    subplot(3,1,2);plot(Xaxis,cumsum(Labview_data(1:1500,3,11,6)),'k');
    ylim([-50 50]);ylabel('Degrees');
    hold on;hline(0,'--k')

    subplot(3,1,3);plot(Xaxis,DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (1:1500,:,4,6),'k');ylim([-5 40]);
    hold on;hline(0,'--k');xlabel('time(s)');ylabel('Degrees');xlim([0 50])
```

----------Figure 1d ----------

```
figure
    plot(Xaxis,nanmean(DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (1:1500,:,2,1:15),4),'b')
    hold on;plot(Xaxis,nanmean(DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (1:1500,:,4,1:15),4),'r');
    ylim([0 12]);xlim([0 50]);xlabel('time(s)');ylabel('Degrees');
    title('Young All Cond');legend('4 deg','16 deg')
    hold on;vline(27,'k:');hold on;vline(40,':k')
```

---------- Figure 2 ----------

```
figure;
    subplot(2,2,1);shadedErrorBar(Xaxis,nanmean...
        (DATA.WITHIN_SUBJECT_Mean_Time_Series(1:1500,:,2,1:15),4)...
        ,DATA.Young_Timeseries_95CI(1:1500,1,2),'r',1);

    hold on;shadedErrorBar(Xaxis,nanmean...
        (DATA.WITHIN_SUBJECT_Mean_Time_Series(1:1500,:,2,16:30),4)...
        ,DATA.Cont_Timeseries_95CI(1:1500,1,2),'g',1);

    hold on;shadedErrorBar(Xaxis,nanmean...
        (DATA.WITHIN_SUBJECT_Mean_Time_Series(1:1500,:,2,31:45),4)...
        ,DATA.SCA_Timeseries_95CI(1:1500,1,2),'b',1);
        xlim([0 50]);xlabel('time(s)');ylabel('Degrees');
        ylim([-10 40]);box 'off';


    subplot(2,2,2);shadedErrorBar(Xaxis,nanmean...
        (DATA.WITHIN_SUBJECT_Mean_Time_Series(1:1500,:,4,1:15),4),...
        DATA.Young_Timeseries_95CI(1:1500,1,4),'r',1);

    hold on;shadedErrorBar(Xaxis,nanmean...
```

```
    (DATA.WITHIN_SUBJECT_Mean_Time_Series(1:1500,:,4,16:30),4),...
    DATA.Cont_Timeseries_95CI(1:1500,1,4),'g',1);

hold on;shadedErrorBar(Xaxis,nanmean...
    (DATA.WITHIN_SUBJECT_Mean_Time_Series(1:1500,:,4,31:45),4),...
    DATA.SCA_Timeseries_95CI(1:1500,1,4),'b',1);
    xlim([0 50]);xlabel('time(s)');ylabel('Degrees');
    ylim([-10 40]);box 'off'


subplot(2,2,3);shadedErrorBar(Xaxis,nanmean...
    (DATA.WITHIN_SUBJECT_Mean_Time_Series(1:1500,:,1,1:15),4),...
    DATA.Young_Timeseries_95CI(1:1500,1,1),'r',1);

hold on;shadedErrorBar(Xaxis,nanmean...
    (DATA.WITHIN_SUBJECT_Mean_Time_Series(1:1500,:,1,16:30),4),...
    DATA.Cont_Timeseries_95CI(1:1500,1,1),'g',1);

hold on;shadedErrorBar(Xaxis,nanmean...
    (DATA.WITHIN_SUBJECT_Mean_Time_Series(1:1500,:,1,31:45),4),...
    DATA.SCA_Timeseries_95CI(1:1500,1,1),'b',1);
    xlim([0 50]);xlabel('time(s)');ylabel('Degrees');
    ylim([-10 40]);box 'off'


subplot(2,2,4);shadedErrorBar(Xaxis,nanmean...
    (DATA.WITHIN_SUBJECT_Mean_Time_Series(1:1500,:,3,1:15),4),...
    DATA.Young_Timeseries_95CI(1:1500,1,3),'r',1);

hold on;shadedErrorBar(Xaxis,nanmean...
    (DATA.WITHIN_SUBJECT_Mean_Time_Series(1:1500,:,3,16:30),4),...
    DATA.Cont_Timeseries_95CI(1:1500,1,3),'g',1);

hold on;shadedErrorBar(Xaxis,nanmean...
    (DATA.WITHIN_SUBJECT_Mean_Time_Series(1:1500,:,3,31:45),4),...
    DATA.SCA_Timeseries_95CI(1:1500,1,3),'b',1);
    xlim([0 50]);xlabel('time(s)');ylabel('Degrees');
    ylim([-10 40]);box 'off'
```

Correlation of SARA Scores with z scored response size

```
% Size: DATA.WITHIN_SUBJECT_Mean_27s_to_40s(4,45)
    Mat_Temp = abs(DATA.WITHIN_SUBJECT_Mean_27s_to_40s(:,31:45))';
    Z_Score = (Mat_Temp - mean(Mat_Temp,1))./std(Mat_Temp,0,1);

% [RHO, PVAL]
    [DATA.Reported_Measures_SARA_BAR_CORR(1,1),...
        DATA.Reported_Measures_SARA_BAR_CORR(1,2)] =...
        corr(repmat(General_Params.SARA_Scores,4,1),...
        reshape(Z_Score,length(Z_Score)*4,1));

clear Mat_Temp Z_Score
```

----------Figure 3a----------

```
% Mean stdev for the baseline across participants
% for the first 10s of the trial
% SIZES: DATA.ALL_DATA_Sorted(1533,8,4,45)
% to DATA.Young_Pre_Stim_Baseline_Stdev(300,1,4,15)

    DATA.Young_Pre_Stim_Baseline_Stdev =...
        nanstd(DATA.ALL_DATA_Sorted(1:300,:,:,1:15),0,2);

    DATA.Cont_Pre_Stim_Baseline_Stdev =...
        nanstd(DATA.ALL_DATA_Sorted(1:300,:,:,16:30),0,2);

    DATA.SCA_Pre_Stim_Baseline_Stdev =...
        nanstd(DATA.ALL_DATA_Sorted(1:300,:,:,31:45),0,2);

% Mean baseline across participants for the first 10s of the trial
% SIZES: DATA.ALL_DATA_Sorted(1533,8,4,45)
% to DATA.Young_Pre_Stim_Baseline_Mean(300,1,4,15)
    DATA.Young_Pre_Stim_ABS_Baseline_Mean =...
        nanmean(abs(DATA.ALL_DATA_Sorted(1:300,:,:,1:15)),2);

    DATA.Cont_Pre_Stim_ABS_Baseline_Mean =...
        nanmean(abs(DATA.ALL_DATA_Sorted(1:300,:,:,16:30)),2);

    DATA.SCA_Pre_Stim_ABS_Baseline_Mean =...
        nanmean(abs(DATA.ALL_DATA_Sorted(1:300,:,:,31:45)),2);


% Figure 3a
 figure;
    shadedErrorBar(Xaxis(1:300,1),nanmean...
        (DATA.Young_Pre_Stim_ABS_Baseline_Mean(:,:,2,:),4),...
        nanmean(DATA.Young_Pre_Stim_Baseline_Stdev...
        (:,:,2,:),4),'r-.',1);hold on;ylim([0 50]);

    shadedErrorBar(Xaxis(1:300,1),nanmean...
        (DATA.Cont_Pre_Stim_ABS_Baseline_Mean(:,:,2,:),4),...
```

```
        nanmean(DATA.Cont_Pre_Stim_Baseline_Stdev...
        (:,:,2,:),4),'g',1);

    shadedErrorBar(Xaxis(1:300,1),nanmean...
        (DATA.SCA_Pre_Stim_ABS_Baseline_Mean(:,:,2,:),4),...
        nanmean(DATA.SCA_Pre_Stim_Baseline_Stdev (:,:,2,:),4),'b--',1);
        box 'off';set(gca,'TickDir','out')
```

----------Figure 3b----------

```
% Size: DATA.WITHIN_SUBJECT_Mean_27s_to_40s(4,45)
Younggroupamp = nanmean(DATA.WITHIN_SUBJECT_Mean_27s_to_40s(:,1:15),2);
Oldercontgroupamp = nanmean(DATA.WITHIN_SUBJECT_Mean_27s_to_40s(:,16:30),2);
SCAgroupamp = nanmean(DATA.WITHIN_SUBJECT_Mean_27s_to_40s(:,31:45),2);


Cohaxis = [40;100];

figure
subplot(1,2,2);
    e = errorbar(Cohaxis,SCAgroupamp(3:4,:) -...
        [(SCAgroupamp(4,1)+SCAgroupamp(3,1))/2 ;...
        (SCAgroupamp(4,1)+SCAgroupamp(3,1))/2],...
        -DATA.SCA_Mean_27s_to_40s_95CI(3:4,:),...
        DATA.SCA_Mean_27s_to_40s_95CI(3:4,:));

        e.Color = [0 0 1];e.LineStyle = '--';
        hold on;plot(Cohaxis,SCAgroupamp(3:4,:) -...
        [(SCAgroupamp(4,1)+SCAgroupamp(3,1))/2 ;...
        (SCAgroupamp(4,1)+SCAgroupamp(3,1))/2],'b.','MarkerSize',12)
        hold on;
    e = errorbar(Cohaxis,Oldercontgroupamp(3:4,:) -...
        [(Oldercontgroupamp(4,1) + Oldercontgroupamp(3,1))/2 ;...
        (Oldercontgroupamp(4,1) + Oldercontgroupamp(3,1))/2],...
        -DATA.Cont_Mean_27s_to_40s_95CI(3:4,:),...
        DATA.Cont_Mean_27s_to_40s_95CI(3:4,:));

        e.Color = [0 1 0];hold on;
        plot(Cohaxis,Oldercontgroupamp(3:4,:)-...
            [(Oldercontgroupamp(4,1) +...
        Oldercontgroupamp(3,1))/2 ; (Oldercontgroupamp(4,1) +...
        Oldercontgroupamp(3,1))/2],'g.','MarkerSize',12)
        hold on;

    e = errorbar(Cohaxis,Younggroupamp(3:4,:)-...
        [(Younggroupamp(4,1)+Younggroupamp(3,1))/2 ;...
        (Younggroupamp(4,1)+Younggroupamp(3,1))/2],...
        -DATA.Young_Mean_27s_to_40s_95CI(3:4,:),...
        DATA.Young_Mean_27s_to_40s_95CI(3:4,:));
        title('16 deg/s');xlabel('Coh(deg/s)');
        ylabel('Ave Bar Angle(deg)');
        ylim([-15 15]);grid 'on';box 'off'
```

```
        e.Color = [1 0 0];e.LineStyle = '-.';
        hold on;plot(Cohaxis,Younggroupamp(3:4,:) -...
        [(Younggroupamp(4,1) + Younggroupamp(3,1))/2 ;...
        (Younggroupamp(4,1) + Younggroupamp(3,1))/2],'r.','MarkerSize',12)
        ax = gca;ax.XTick = [40 100];xlim([0 140])

subplot(1,2,1);
    e = errorbar(Cohaxis,SCAgroupamp(1:2,:)-...
        [(SCAgroupamp(2,1)+SCAgroupamp(1,1))/2 ;...
        (SCAgroupamp(2,1)+SCAgroupamp(1,1))/2],...
        -DATA.SCA_Mean_27s_to_40s_95CI(1:2,:),...
        DATA.SCA_Mean_27s_to_40s_95CI(1:2,:));

        e.Color = [0 0 1];e.LineStyle = '--';...
            hold on;plot(Cohaxis,SCAgroupamp(1:2,:)-...
        [(SCAgroupamp(2,1)+SCAgroupamp(1,1))/2 ;...
        (SCAgroupamp(2,1)+SCAgroupamp(1,1))/2],'b.','MarkerSize',12)
        hold on;
    e = errorbar(Cohaxis,Oldercontgroupamp(1:2,:)-...
        [(Oldercontgroupamp(2,1)+Oldercontgroupamp(1,1))/2 ;...
        (Oldercontgroupamp(2,1)+Oldercontgroupamp(1,1))/2],...
        -DATA.Cont_Mean_27s_to_40s_95CI(1:2,:),...
        DATA.Cont_Mean_27s_to_40s_95CI(1:2,:));

        e.Color = [0 1 0];hold on;
        plot(Cohaxis,Oldercontgroupamp(1:2,:)-[(Oldercontgroupamp(2,1) + ...
        Oldercontgroupamp(1,1))/2 ;(Oldercontgroupamp(2,1)+...
        Oldercontgroupamp(1,1))/2],'g.','MarkerSize',12)
        hold on;
    e = errorbar(Cohaxis,Younggroupamp(1:2,:)-...
        [(Younggroupamp(2,1)+Younggroupamp(1,1))/2 ;...
        (Younggroupamp(2,1)+Younggroupamp(1,1))/2],...
        -DATA.Young_Mean_27s_to_40s_95CI(1:2,:),...
        DATA.Young_Mean_27s_to_40s_95CI(1:2,:));
        title('4 deg/s');xlabel('Coh(deg/s)');
        ylabel('Ave Bar Angle(deg)');ylim([-5 5]);grid 'on';box 'off'

        e.Color = [1 0 0];e.LineStyle = '-.';hold on;
        plot(Cohaxis,Younggroupamp(1:2,:) -...
        [(Younggroupamp(2,1)+Younggroupamp(1,1))/2 ;...
        (Younggroupamp(2,1)+Younggroupamp(1,1))/2],'r.','MarkerSize',12)
        ax = gca;ax.XTick = [40 100];xlim([0 140])
```

----------Figure 3C----------

```
% Test to examine relative change due to velocity
     X_Vals = [ones(15,1) ones(15,1)*2 ones(15,1)*3 ones(15,1)...
         *4 ones(15,1)*5 ones(15,1)*6 ones(15,1)*7 ones(15,1)...
         *8 ones(15,1)*9 ones(15,1)*10 ones(15,1)*11 ones(15,1)*12];
% Size: DATA.WITHIN_SUBJECT_Mean_Time_Series(1533,1,4,45)
```

```
% Noise Comparison
    Percent_Diff_Noise_4(:,1) = reshape((nanmean...
        (DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,2,31:45),1)...
        - nanmean(DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,1,31:45),1)) ./...
        (nanmean(DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,2,31:45),1)),15,1);

    Percent_Diff_Noise_16(:,1) = reshape((nanmean...
        (DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,4,31:45),1)...
        - nanmean(DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,3,31:45),1)) ./...
        (nanmean(DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,4,31:45),1)),15,1);

    Percent_Diff_Noise_4(:,2) = reshape((nanmean...
        (DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,2,16:30),1) -...
        nanmean(DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,1,16:30),1)) ./...
        (nanmean(DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,2,16:30),1)),15,1);

    Percent_Diff_Noise_16(:,2) = reshape((nanmean...
        (DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,4,16:30),1) -...
        nanmean(DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,3,16:30),1)) ./...
        (nanmean(DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,4,16:30),1)),15,1);

    Percent_Diff_Noise_4(:,3) = reshape((nanmean...
        (DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,2,1:15),1) -...
        nanmean(DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,1,1:15),1)) ./...
        (nanmean(DATA.WITHIN_SUBJECT_Mean_Time_Series...
```

```
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,2,1:15),1)),15,1);

    Percent_Diff_Noise_16(:,3) = reshape((nanmean...
        (DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,4,1:15),1) -...
        nanmean(DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,3,1:15),1)) ./...
        (nanmean(DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,4,1:15),1)),15,1);


% Velocity Comparison
    Percent_Diff_Vel_4(:,1) = reshape((nanmean...
        (DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,3,31:45),1) -...
        nanmean(DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,1,31:45),1)) ./...
        (nanmean(DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,3,31:45),1)),15,1);

    Percent_Diff_Vel_16(:,1) = reshape((nanmean...
        (DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,4,31:45),1) -...
        nanmean(DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,2,31:45),1)) ./...
        (nanmean(DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,4,31:45),1)),15,1);

    Percent_Diff_Vel_4(:,2) = reshape((nanmean...
        (DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,3,16:30),1) -...
        nanmean(DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,1,16:30),1)) ./...
        (nanmean(DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,3,16:30),1)),15,1);

    Percent_Diff_Vel_16(:,2) = reshape((nanmean...
        (DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,4,16:30),1) -...
```

```
        nanmean(DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs...
        :General_Params.End_Point*General_Params.Fs,:,2,16:30),1)) ./...
        (nanmean(DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,4,16:30),1)),15,1);

    Percent_Diff_Vel_4(:,3) = reshape((nanmean...
        (DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,3,1:15),1) -...
        nanmean(DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,1,1:15),1)) ./...
        (nanmean(DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,3,1:15),1)),15,1);

    Percent_Diff_Vel_16(:,3) = reshape((nanmean...
        (DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,4,1:15),1) -...
        nanmean(DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,2,1:15),1)) ./...
        (nanmean(DATA.WITHIN_SUBJECT_Mean_Time_Series...
        (General_Params.Start_Point*General_Params.Fs:...
        General_Params.End_Point*General_Params.Fs,:,4,1:15),1)),15,1);

figure
    scatter(X_Vals(:,1),Percent_Diff_Noise_4(:,1)...
        ,70,[0 0 1],'filled','MarkerFaceAlpha',2/8);hold on;
e = errorbar(X_Vals(1,1),mean(Percent_Diff_Noise_4(:,1)),...
    (-std(Percent_Diff_Noise_4(:,1),0,1)/sqrt(15))*1.96,...
    (std(Percent_Diff_Noise_4(:,1),0,1)/sqrt(15))*1.96);
    e.Color = [0 0 1];e.LineStyle = '--';hold on;
    plot(X_Vals(1,1),mean(Percent_Diff_Noise_4(:,1)),'b.','MarkerSize',40);
    hold on;

    scatter(X_Vals(:,2),Percent_Diff_Noise_4(:,2)...
        ,70,[0 1 0],'filled','MarkerFaceAlpha',2/8)
e = errorbar(X_Vals(1,2),mean(Percent_Diff_Noise_4(:,2)),...
    (-std(Percent_Diff_Noise_4(:,2),0,1)/sqrt(15))*1.96,...
    (std(Percent_Diff_Noise_4(:,2),0,1)/sqrt(15))*1.96);
    e.Color = [0 1 0];e.LineStyle = '--';hold on;
    plot(X_Vals(1,2),mean(Percent_Diff_Noise_4(:,2)),'g.','MarkerSize',40);
    hold on;

    scatter(X_Vals(:,3),Percent_Diff_Noise_4(:,3)...
        ,70,[1 0 0],'filled','MarkerFaceAlpha',2/8);hold on
e = errorbar(X_Vals(1,3),mean(Percent_Diff_Noise_4(:,3))...
    ,(-std(Percent_Diff_Noise_4(:,3),0,1)/sqrt(15))*1.96,...
    (std(Percent_Diff_Noise_4(:,3),0,1)/sqrt(15))*1.96);
```

```
    e.Color = [1 0 0];e.LineStyle = '--';hold on;
    plot(X_Vals(1,3),mean(Percent_Diff_Noise_4(:,3)),'r.','MarkerSize',40);
    hold on;

    scatter(X_Vals(:,4),Percent_Diff_Noise_16(:,1)...
        ,70,[0 0 1],'filled','MarkerFaceAlpha',2/8);hold on;
e = errorbar(X_Vals(1,4),mean(Percent_Diff_Noise_16(:,1)),...
    (-std(Percent_Diff_Noise_16(:,1),0,1)/sqrt(15))*1.96,...
    (std(Percent_Diff_Noise_16(:,1),0,1)/sqrt(15))*1.96);
    e.Color = [0 0 1];e.LineStyle = '--';plot(X_Vals(1,4),...
    mean(Percent_Diff_Noise_16(:,1)),'b.','MarkerSize',40);
    hold on;

    scatter(X_Vals(:,5),Percent_Diff_Noise_16(:,2)...
        ,70,[0 1 0],'filled','MarkerFaceAlpha',2/8)
e = errorbar(X_Vals(1,5),mean(Percent_Diff_Noise_16(:,2)),...
    (-std(Percent_Diff_Noise_16(:,2),0,1)/sqrt(15))*1.96,...
    (std(Percent_Diff_Noise_16(:,2),0,1)/sqrt(15))*1.96);
    e.Color = [0 1 0];e.LineStyle = '--';plot(X_Vals(1,5),...
        mean(Percent_Diff_Noise_16(:,2)),'g.','MarkerSize',40);
    hold on;

    scatter(X_Vals(:,6),Percent_Diff_Noise_16(:,3)...
        ,70,[1 0 0],'filled','MarkerFaceAlpha',2/8);
e = errorbar(X_Vals(1,6),mean(Percent_Diff_Noise_16(:,3))...
    ,(-std(Percent_Diff_Noise_16(:,3),0,1)/sqrt(15))*1.96,...
    (std(Percent_Diff_Noise_16(:,3),0,1)/sqrt(15))*1.96);
    e.Color = [1 0 0];e.LineStyle = '--';plot(X_Vals(1,6),...
        mean(Percent_Diff_Noise_16(:,3)),'r.','MarkerSize',40);
    hold on;

    scatter(X_Vals(:,7),Percent_Diff_Vel_4(:,1)...
        ,70,[0 0 1],'filled','MarkerFaceAlpha',2/8);hold on;
e = errorbar(X_Vals(1,7),mean(Percent_Diff_Vel_4(:,1)),...
    (-std(Percent_Diff_Vel_4(:,1),0,1)/sqrt(15))*1.96,...
    (std(Percent_Diff_Vel_4(:,1),0,1)/sqrt(15))*1.96);
    e.Color = [0 0 1];e.LineStyle = '--';hold on;
    plot(X_Vals(1,7),mean(Percent_Diff_Vel_4(:,1)),'b.','MarkerSize',40);
    hold on;

    scatter(X_Vals(:,8),Percent_Diff_Vel_4(:,2)...
        ,70,[0 1 0],'filled','MarkerFaceAlpha',2/8)
    e = errorbar(X_Vals(1,8),mean(Percent_Diff_Vel_4(:,2))...
        ,(-std(Percent_Diff_Vel_4(:,2),0,1)/sqrt(15))*1.96,...
        (std(Percent_Diff_Vel_4(:,2),0,1)/sqrt(15))*1.96);
    e.Color = [0 1 0];e.LineStyle = '--';hold on;
    plot(X_Vals(1,8),mean(Percent_Diff_Vel_4(:,2)),'g.','MarkerSize',40);
    hold on;

    scatter(X_Vals(:,9),Percent_Diff_Vel_4(:,3)...
        ,70,[1 0 0],'filled','MarkerFaceAlpha',2/8);hold on
e = errorbar(X_Vals(1,9),mean(Percent_Diff_Vel_4(:,3)),...
    (-std(Percent_Diff_Vel_4(:,3),0,1)/sqrt(15))*1.96,...
```

```
    (std(Percent_Diff_Vel_4(:,3),0,1)/sqrt(15))*1.96);
    e.Color = [1 0 0];e.LineStyle = '--';hold on;
    plot(X_Vals(1,9),mean(Percent_Diff_Vel_4(:,3)),'r.','MarkerSize',40);
    hold on;

    scatter(X_Vals(:,10),Percent_Diff_Vel_16(:,1)...
        ,70,[0 0 1],'filled','MarkerFaceAlpha',2/8);hold on;
e = errorbar(X_Vals(1,10),mean(Percent_Diff_Vel_16(:,1)),...
    (-std(Percent_Diff_Vel_16(:,1),0,1)/sqrt(15))*1.96,...
    (std(Percent_Diff_Vel_16(:,1),0,1)/sqrt(15))*1.96);
    e.Color = [0 0 1];e.LineStyle = '--';plot(X_Vals(1,10),...
        mean(Percent_Diff_Vel_16(:,1)),'b.','MarkerSize',40);
    hold on;

    scatter(X_Vals(:,11),Percent_Diff_Vel_16(:,2)...
        ,70,[0 1 0],'filled','MarkerFaceAlpha',2/8)
e = errorbar(X_Vals(1,11),mean(Percent_Diff_Vel_16(:,2)),...
    (-std(Percent_Diff_Vel_16(:,2),0,1)/sqrt(15))*1.96,...
    (std(Percent_Diff_Vel_16(:,2),0,1)/sqrt(15))*1.96);
    e.Color = [0 1 0];e.LineStyle = '--';plot(X_Vals(1,11),...
        mean(Percent_Diff_Vel_16(:,2)),'g.','MarkerSize',40);
    hold on;

    scatter(X_Vals(:,12),Percent_Diff_Vel_16(:,3)...
        ,70,[1 0 0],'filled','MarkerFaceAlpha',2/8);
e = errorbar(X_Vals(1,12),mean(Percent_Diff_Vel_16(:,3)),...
    (-std(Percent_Diff_Vel_16(:,3),0,1)/sqrt(15))*1.96,...
    (std(Percent_Diff_Vel_16(:,3),0,1)/sqrt(15))*1.96);axis([0 13 -0.5 1])
    e.Color = [1 0 0];e.LineStyle = '--';plot(X_Vals(1,12),...
        mean(Percent_Diff_Vel_16(:,3)),'r.','MarkerSize',40);
    ylabel('Proportion Change')
    hold off;


clear Percent_Diff_Vel_4 Percent_Diff_Vel_16 Percent_Diff_Noise_16...
    Percent_Diff_Noise_4
```

Relative size of the response between groups reported in the discussion

```
    DATA.Reported_Measures_Response_Size_Multiples(1,1) =...
        SCAgroupamp(4,1) / Oldercontgroupamp(4,1);

    DATA.Reported_Measures_Response_Size_Multiples(2,1) =...
        SCAgroupamp(4,1) / Younggroupamp(4,1);

    DATA.Reported_Measures_Response_Size_Multiples(3,1) =...
        Oldercontgroupamp(4,1) / Younggroupamp(4,1);
```

Data to fit Maximum Likelihood Model to:

```
    Model_data.Average_Data_for_Model_Fit =...
        abs([mean(DATA.ALL_DATA_Mean_27s_to_40s_Sorted(1,1,31:45),3)...
        mean(DATA.ALL_DATA_Mean_27s_to_40s_Sorted(1,2,31:45),3)...
         mean(DATA.ALL_DATA_Mean_27s_to_40s_Sorted(1,3,31:45),3)...
         mean(DATA.ALL_DATA_Mean_27s_to_40s_Sorted(1,4,31:45),3) ;...
         mean(DATA.ALL_DATA_Mean_27s_to_40s_Sorted(1,1,16:30),3)...
         mean(DATA.ALL_DATA_Mean_27s_to_40s_Sorted(1,2,16:30),3)...
         mean(DATA.ALL_DATA_Mean_27s_to_40s_Sorted(1,3,16:30),3)...
         mean(DATA.ALL_DATA_Mean_27s_to_40s_Sorted(1,4,16:30),3) ;...
         mean(DATA.ALL_DATA_Mean_27s_to_40s_Sorted(1,1,1:15),3)...
         mean(DATA.ALL_DATA_Mean_27s_to_40s_Sorted(1,2,1:15),3)...
         mean(DATA.ALL_DATA_Mean_27s_to_40s_Sorted(1,3,1:15),3)...
         mean(DATA.ALL_DATA_Mean_27s_to_40s_Sorted(1,4,1:15),3)]);
```

Group Amplitude arrays for bootstrapping the model

```
Model_data.Young_Data_for_Model =...
    [DATA.ALL_DATA_Mean_27s_to_40s_Sorted(1,1,1:15)...
    DATA.ALL_DATA_Mean_27s_to_40s_Sorted(1,2,1:15)...
    DATA.ALL_DATA_Mean_27s_to_40s_Sorted(1,3,1:15)...
    DATA.ALL_DATA_Mean_27s_to_40s_Sorted(1,4,1:15)];

Model_data.Aged_Data_for_Model =...
    [DATA.ALL_DATA_Mean_27s_to_40s_Sorted(1,1,16:30)...
    DATA.ALL_DATA_Mean_27s_to_40s_Sorted(1,2,16:30)...
    DATA.ALL_DATA_Mean_27s_to_40s_Sorted(1,3,16:30)...
    DATA.ALL_DATA_Mean_27s_to_40s_Sorted(1,4,16:30)];

Model_data.SCA_Data_for_Model =...
    [DATA.ALL_DATA_Mean_27s_to_40s_Sorted(1,1,31:45)...
    DATA.ALL_DATA_Mean_27s_to_40s_Sorted(1,2,31:45)...
    DATA.ALL_DATA_Mean_27s_to_40s_Sorted(1,3,31:45)...
    DATA.ALL_DATA_Mean_27s_to_40s_Sorted(1,4,31:45)];
```

This arranges the data for R to run the multilevel model

Cond 1 4deg/s Noise, Cond 2 4deg/s Coh Cond 3 16deg/s Noise, Cond 4 16deg/s Coh

```
    R_Data = nan(1440,5);
    k=1;
    j=1;
    for cond = 1:4
        for sub = 1:General_Params.N_YOUNG
            for trial = 1:8
                R_Data(k,1) = 1;
                R_Data(k,2) = cond;
                R_Data(k,3) = sub;
                R_Data(k,4) = trial;
                R_Data(k,5) = ...
```

```
                DATA.ALL_DATA_Mean_27s_to_40s_Sorted(trial,cond,sub);
                j=j+1;
                k=k+1;
            end
        end
    end

    j=1;
    for cond = 1:4
        for sub = 1:General_Params.N_AGED
            for trial = 1:8
                R_Data(k,1) = 2;
                R_Data(k,2) = cond;
                R_Data(k,3) = sub;
                R_Data(k,4) = trial;
                R_Data(k,5) = ...
                DATA.ALL_DATA_Mean_27s_to_40s_Sorted(trial,cond,sub+15);
                j=j+1;
                k=k+1;
            end
        end
    end
    j=1;
    for cond = 1:4
        for sub = 1:General_Params.N_SCA
            for trial = 1:8
                R_Data(k,1) = 3;
                R_Data(k,2) = cond;
                R_Data(k,3) = sub;
                R_Data(k,4) = trial;
                R_Data(k,5) = ...
                DATA.ALL_DATA_Mean_27s_to_40s_Sorted(trial,cond,sub+30);
                j=j+1;
                k=k+1;
            end
        end
    end
```

Gradient descent to fit the model published run can be found in the file: Published_CI_Data

```
if Run_CI_model == 1

keep Model_data General_Params

% Maximum Likelihood model and cost function
    MaxLike = @(Vision,Visionstd,Vestibular,Vestibularstd,Uns)...
        (((Vision./Visionstd.^2) + (Vestibular./Vestibularstd.^2)) ./...
        ((Uns./Visionstd.^2)+(Uns./Vestibularstd.^2)));

    cost = @(Map,Recorded_values) sum(sum((Map - Recorded_values).^2,1),2);
```

```
    learningRate = 0.05;
    Gradient_Descent_Iterations = 100;
    New_Starting_Positions = 5000;
    num_draws = 10000;
    Empirical_Bar_Angle_values = [];

% Increase the range of the starting point
    noise_multiplier = 10;

    Minval.Cost_History = nan(num_draws,New_Starting_Positions);

for draw = 1:num_draws

    display(draw)

    keep Minval MaxLike cost learningRate Gradient_Descent_Iterations...
        New_Starting_Positions draw num_draws Recorded_values...
        noise_multiplier Model_data NSCA NAGED NYOUNG


% Draw one subject from each group;

    SCA = ceil(rand*15);
    Aged = ceil(rand*15);
    Young = ceil(rand*15);

    Empirical_Bar_Angle_values =...
        [Model_data.SCA_Data_for_Model(1,1,SCA)...
        Model_data.SCA_Data_for_Model(1,2,SCA)...
         Model_data.SCA_Data_for_Model(1,3,SCA)...
         Model_data.SCA_Data_for_Model(1,4,SCA) ; ...
         Model_data.Aged_Data_for_Model(1,1,Aged)...
         Model_data.Aged_Data_for_Model(1,2,Aged)...
         Model_data.Aged_Data_for_Model(1,3,Aged)...
         Model_data.Aged_Data_for_Model(1,4,Aged) ; ...
         Model_data.Young_Data_for_Model(1,1,Young)...
         Model_data.Young_Data_for_Model(1,2,Young)...
         Model_data.Young_Data_for_Model(1,3,Young)...
         Model_data.Young_Data_for_Model(1,4,Young)];

    costmin = inf;
    last_entrance = 0;
    k = 1;
     for j = 1:New_Starting_Positions
        keep Minval MaxLike cost learningRate Recorded_values...
            j costmin k noise_multiplier draw num_draws...
            Gradient_Descent_Iterations New_Starting_Positions...
            last_entrance Model_data NSCA NAGED NYOUNG

        if num_draws == 1
        display(j)
        end
```

```
        % Educated guess as to the parameters starting postions perturbed on
        % each loop to minimize the effect of local minima
Parameters = [14 + (rand*noise_multiplier - (noise_multiplier / 2)) ;...
              11 + (rand * noise_multiplier - (noise_multiplier / 2)) ;...
              5 + (rand*noise_multiplier -(noise_multiplier / 2));...
              27 + (rand*noise_multiplier-(noise_multiplier / 2)) ;...
              47 + (rand*noise_multiplier-(noise_multiplier / 2)) ;...
              17 + (rand*noise_multiplier -(noise_multiplier / 2));...
              11 + (rand*noise_multiplier-(noise_multiplier / 2))];


            New_Min_loop = 1;
            for iterations = 1:Gradient_Descent_Iterations

            % Vestibular standard deviation (3 noise levels for 3 groups)
            Vestibularstd = [ones(1,4)*Parameters(1) ;...
                ones(1,4)*Parameters(2) ; ones(1,4)*Parameters(3)];

            % Mean visual bar angle both velocities (16deg/s or 4deg/s)
            Vision = [ones(3,2)*Parameters(4) ones(3,2)*Parameters(5)];

            % Visual standard deviation (Noisy or coherent)
            Visionstd = [ones(3,1)*Parameters(6) ones(3,1)*Parameters(7)...
                         ones(3,1)*Parameters(6) ones(3,1)*Parameters(7)];

                Vestibular = zeros(3,4);
                Uns = ones(3,4);

                % Hypothesis Function
                Theoretical_Bar_Angle_Values = MaxLike(Vision,Visionstd,...
                    Vestibular,Vestibularstd,Uns);

                  % Keeping track of the cost function
            costHistory(iterations) = cost...
                (Theoretical_Bar_Angle_Values,Empirical_Bar_Angle_values);
 % enter this loop each time the cost is lower than the cached lowest cost...
 % that way we settle on a single value for each draw over mulitple new start

            if costmin > costHistory(iterations)
                Minval.ParametersHistory(draw,:) = Parameters';

                % sum of square differences
                Minval.ParametersFit.LSQ(draw,1) = sum...
                    (sum((Theoretical_Bar_Angle_Values -...
                    Empirical_Bar_Angle_values).^2,1),2);

                % Root mean square differnce
                Minval.ParametersFit.RMSD(draw,1) =...
                    sqrt(Minval.ParametersFit.LSQ(draw,1)/12);

                rsquare_array =...
                    [reshape(Theoretical_Bar_Angle_Values,12,1)...
                    reshape(Empirical_Bar_Angle_values,12,1)];
```

```
            [R,P] = corrcoef(rsquare_array(:,1),...
                rsquare_array(:,2));

            Minval.ParametersFit.R(draw,1) = R(2,1);
            Minval.ParametersFit.R_square(draw,1) = R(2,1).^2;
            Minval.ParametersFit.R(draw,2) = P(2,1);
            Minval.Cost(draw,1) = costmin;
            %this is across iterations and starting points
            Minval.Cost_History(draw,k) = costHistory(iterations);

            %Best fit MAP for each draw
            Minval.MAP(:,:,draw) = Theoretical_Bar_Angle_Values;

            k = k + 1;
            New_Min_loop = New_Min_loop + 1;
            costmin = costHistory(iterations);
            last_entrance = j;
        end

            % Scaled error function
            h = (Theoretical_Bar_Angle_Values -...
                Empirical_Bar_Angle_values).*...
                Theoretical_Bar_Angle_Values;


            % Updating the parameters

            Parameters(1) = Parameters(1) - learningRate...
                * mean(h(1,:),2);% Vest stdev SCA

            Parameters(2) = Parameters(2) - learningRate...
                * mean(h(2,:),2);% Vest stdev Aged

            Parameters(3) = Parameters(3) - learningRate *...
                mean(h(3,:),2);% Vest stdev Young

            Parameters(4) = Parameters(4) - learningRate *...
                mean([h(:,1) ; h(:,2)],1);% Visual Vel Slow

            Parameters(5) = Parameters(5) - learningRate *...
                mean([h(:,3) ; h(:,4)],1);% Visual Vel Fast


            % These parameters tend to like to go negative so
            % they've been prevented
            if Parameters(6) >= 0
                Parameters(6) = Parameters(6) - learningRate *...
                    mean([h(:,1) ; h(:,3)],1); % Visual Stdev Noisy
            else
                Parameters(6) = 0;
            end
```

```
                if Parameters(7) >= 0
                    Parameters(7) = Parameters(7) - -learningRate *...
                        mean([h(:,2) ; h(:,4)],1); % Visual Stdev Coherent
                else
                    Parameters(7) = 0;
                end


            end

        end

end
```

Confidence Interval Calculation

To run this lower cell you have to either run the Run_CI_model cell above or load the Published_CI_Data.mat file in the folder with this script

```
% Parameters = [
% Vestib_SCA_STD
% Vestib_Aged_STD
% Vestib_Young_STD
% Vision_4deg/s_Mean
% Vision_16deg/s_Mean
% Vision_std_noisy
% Vision_std_Coh]

% Data from gradient descent model fitting
    DATA.Reported_Measures_Model_Parameters_Stats(:,1) =...
        mean(Minval.ParametersHistory,1); % Average Parameters
    DATA.Reported_Measures_Model_Parameters_Stats(:,2) =...
        std(Minval.ParametersHistory,0,1); % Parameters stdev
    DATA.Reported_Measures_Model_Fit_Stats(1,1) =...
        mean(Minval.ParametersFit.R_square,1); % Average r^2
    DATA.Reported_Measures_Model_Fit_Stats(1,2) =...
        std(Minval.ParametersFit.R_square,0,1); % r^2 stdev
    DATA.Reported_Measures_Model_Fit_Stats(2,1) =...
        mean(Minval.ParametersFit.RMSD,1); % Average root mean square
    DATA.Reported_Measures_Model_Fit_Stats(2,2) =...
        std(Minval.ParametersFit.RMSD,0,1); % root mean square stdev

    % The Average Model Data
    Empirical_Bar_Angle_values = Model_data.Average_Data_for_Model_Fit;

    % Confidence Intervals for the Empirical Data
    Empirical_Bar_Angle_CI_values = ...
        [(nanstd(Model_data.SCA_Data_for_Model,0,3)./...
        sqrt(General_Params.N_SCA)).*1.96 ;...
        (nanstd(Model_data.Aged_Data_for_Model,0,3)./...
        sqrt(General_Params.N_AGED)).*1.96 ;...
        (nanstd(Model_data.Young_Data_for_Model,0,3)./...
```

```
        sqrt(General_Params.N_YOUNG)).*1.96];

    % Vestibular standard deviation
    Vestibularstd = [ones(1,4)*...
        DATA.Reported_Measures_Model_Parameters_Stats(1,1) ;...
        ones(1,4)*DATA.Reported_Measures_Model_Parameters_Stats(2,1) ;...
        ones(1,4)*DATA.Reported_Measures_Model_Parameters_Stats(3,1)];

    % Mean visual bar angle estimate
    Vision = [ones(3,2)*...
        DATA.Reported_Measures_Model_Parameters_Stats(4,1) ones(3,2)*...
        DATA.Reported_Measures_Model_Parameters_Stats(5,1)];

    % Visual standard deviation
    Visionstd = [ones(3,1)...
        *DATA.Reported_Measures_Model_Parameters_Stats(6,1) ones(3,1)*...
        DATA.Reported_Measures_Model_Parameters_Stats(7,1) ones(3,1)*...
        DATA.Reported_Measures_Model_Parameters_Stats(6,1) ones(3,1)*...
        DATA.Reported_Measures_Model_Parameters_Stats(7,1)];

    Vestibular = zeros(3,4);
    Uns = ones(3,4);


% Estimate Confidence Intervals
    Average_of_All_Models = mean(Minval.MAP(:,:,:),3);
    All_MAPs = Minval.MAP(:,:,:);

    Int = 1000;
    for j = 1:Int
        Subset_means(:,:,j) = mean(All_MAPs(:,:,j*10-9:j*10),3);
    end

% Create a Matrix to speed the difference distribution Calc
    Average_of_all_Models_Repeated = repmat(Average_of_All_Models,1,1,Int);

% Make the difference distribution
    difference_between = Subset_means - Average_of_all_Models_Repeated;

% Sort from by size difference
    difference_between_sorted = sort(difference_between,3);

% For 10000 draws the 2.5% and 97.5% are 25 and 975
    Model_CI = difference_between_sorted(:,:,[25 975]);
```

---------- Figure 5 Lower ----------

```
Velaxis=[4;16];
x = 1:4;
x2 = [0.8 2.2 2.8 4.2];

figure
suptitle('Average of model')
hold on

plot(x2(1:2),Average_of_All_Models(1,[1 3])...
    ,'ob','MarkerSize',10,'MarkerFaceColor','b','MarkerEdgeColor','k');
plot(x2(3:4),Average_of_All_Models(1,[2 4])...
    ,'ob','MarkerSize',10,'MarkerFaceColor','b','MarkerEdgeColor','k');
errorbar(x(1:2),Empirical_Bar_Angle_values(1,[1 3])...
    ,-Empirical_Bar_Angle_CI_values(1,[1 3]),...
    Empirical_Bar_Angle_CI_values(1,[1 3])...
    ,'b','LineWidth',2,'MarkerEdgeColor','k');
plot(x(1:2),Empirical_Bar_Angle_values(1,[1 3])...
    ,'sb','MarkerSize',10,'MarkerFaceColor','b','MarkerEdgeColor','k');
errorbar(x(3:4),Empirical_Bar_Angle_values(1,[2 4])...
    ,-Empirical_Bar_Angle_CI_values(1,[2 4]),...
    Empirical_Bar_Angle_CI_values(1,[2 4]),'b','LineWidth',2);
plot(x(3:4),Empirical_Bar_Angle_values(1,[2 4]),...
    'sb','MarkerSize',10,'MarkerFaceColor','b','MarkerEdgeColor','k');


plot(x2(1:2),Average_of_All_Models(2,[1 3]),...
    'og','MarkerSize',10,'MarkerFaceColor','g','MarkerEdgeColor','k');
plot(x2(3:4),Average_of_All_Models(2,[2 4]),...
    'og','MarkerSize',10,'MarkerFaceColor','g','MarkerEdgeColor','k');
errorbar(x(1:2),Empirical_Bar_Angle_values(2,[1 3]),...
    -Empirical_Bar_Angle_CI_values(2,[1 3]),...
    Empirical_Bar_Angle_CI_values(2,[1 3]),'g','LineWidth',2);
plot(x(1:2),Empirical_Bar_Angle_values(2,[1 3]),...
    'sg','MarkerSize',10,'MarkerFaceColor','g','MarkerEdgeColor','k');
errorbar(x(3:4),Empirical_Bar_Angle_values(2,[2 4]),...
    -Empirical_Bar_Angle_CI_values(2,[2 4]),...
    Empirical_Bar_Angle_CI_values(2,[2 4]),'g','LineWidth',2);
plot(x(3:4),Empirical_Bar_Angle_values(2,[2 4]),...
    'sg','MarkerSize',10,'MarkerFaceColor','g','MarkerEdgeColor','k');


plot(x2(1:2),Average_of_All_Models(3,[1 3]),...
    'or','MarkerSize',10,'MarkerFaceColor','r','MarkerEdgeColor','k');
plot(x2(3:4),Average_of_All_Models(3,[2 4]),...
    'or','MarkerSize',10,'MarkerFaceColor','r','MarkerEdgeColor','k');
errorbar(x(1:2),Empirical_Bar_Angle_values(3,[1 3]),...
    -Empirical_Bar_Angle_CI_values(3,[1 3]),...
    Empirical_Bar_Angle_CI_values(3,[1 3]),'r','LineWidth',2);
plot(x(1:2),Empirical_Bar_Angle_values(3,[1 3]),...
    'sr','MarkerSize',10,'MarkerFaceColor','r','MarkerEdgeColor','k');
errorbar(x(3:4),Empirical_Bar_Angle_values(3,[2 4]),...
```

```
    -Empirical_Bar_Angle_CI_values(3,[2 4]),...
    Empirical_Bar_Angle_CI_values(3,[2 4]),'r','LineWidth',2);
plot(x(3:4),Empirical_Bar_Angle_values(3,[2 4]),...
'sr','MarkerSize',10,'MarkerFaceColor','r','MarkerEdgeColor','k');
errorbar(x2(1:2),Average_of_All_Models(1,[1 3]),Model_CI (1,[1 3],1),...
    Model_CI (1,[1 3],2),'k','LineWidth',1,'MarkerEdgeColor','k');
errorbar(x2(3:4),Average_of_All_Models(1,[2 4]),Model_CI (1,[2 4],1),...
    Model_CI (1,[2 4],2),'k','LineWidth',1,'MarkerEdgeColor','k');
errorbar(x2(1:2),Average_of_All_Models(3,[1 3]),Model_CI (3,[1 3],1),...
    Model_CI (3,[1 3],2),'k','LineWidth',1,'MarkerEdgeColor','k');
errorbar(x2(3:4),Average_of_All_Models(3,[2 4]),Model_CI (3,[2 4],1),...
    Model_CI (3,[2 4],2),'k','LineWidth',1,'MarkerEdgeColor','k');
errorbar(x2(3:4),Average_of_All_Models(2,[2 4]),Model_CI (2,[2 4],1),...
    Model_CI (2,[2 4],2),'k','LineWidth',1,'MarkerEdgeColor','k');
errorbar(x2(1:2),Average_of_All_Models(2,[1 3]),Model_CI (2,[1 3],1),...
    Model_CI (2,[1 3],2),'k','LineWidth',1,'MarkerEdgeColor','k');
```

---------- Figure 5 Upper ----------

```
    MaxLike = @(Vision,Visionstd,Vestibular,Vestibularstd, Uns)...
        (((Vision./Visionstd.^2) + (Vestibular./Vestibularstd.^2)) ./...
        ((Uns./Visionstd.^2) + (Uns./Vestibularstd.^2)));
% If you have just run the Run_CI_model cell above the line above is unecessary
    X = -100:0.5:100;
    Vestib_Mode = 0;
    Vestib_std_Young = DATA.Reported_Measures_Model_Parameters_Stats(3,1);
    Vestib_std_Aged = DATA.Reported_Measures_Model_Parameters_Stats(2,1);
    Vestib_std_SCA = DATA.Reported_Measures_Model_Parameters_Stats(1,1);
    Vision_std_Coh = DATA.Reported_Measures_Model_Parameters_Stats(7,1);
    Vision_std_Noisy = DATA.Reported_Measures_Model_Parameters_Stats(6,1);
    Vision_16deg = DATA.Reported_Measures_Model_Parameters_Stats(5,1);
    Vision_4deg = DATA.Reported_Measures_Model_Parameters_Stats(4,1);
    Uns = 1;

    Upper_Y_Lim = 0.077;

figure
        % SCA 4deg/s Noisy
    VESTIB = normpdf(X,Vestib_Mode,Vestib_std_SCA);
    VISION = normpdf(X,Vision_4deg,Vision_std_Noisy);
    ML(1,1) = MaxLike(Vision_4deg,Vision_std_Noisy,...
        Vestib_Mode,Vestib_std_SCA, Uns);
    ML_stdev = sqrt(1/((1/Vision_std_Noisy^2)+(1/Vestib_std_SCA^2)));
    ML_pdf = normpdf(X,ML(1,1),ML_stdev);
    subplot(3,4,1);plot(X,VESTIB,'-.b');
    xlim([-50 100]);ylim([0 Upper_Y_Lim]);
        hold on;plot(X,VISION,'--b');xlim([-50 100]);
        hold on;plot(X,ML_pdf,'k');xlim([-50 100]);
        box 'off';set(gca,'TickDir','out');
```

```
        % Aged 4deg/s Noisy
    VESTIB = normpdf(X,Vestib_Mode,Vestib_std_Aged);
    VISION = normpdf(X,Vision_4deg,Vision_std_Noisy);
    ML(2,1) = MaxLike(Vision_4deg,Vision_std_Noisy,...
        Vestib_Mode,Vestib_std_Aged, Uns);
    ML_stdev = sqrt(1/((1/Vision_std_Noisy^2)+(1/Vestib_std_Aged^2)));
    ML_pdf = normpdf(X,ML(2,1),ML_stdev);
    subplot(3,4,5);plot(X,VESTIB,'-.g');
    xlim([-50 100]);ylim([0 Upper_Y_Lim]);
        hold on;plot(X,VISION,'--g');xlim([-50 100]);
        hold on;plot(X,ML_pdf,'k');
        xlim([-50 100]);box 'off';set(gca,'TickDir','out');

         % Young 4deg/s Noisy
    VESTIB = normpdf(X,Vestib_Mode,Vestib_std_Young);
    VISION = normpdf(X,Vision_4deg,Vision_std_Noisy);
    ML(3,1) = MaxLike(Vision_4deg,Vision_std_Noisy,...
        Vestib_Mode,Vestib_std_Young, Uns);
    ML_stdev = sqrt(1/((1/Vision_std_Noisy^2)+(1/Vestib_std_Young^2)));
    ML_pdf = normpdf(X,ML(3,1),ML_stdev);
    subplot(3,4,9);plot(X,VESTIB,'-.r');
    xlim([-50 100]);ylim([0 Upper_Y_Lim]);
        hold on;plot(X,VISION,'--r');xlim([-50 100]);
        hold on;plot(X,ML_pdf,'k');xlim([-50 100]);
        box 'off';set(gca,'TickDir','out');

%-------------------------------------------------------------------

        % SCA 16deg/s Noisy
    VESTIB = normpdf(X,Vestib_Mode,Vestib_std_SCA);
    VISION = normpdf(X,Vision_16deg,Vision_std_Noisy);
    ML(1,3) = MaxLike(Vision_16deg,Vision_std_Noisy,...
        Vestib_Mode,Vestib_std_SCA, Uns);
    ML_stdev = sqrt(1/((1/Vision_std_Noisy^2)+(1/Vestib_std_SCA^2)));
    ML_pdf = normpdf(X,ML(1,3),ML_stdev);
    subplot(3,4,2);plot(X,VESTIB,'-.b');
    xlim([-50 100]);ylim([0 Upper_Y_Lim]);
        hold on;plot(X,VISION,'--b');xlim([-50 100]);
        hold on;plot(X,ML_pdf,'k');
        xlim([-50 100]);box 'off';set(gca,'TickDir','out');

        % Aged 16deg/s Noisy
    VESTIB = normpdf(X,Vestib_Mode,Vestib_std_Aged);
    VISION = normpdf(X,Vision_16deg,Vision_std_Noisy);
    ML(2,3) = MaxLike(Vision_16deg,Vision_std_Noisy,...
        Vestib_Mode,Vestib_std_Aged, Uns);
    ML_stdev = sqrt(1/((1/Vision_std_Noisy^2)+(1/Vestib_std_Aged^2)));
    ML_pdf = normpdf(X,ML(2,3),ML_stdev);
    subplot(3,4,6);plot(X,VESTIB,'-.g');
    xlim([-50 100]);ylim([0 Upper_Y_Lim]);
```

```
        hold on;plot(X,VISION,'--g');xlim([-50 100]);
        hold on;plot(X,ML_pdf,'k');
        xlim([-50 100]);box 'off';set(gca,'TickDir','out');

         % Young 16deg/s Noisy
    VESTIB = normpdf(X,Vestib_Mode,Vestib_std_Young);
    VISION = normpdf(X,Vision_16deg,Vision_std_Noisy);
    ML(3,3) = MaxLike(Vision_16deg,Vision_std_Noisy,...
        Vestib_Mode,Vestib_std_Young, Uns);
    ML_stdev = sqrt(1/((1/Vision_std_Noisy^2)+(1/Vestib_std_Young^2)));
    ML_pdf = normpdf(X,ML(3,3),ML_stdev);
    subplot(3,4,10);plot(X,VESTIB,'-.r');
    xlim([-50 100]);ylim([0 Upper_Y_Lim]);
        hold on;plot(X,VISION,'--r');xlim([-50 100]);
        hold on;plot(X,ML_pdf,'k');
        xlim([-50 100]);box 'off';set(gca,'TickDir','out');

%-------------------------------------------------------------------------
        % SCA 4deg/s
    VESTIB = normpdf(X,Vestib_Mode,Vestib_std_SCA);
    VISION = normpdf(X,Vision_4deg,Vision_std_Coh);
    ML(1,2) = MaxLike(Vision_4deg,Vision_std_Coh,...
        Vestib_Mode,Vestib_std_SCA, Uns);
    ML_stdev = sqrt(1/((1/Vision_std_Coh^2)+(1/Vestib_std_SCA^2)));
    ML_pdf = normpdf(X,ML(1,2),ML_stdev);
    subplot(3,4,3);plot(X,VESTIB,'-.b');
    xlim([-50 100]);ylim([0 Upper_Y_Lim]);
        hold on;plot(X,VISION,'--b');xlim([-50 100]);
        hold on;plot(X,ML_pdf,'k');
        xlim([-50 100]);box 'off';set(gca,'TickDir','out');

        % Aged 4deg/s
    VESTIB = normpdf(X,Vestib_Mode,Vestib_std_Aged);
    VISION = normpdf(X,Vision_4deg,Vision_std_Coh);
    ML(2,2) = MaxLike(Vision_4deg,Vision_std_Coh,...
        Vestib_Mode,Vestib_std_Aged, Uns);
    ML_stdev = sqrt(1/((1/Vision_std_Coh^2)+(1/Vestib_std_Aged^2)));
    ML_pdf = normpdf(X,ML(2,2),ML_stdev);
    subplot(3,4,7);plot(X,VESTIB,'-.g');
    xlim([-50 100]);ylim([0 Upper_Y_Lim]);
        hold on;plot(X,VISION,'--g');xlim([-50 100]);
        hold on;plot(X,ML_pdf,'k');
        xlim([-50 100]);box 'off';set(gca,'TickDir','out');

         % Young 4deg/s
    VESTIB = normpdf(X,Vestib_Mode,Vestib_std_Young);
    VISION = normpdf(X,Vision_4deg,Vision_std_Coh);
    ML(3,2) = MaxLike(Vision_4deg,Vision_std_Coh,...
        Vestib_Mode,Vestib_std_Young, Uns);
    ML_stdev = sqrt(1/((1/Vision_std_Coh^2)+(1/Vestib_std_Young^2)));
    ML_pdf = normpdf(X,ML(3,2),ML_stdev);
    subplot(3,4,11);plot(X,VESTIB,'-.r');
    xlim([-50 100]);ylim([0 Upper_Y_Lim]);
        hold on;plot(X,VISION,'--r');xlim([-50 100]);
```

```
        hold on;plot(X,ML_pdf,'k');
        xlim([-50 100]);box 'off';set(gca,'TickDir','out');

%-------------------------------------------------------------------------
        % SCA 16deg/s
    VESTIB = normpdf(X,Vestib_Mode,Vestib_std_SCA);
    VISION = normpdf(X,Vision_16deg,Vision_std_Coh);
    ML(1,4) = MaxLike(Vision_16deg,Vision_std_Coh,...
        Vestib_Mode,Vestib_std_SCA, Uns);
    ML_stdev = sqrt(1/((1/Vision_std_Coh^2)+(1/Vestib_std_SCA^2)));
    ML_pdf = normpdf(X,ML(1,4),ML_stdev);
    subplot(3,4,4);plot(X,VESTIB,'-.b');
    xlim([-50 100]);ylim([0 Upper_Y_Lim]);
        hold on;plot(X,VISION,'--b');xlim([-50 100]);
        hold on;plot(X,ML_pdf,'k');
        xlim([-50 100]);box 'off';set(gca,'TickDir','out');

        % Aged 16deg/s
    VESTIB = normpdf(X,Vestib_Mode,Vestib_std_Aged);
    VISION = normpdf(X,Vision_16deg,Vision_std_Coh);
    ML(2,4) = MaxLike(Vision_16deg,Vision_std_Coh,...
        Vestib_Mode,Vestib_std_Aged, Uns);
    ML_stdev = sqrt(1/((1/Vision_std_Coh^2)+(1/Vestib_std_Aged^2)));
    ML_pdf = normpdf(X,ML(2,4),ML_stdev);
    subplot(3,4,8);plot(X,VESTIB,'-.g');
    xlim([-50 100]);ylim([0 Upper_Y_Lim]);
        hold on;plot(X,VISION,'--g');xlim([-50 100]);
        hold on;plot(X,ML_pdf,'k');
        xlim([-50 100]);box 'off';set(gca,'TickDir','out');

         % Young 16deg/s
    VESTIB = normpdf(X,Vestib_Mode,Vestib_std_Young);
    VISION = normpdf(X,Vision_16deg,Vision_std_Coh);
    ML(3,4) = MaxLike(Vision_16deg,Vision_std_Coh,...
        Vestib_Mode,Vestib_std_Young, Uns);
    ML_stdev = sqrt(1/((1/Vision_std_Coh^2)+(1/Vestib_std_Young^2)));
    ML_pdf = normpdf(X,ML(3,4),ML_stdev);
    subplot(3,4,12);plot(X,VESTIB,'-.r');
    xlim([-50 100]);ylim([0 Upper_Y_Lim]);
        hold on;plot(X,VISION,'--r');xlim([-50 100]);
        hold on;plot(X,ML_pdf,'k');
        xlim([-50 100]);box 'off';set(gca,'TickDir','out');

end
```

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Multilevel Mixed Effects Model and Figure 4 From: Cerebellar degeneration increases visual influence on dynamic estimates of verticality

Derived from the Statistical Consulting Studios model

Sept 1 2018

```
library("tidyverse")    # Loads the CORE packages
library("magrittr")     # More pipe operators to code

# get data into R
library("readxl")       # Import excel files (xls, xlsx)

# plots: exploratory, results, and residuals
library("gpairs")       # generalized pairs plots
library("GGally")       # extends ggplot2, speciallized plots
library("gridExtra")    # place ggplots together as one plot

# display result tables
library("car")          # Companion to Applied Regression
library("stargazer")    # Display nice tables: summary & regression
library("pander")       # create HTML tables

# fit multilevel models, and work with output
library("lme4")         # Linear, generalized linear, & nonlinear mixed models
library("effects")
library("merTools")
library("emmeans")
library("modelr")

panderOptions('digits', 2)
panderOptions('round', 2)
panderOptions('keep.trailing.zeros', TRUE)
```

```
# Time in this script refers to trial in the manuscript
raw <- read_excel("All Data.xlsx",
                  sheet = 1,
                  col_type = rep("numeric", times = 5)) %>%
  mutate(ID = (Group*100 + Sub) %>% factor) %>%
  mutate(Noise = ifelse(Cond %in% c(1, 3), 1, 0) %>%
           factor(levels = 0:1,
                  labels = c("No", "Yes"))) %>%
  mutate(Velocity = ifelse(Cond %in% c(3, 4), 1, 0) %>%
           factor(levels = 0:1,
                  labels = c("Low", "High"))) %>%
  mutate(Group = Group %>% factor(levels = 1:3,
                                  labels = c("Young", "Aged", "SCA"))) %>%
  mutate(Trial = Time %>% factor(levels = 1:8,
                                  labels = c("1", "2", "3","4", "5", "6", "7", "8")))%>%
  mutate(Sub = Sub %>% factor) %>%
```

```
  mutate(Conditions = Cond %>% factor) %>%
  dplyr::select(ID, Conditions, Group, Time, Trial, Noise, Velocity, Angle) %>%
  data.frame

raw <- raw[-402,]# remove the outlier
```

```
# Likelihood ratio tests comparing incresingly complex models
model1 <- lmer(Angle ~ 1 + (Time | ID /Conditions),
               data = raw,
               REML = FALSE)

model2 <- lmer(Angle ~ Velocity*Group + (Time | ID /Conditions),
               data = raw,
               REML = FALSE)
anova(model1, model2)

model3 <- lmer(Angle ~ Velocity*Group  + Noise*Velocity + (Time | ID /Conditions),
               data = raw,
               REML = FALSE)
anova(model2, model3)

model4 <- lmer(Angle ~  Velocity*Group  + Noise*Velocity + Noise*Group
               + (Time | ID /Conditions),
               data = raw,
               REML = FALSE)
anova(model3, model4)

model5 <- lmer(Angle ~  Velocity*Group  + Noise*Velocity + Time*Group
               + Noise*Group +
                 (Time | ID /Conditions),
               data = raw,
               REML = FALSE)
anova(model4, model5)

model6 <- lmer(Angle ~  Velocity*Group  + Noise*Velocity + Time*Group
               + Noise*Group + Time*Noise + (Time | ID /Conditions),
               data = raw,
               REML = FALSE)
anova(model5, model6)

model7 <- lmer(Angle ~  Velocity*Group  + Noise*Velocity + Time*Group
               + Noise*Group + Time*Noise + Time*Velocity + (Time | ID /Conditions),
               data = raw,
               REML = FALSE)
anova(model6, model7)
```

```
# Will take some time to run

# Figure 4 in the Paper, Colors, line segmentation, line weight and errorbar widths (not heights) were
# Bootstrap confidence intervals for the model depicted in Figure 4
# Depending on the data drawn for the bootstrap there may be some fitting attemps that fail to converge

## Creating bootstrapped samples
raw_boot <- purrr::map(1:10000, ~resample_bootstrap(raw))
```

```
## Running model7 for each bootstrapped sample
raw_boot2 <- raw_boot %>%
  purrr::map(~lmer(Angle ~  Velocity*Group  + Noise*Velocity + Time*Group
                   + Noise*Group + Time*Noise + Time*Velocity + (Time | ID /Conditions),
                 data = .x,
                 REML = FALSE))

## Obtaining the predicted values of Angle for each bootstrapped sample
## and binding them into a single data.frame
confint_data <- purrr::map2(raw_boot2, 1:length(raw_boot2), ~{
  .x@frame$pred <- predict(.x)
  .x@frame$boot <- .y
  data.frame(.x@frame)
  }) %>%
  do.call("rbind", .)


confint_data %>%
  ## group by these to get the average prediction per bootstrapped sample
  group_by(Velocity, Group, Noise, Time, Conditions, boot) %>%
  summarize(pred = mean(pred)) %>%
  ## group by these to get the average prediction
  group_by(Velocity, Group, Noise, Time, Conditions) %>%
  ## and CI's across bootstrapped samples
  summarize(mean_pred = mean(pred),
            pred95 = quantile(pred, .975),
            pred05 = quantile(pred, .025),
            pred68 = quantile(pred, .84),
            pred32 = quantile(pred, .16)) %>%
    ggplot(aes(x = Time,
               y = mean_pred,
               color = Group,
               fill  = Group,
               group = Group)) +
    geom_line() +
    geom_ribbon(aes(ymin = pred05,
                    ymax = pred95),
                alpha = .2, color = NA) +
    geom_ribbon(aes(ymin = pred68,
                    ymax = pred32),
                alpha = .2, color = NA) +
    facet_grid(Noise ~ Velocity, labeller = "label_both") +
  theme_bw() +
  theme(legend.key.width = unit(1, "cm")) +
  scale_linetype_manual(values = c("solid", "longdash", "dotted")) +
  labs(x = "Observation", y = "Predicted") +
  stat_summary(aes(x = Time, y = Angle, color = Group),
               #errorbars 2 stdev
               data = raw, fun.data = "mean_cl_normal", size = 0.5, geom = "errorbar") +
  stat_summary(aes(x = Time, y = Angle, color = Group),
               data = raw, fun.data = "mean_cl_normal", size = 0.5)
```

```r
# Bonferroni corrected comparisons used in table 2

#Compare Groups
model7 %>%
  emmeans::emmeans( ~ Group, lmer.df='satterthwaite') %>%
  pairs(adjust = "none") %>%
  data.frame() %>%
  dplyr::mutate(p.value     = round(p.value,    6),  # unadjusted
                p.value_adj = round(p.value*19, 6))
```

```r
#Velocity by group comparison
model7 %>%
  emmeans::emmeans( ~ Velocity|Group, lmer.df='satterthwaite') %>%
  pairs(adjust = "none") %>%
  data.frame() %>%
  dplyr::mutate(p.value     = round(p.value,    6),  # unadjusted
                p.value_adj = round(p.value*19, 6))
```

```r
# Velocity by Group interaction
model7 %>%
  emmeans::emmeans( ~ Group*Velocity|Group, lmer.df='satterthwaite') %>%
  pairs(adjust = "none", interaction = "pairwise") %>%
  data.frame() %>%
  dplyr::mutate(p.value     = round(p.value,    6),  # unadjusted
                p.value_adj = round(p.value*19, 6))
```

```r
#Noise Within each group
model7 %>%
  emmeans::emmeans( ~ Noise|Group, lmer.df='satterthwaite') %>%
  pairs(adjust = "none") %>%
  data.frame() %>%
  dplyr::mutate(p.value     = round(p.value,    6),  # unadjusted
                p.value_adj = round(p.value*19, 6))
```

```r
# Noise by Group interaction

model7 %>%
  emmeans::emmeans( ~ Noise*Group|Group, lmer.df='satterthwaite') %>%
  pairs(adjust = "none", interaction = "pairwise") %>%
  data.frame() %>%
  dplyr::mutate(p.value     = round(p.value,    6),  # unadjusted
                p.value_adj = round(p.value*19, 6))
```

```r
#Noise by Velocity Interaction

model7 %>%
  emmeans::emmeans( ~ Velocity*Noise, lmer.df='satterthwaite') %>%
  pairs(adjust = "none", interaction = "pairwise") %>%
  data.frame() %>%
  dplyr::mutate(p.value     = round(p.value,    6),  # unadjusted
                p.value_adj = round(p.value*19, 6))
```

```r
#Effect of Time compared between Groups
model7 %>%
  emtrends(~Group, var = "Time", lmer.df='satterthwaite') %>%
```

```
  pairs(adjust = "none") %>%
  data.frame() %>%
  dplyr::mutate(p.value     = round(p.value,    6),  # unadjusted
                p.value_adj = round(p.value*19, 6))
```

```
# Effect of group at Time 1
model7 %>%
  emmeans::emmeans(~ Group, at = list(Time = 1), lmer.df='satterthwaite') %>%
  pairs(adjust = "None") %>%
  data.frame() %>%
  dplyr::mutate(p.value     = round(p.value,    6),  # unadjusted
                p.value_adj = round(p.value*3, 6))
```