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Predicting Conflict Errors: Integrating Convolutional Neural Networks and Whole-Brain Modeling of Preparatory Electrophysiological Activity

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Cognitive control refers to humans' ability to regulate, coordinate, and sequence their thoughts and activities in accordance with their behavioral goals. Despite extensive research in the last two decades, the underlying mechanisms of cognitive control in humans are still not fully understood. The neural activity is often difficult to interpret, and the precise mechanisms by which they contribute to cognitive control remained unclear. This could imply that the commonly used analysis methods that are agnostic to theoretical neural-mass dynamics are incapable of fully elucidating the complex dynamics of cognitive control. In this study, a convolutional neural network is utilized to interpret both empirical and theoretical data as part of a multi-modal computational framework that we are building. According to our findings, the insula and angular cortices have the highest predictive value for conflict-error. Yet the whole-brain model only supported the stimulation of the angular gyrus for enhancing cognitive control.


```
restoredefaultpath % reset matlab path
addpath('C:\MatlabToolboxes\fieldtrip-master\fieldtrip-master')
ft_defaults()
```

```
-------------------------------------------------------------------------------------------
FieldTrip is developed by members and collaborators of the Donders Institute for Brain,
Cognition and Behaviour at Radboud University, Nijmegen, the Netherlands.

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Please cite the FieldTrip reference paper when you have used FieldTrip in your study.
Robert Oostenveld, Pascal Fries, Eric Maris, and Jan-Mathijs Schoffelen. FieldTrip: Open
Source Software for Advanced Analysis of MEG, EEG, and Invasive Electrophysiological Data.
Computational Intelligence and Neuroscience, vol. 2011, Article ID 156869, 9 pages, 2011.
doi:10.1155/2011/156869.
-------------------------------------------------------------------------------------------
```

```
addpath(genpath(pwd))
```

Behavioral Data

Database1:

```
BHV = report_behvaior_dataset1();
```

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variables. Those variables are extended with rows containing default values.
total number of individuals: 35
number of Hit : 204.17 +/- 15.01
mean rt of Hit : 726.45 +/- 54.70
number of Error : 21.11 +/- 13.32
mean rt of Error : 715.15 +/- 95.15
```

Localizeing time and spcae using CNN

The data from the python scripts are stored in matlab object for further postprocessing and visualizetion

```
% clear memory and load the data object
clc
clear all
disp('loading CNN data')
```

```
loading CNN data
```

```
load data\interp\matlab\CNNData.mat
disp('done!')
```

```
done!
```

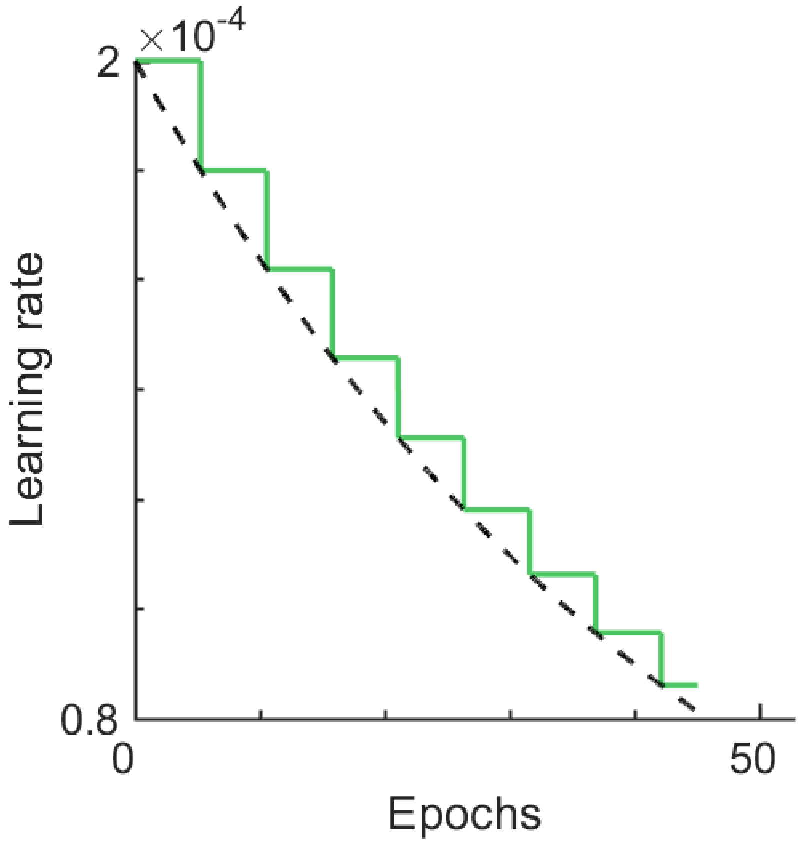
Step 1) displaying the accuracy for traning, cross validation and testing

```
Data.whats_acc
```

```
training : 66.7
cross-val : 64.2
testing : 64.3
```

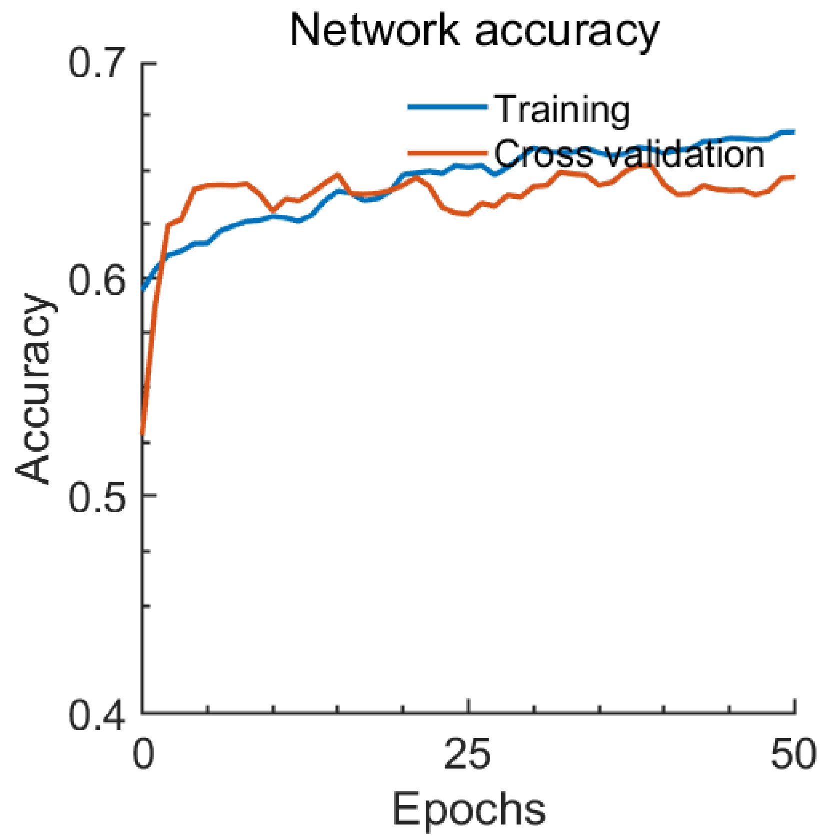
Step 2) learning rate

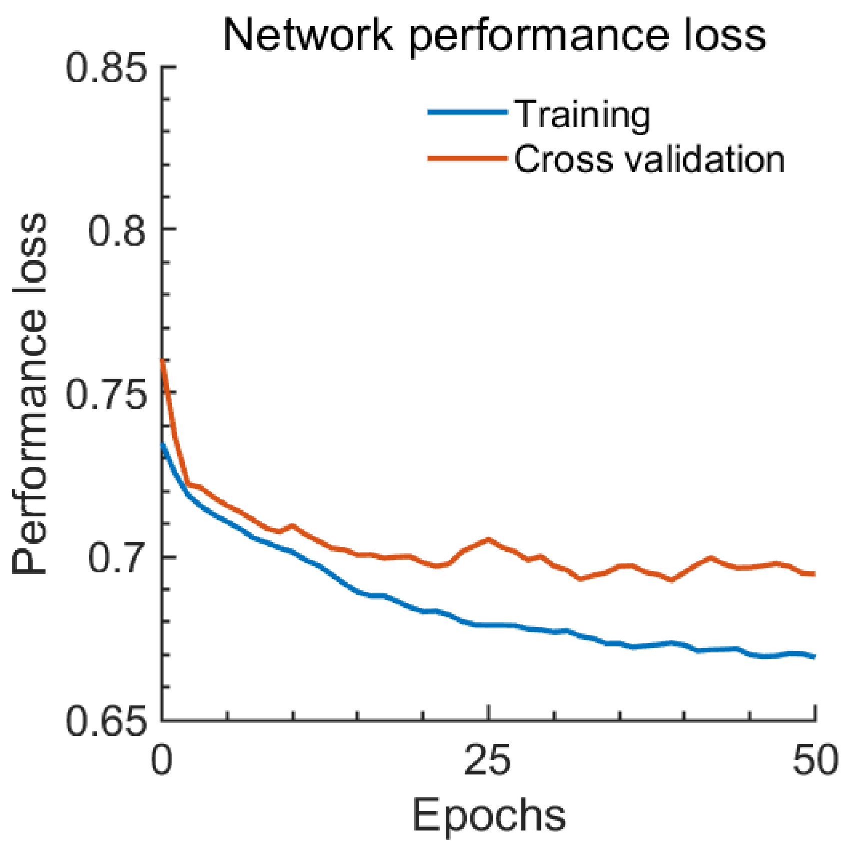
```
Data.plot_learning_rate(45, 2e-4, .90, 1000, 16)
```



Step 3) plotting the learning curve to show the training and cross validation the accuracy and the performance loss function

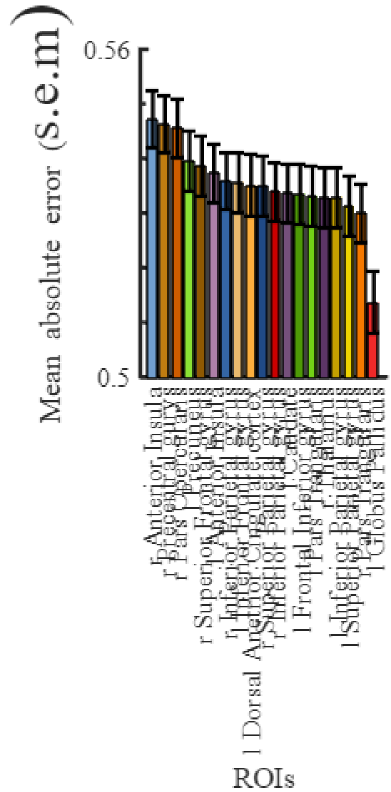
```
Data.plot_learning_loss
```


Network accuracy
0.7
0.6
0.5
0.4
Accuracy
0
25
50
Epochs
Training
Cross validation


Network performance loss
0.85
0.8
0.75
0.7
0.65
Performance loss
0
25
50
Epochs
Training
Cross validation

Step 4) dispalying mean activation error per channel for class **conflict error**

```
[m,s, ix] = Data.plot_MAE_chan([.50,.56],[.75 1 1], 1);
```



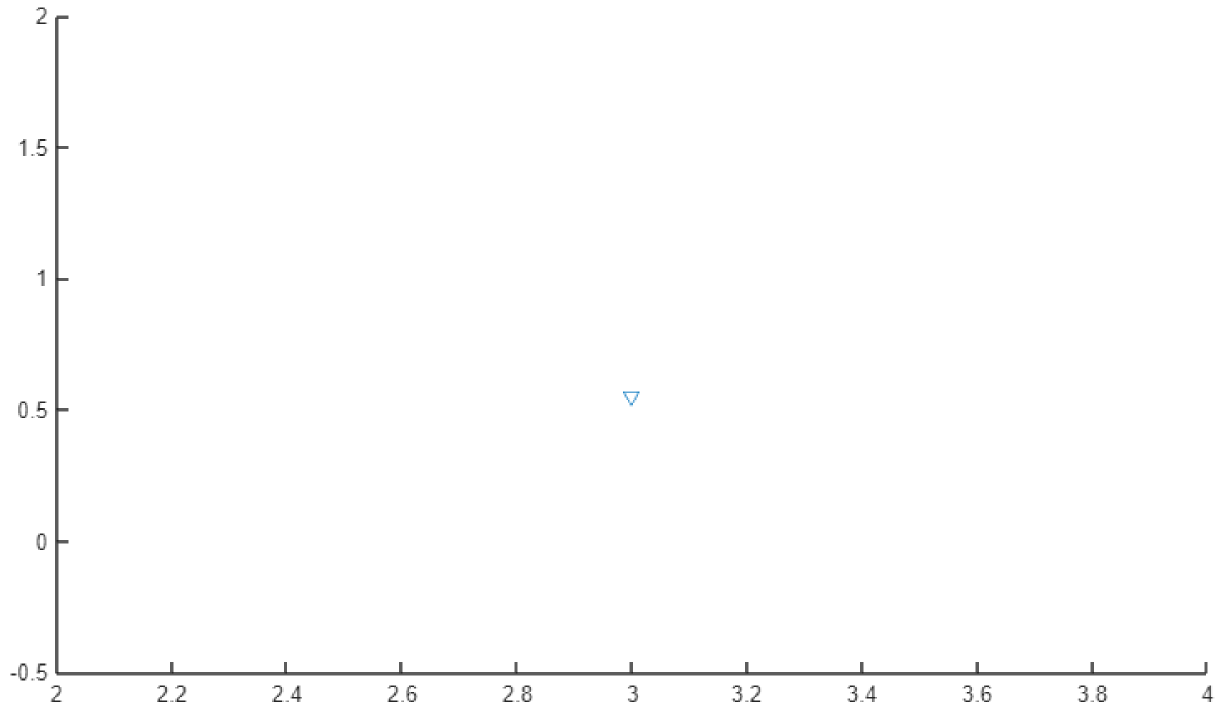

```
m = flipud(m); % decending
s = flipud(s); % decending
save('OrderMAE.mat', 'ix');
```

Step 5) find the explanability knee

```
window_size = 3;
knee= find_knee(m, window_size)
```

```
knee = 3
```

```
scatter(knee, m(knee)*1.01, 'v')
```




```
% permtation test
% for reproducibility
rng(1)
nrep = 5e3;
iperm = randi(length(Data.MeanAverageError_chan.MAE_AVG(:,1)), 1,nrep);

t = ((1-Data.MeanAverageError_chan.MAE_AVG(:,1)) -...
        nanmean(1-Data.MeanAverageError_chan.MAE_AVG(iperm,1)))...
        ./ (std(1-Data.MeanAverageError_chan.MAE_AVG(iperm,1)));


fprintf('t = %1.2f \n', t(fliplr(ix(end-2:end)')))
```

```
t = 1.73
t = 1.57
t = 1.48
```

```
format long
ci = 0;
for i = fliplr(ix(end-2:end)')
    Data.nodeLabel(i,:)
    ci = ci+1;
    p(ci) = mean(Data.MeanAverageError_chan.MAE_AVG(i,1)>=Data.MeanAverageError_chan.MAE_AVG(ip
    p(ci)
    1-Data.MeanAverageError_chan.MAE_AVG(i,1)
end
```

```
ans = 1×6 table
```

	RegionLabel	Extent	t_value	x	y	z
1	'r Anterior Insula'	2022	6.2551999092...	38	18	2

```
ans =
   0.049200000000000
ans = single
   0.5473534
ans = 1×6 table
```

	RegionLabel	Extent	t_value	x	y	z
1	'r Precentral gurys'	663	5.1622557640...	38	-14	62

```
ans =
   0.099400000000000
ans = single
   0.5462679
ans = 1×6 table
```

	RegionLabel	Extent	t_value	x	y	z
1	'r Pars Opercularis'	2022	6.8682842254...	46	8	28

```
ans =
   0.151600000000000
ans = single
   0.5456350
```

```
fprintf('p = %1.3f', round(p,3))
```

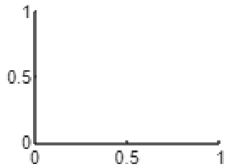
```
p = 0.049p = 0.099p = 0.152
```

Step 5) gradCAM

```
% clf
% s2r = Data.plot_grad_cam(Data, ...
%     'C:\Users\behira\OneDrive - Karolinska Institutet\Desktop\Manuscript\CognitiveControl\scr
%     'C:\Users\behira\OneDrive - Karolinska Institutet\Desktop\Manuscript\CognitiveControl\scr
```

Step 6) displaying the learned filter for each ROI

```
peaks_f = Data.plot_learned_filters(14, fliplr(ix));
```




```
Error using interp1>reshapeAndSortXandV
X and V must be of the same length.

Error in interp1 (line 128)
    [X,V,orig_size_v] = reshapeAndSortXandV(X,V);

Error in CNNdata/plot_learned_filters (line 135)
                AMP = interp1(1:length(pow),smooth(pow, 5, 'sgolay'),...
```

Time course test sample source filtered by CNN

```
[b, p, CI, stat]=Data.apply_filter([9,8]);
close all
col = Data.getColor();
pl(1) = plot(Data.data_incong_hit_err.data.time(1:length(stat{1, 1}.tstat)),  stat{1, 1}.tstat,
hold on
pl(2) = plot(Data.data_incong_hit_err.data.time(1:length(stat{1, 2}.tstat)), stat{1, 2}.tstat,
xlim([-.8,-.6])
box off
xticks(-.8:.1:-.6); yticks(-2.5:2.5:2.5)
set(gca, 'FontName', 'Arial Nova Cond', 'FontSize', 16, 'LineWidth', 2)
ylim([-2.5, 2.5])
yline(tinv(.025, stat{1, 1}.df(1)), 'LineStyle', '--'), yline(tinv(.975, stat{1, 1}.df(1)), 'Li
xlabel('Time(s)')
ylabel('T-value')
```

```
title('Hit > Error')
legend(pl, Data.nodeLabel{[9,8],"RegionLabel"}, 'Box', 'off')
```

The simulated time courses using neural mass model for each stimulation setting Is tested with the trained CNN

```
close all
path = {'data\source\python_simulation\C\'; 'data\source\python_simulation'};
%% Construct result_stimulation object
sine_stimulation_results = results_stimulation(path);
%% Plot the search parameter
sine_stimulation_results.plot_parameters();
print -dsvg figures\DS01\DS01_fitC.svg

xlim([0.0025 0.0273])
ylim([0.045 0.543])
ax = gca;
chart = ax.Children(2);
datatip(chart,0.02066,0.5321);
```

```
sine_stimulation_results.report_stat(5e3);
```

```
%% Plot TCs after in silico stimulation
figure
sine_stimulation_results.plot_stimulatation_inslico_TCs()
```

```
figure('Units','normalized',Position=[0 0 1 1])
sine_stimulation_results.stimulating_three_first_rois(["ROI 12-6"])
pbaspect([.33,1,1])
print -dsvg -vector figures\DS01\DS01_stimulation_heatmap.svg
```

```
ROIS = [ "ROI 9-1","ROI 8-2", "ROI 16-3", "ROI 3-4", "ROI 17-5" "ROI 12-6"...
    "ROI 10-7", "ROI 6-8", "ROI 11-9", "ROI 15-10", "ROI 19-11", "ROI 2-12", "ROI 14-13", "ROI
    "ROI 1-16", "ROI 7-17", "ROI 5-18", "ROI 18-19"];
figure('Units','normalized',Position=[0 0 1 1])
sine_stimulation_results.stimulating_three_first_rois(ROIS)
print -dsvg -vector figures\DS01\DS01_supp_stimulation_heatmap.svg
```

```
[t, p , cirange] = sine_stimulation_results.stimulating_rois_stat(ROIS);
a = linspace(.33,5, 20);
f = linspace(2,200, 20);
[tmax, imx] = max(t,[],'all');
[ind.f,ind.a, ind.roi] = ind2sub(size(t), imx);
fprintf("ROI (%s): t(18) = %1.2f, p = %1.4f @ a= %1.2f f= %1.2f\n", ROIS(ind.roi), t(imx), 2*(
```

```
clf
ax = sine_stimulation_results.implot(t(:,:,ind.roi),[2,4.5]);
pbaspect([.33,1,1])
cb = colorbar();
ylabel(cb, 'T-value')
axis xy
ax.XAxis.Color = 'w'
ax.YAxis.Color = 'w'
print -dsvg -vector figures\DS01\DS01_stimulation_heatmap_stats.svg
```

```
figure
s =sine_stimulation_results.stimulating_traceplot(["ROI 9-1", "ROI 8-2", "ROI 16-3", "ROI 3-4",
    "ROI 10-7", "ROI 6-8", "ROI 11-9", "ROI 15-10", "ROI 19-11", "ROI 2-12", "ROI 14-13", "ROI
    "ROI 1-16", "ROI 7-17", "ROI 5-18", "ROI 18-19"])
print -dsvg -vector figures\DS01\DS01_stimulation_bar.svg
```