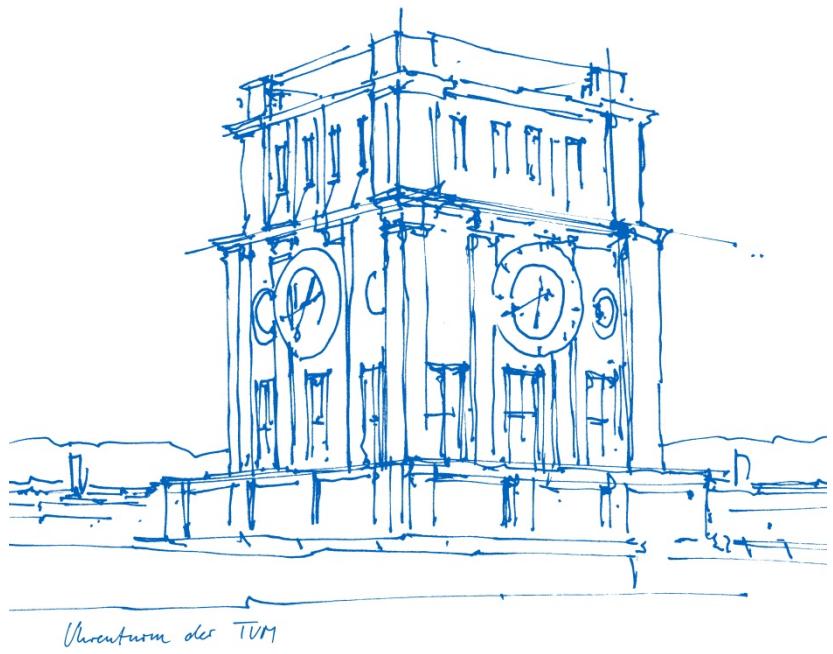


Temporal Data Analysis of EEG Sets

Update

May 25, 2020



Overview

1. Simple Fisher Score (update: all channels, same time window, median)
2. MI & Fisher Score feature heat map (threshold: top 5% quantile)
3. MI & Fisher Score for multivariate analysis?

What is better? Temporal or Spectral?

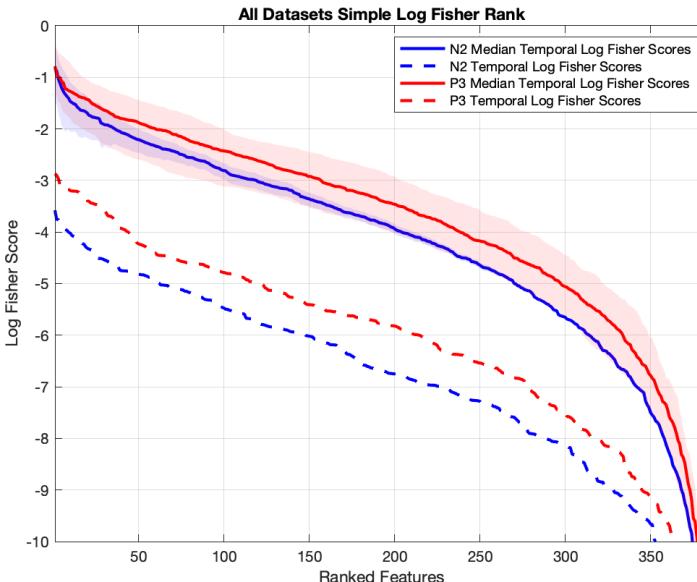
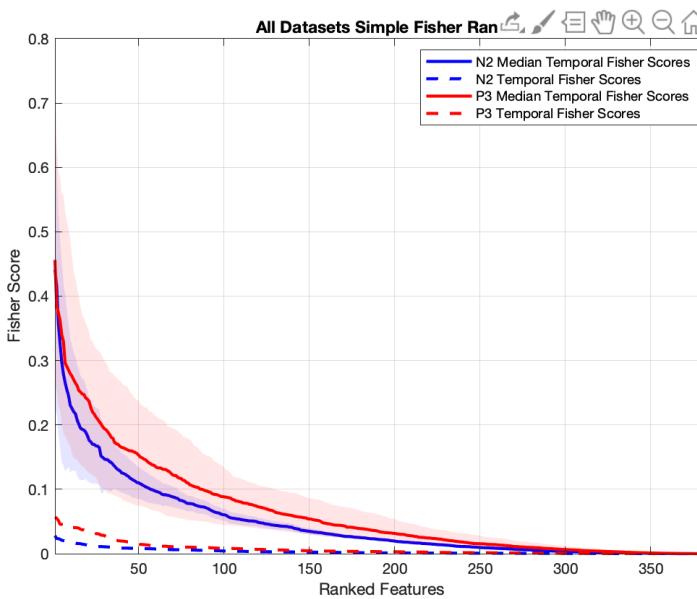
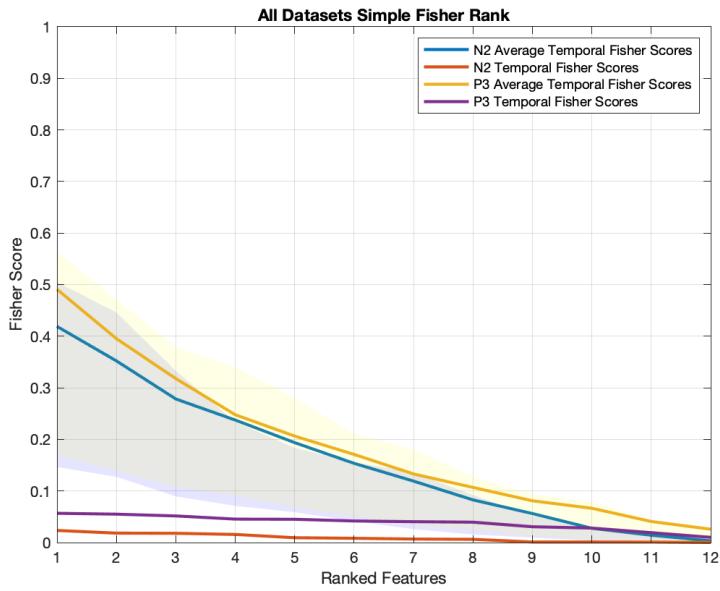
1. All datasets
2. All subjects within dataset
3. One subject

All Subjects – Simple Fisher Rank

N2: 220 - 260ms

P3: 270 – 310ms

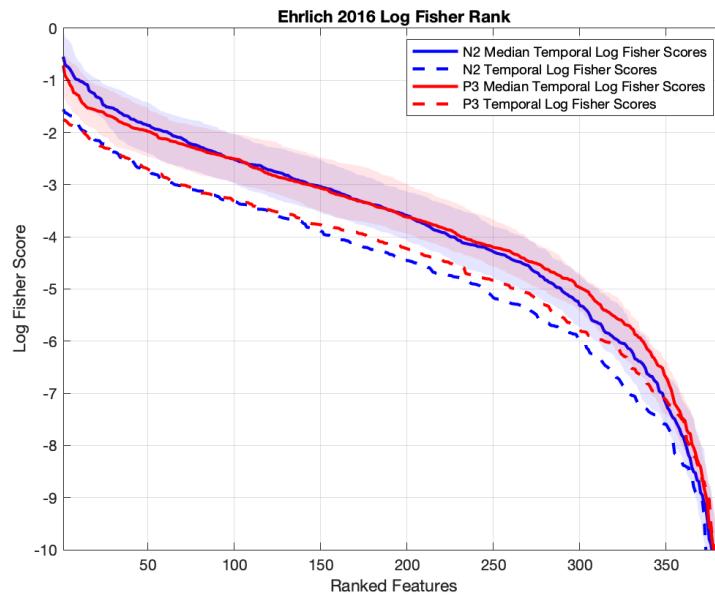
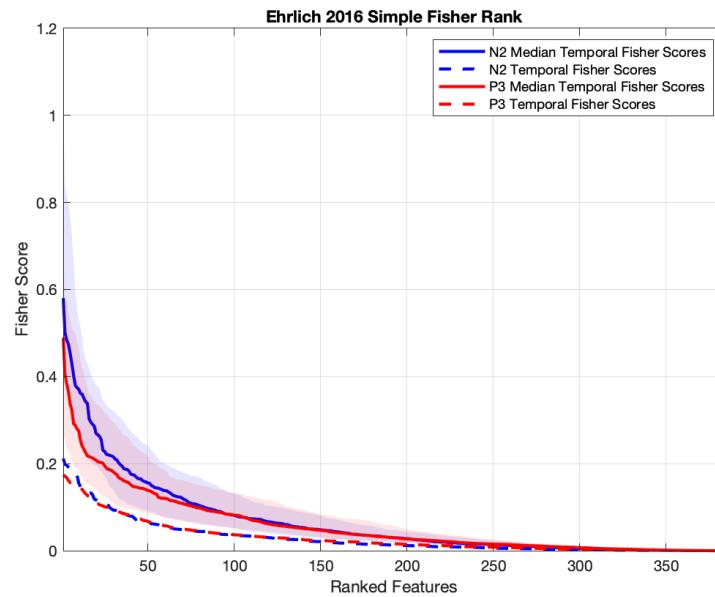
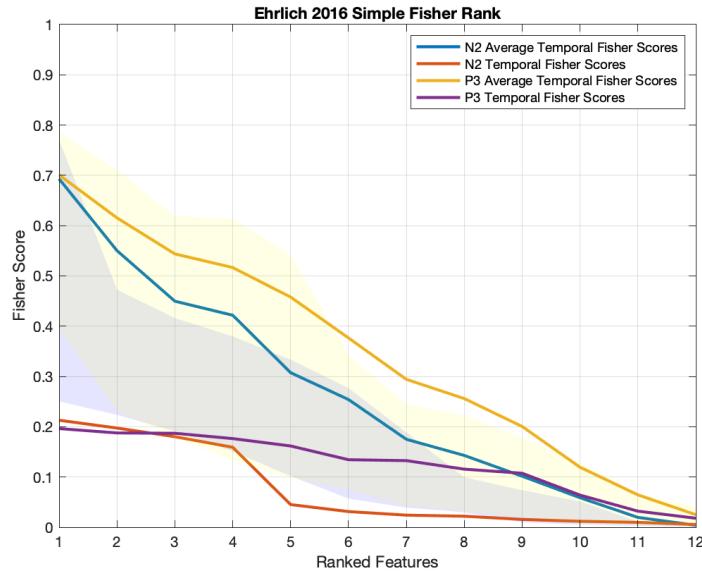
Last time (Cz & FCz, same window)



Ehrlich 2016 – Simple Fisher Rank

N2: 220 - 260ms
P3: 270 – 310ms

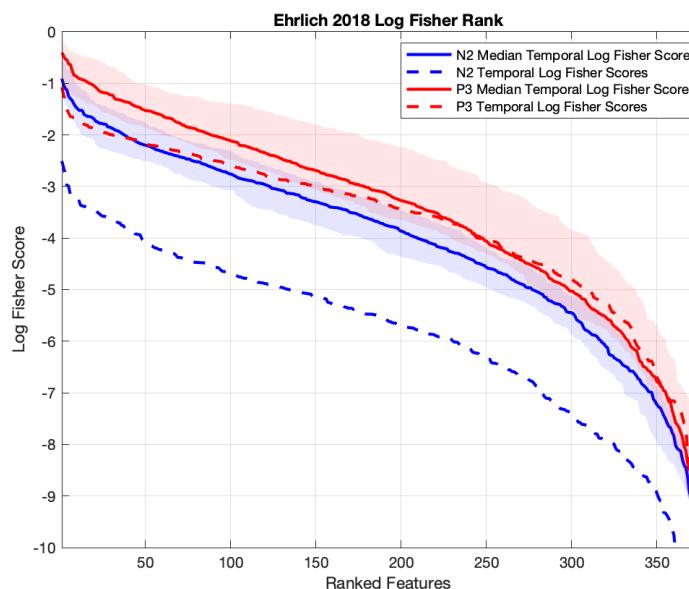
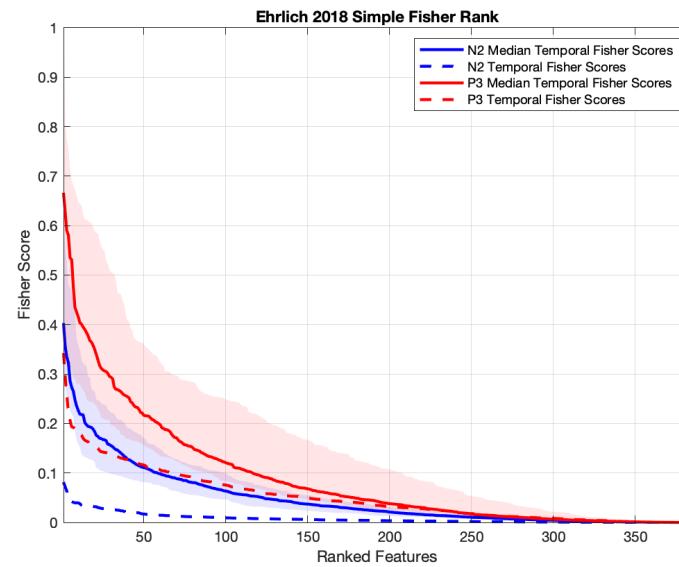
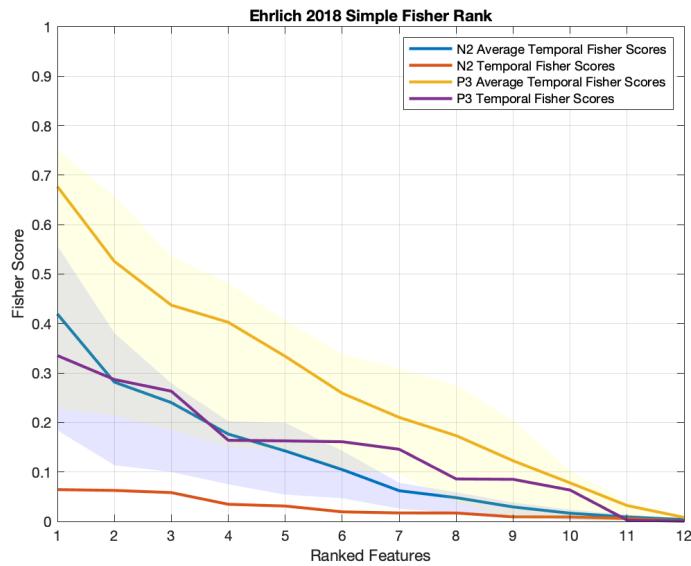
Last time (Cz & FCz), different window



Ehrlich 2018 – Simple Fisher Rank

N2: 220 - 260ms
P3: 270 – 310ms

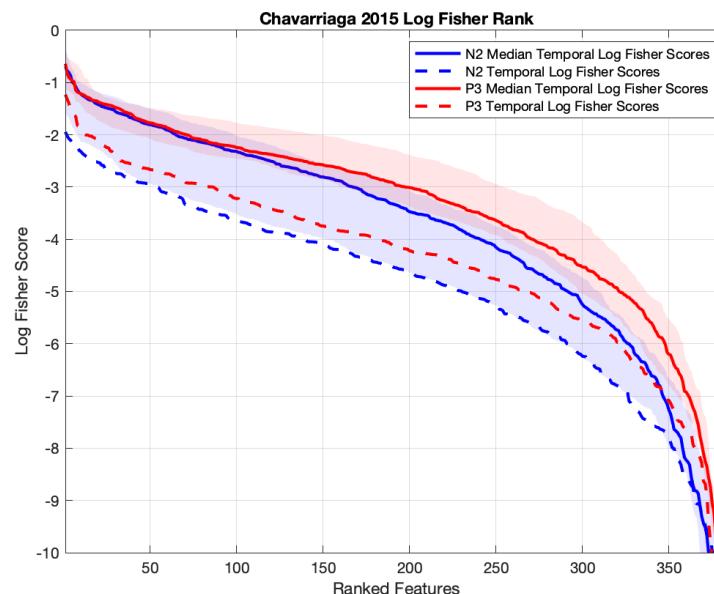
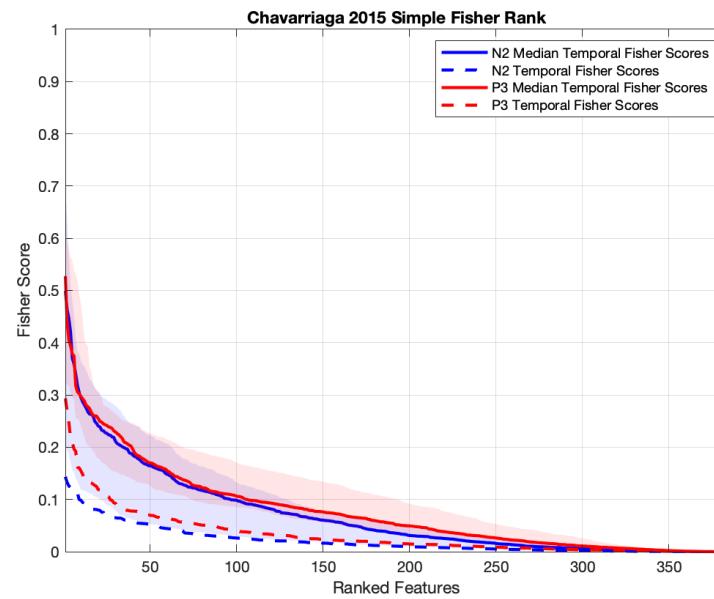
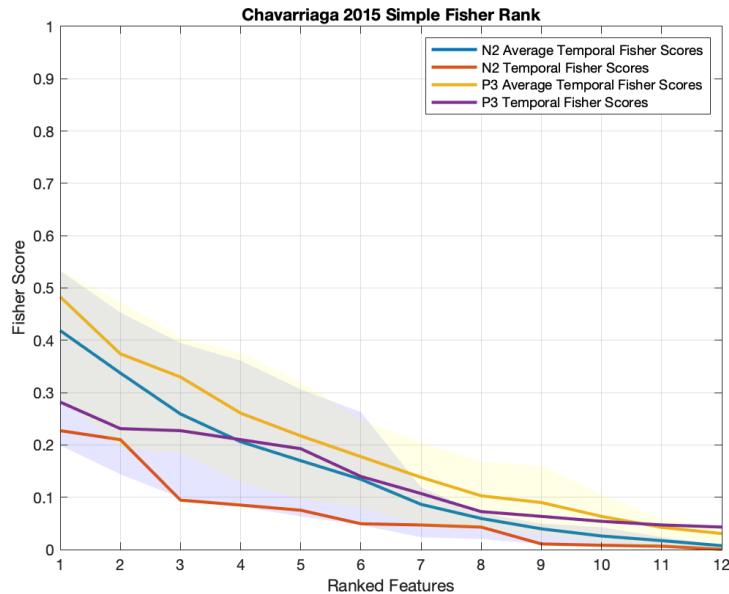
Last time (Cz & FCz), different window



Chavarriaga 2015 – Simple Fisher Rank

N2: 220 - 260ms
 P3: 270 – 310ms

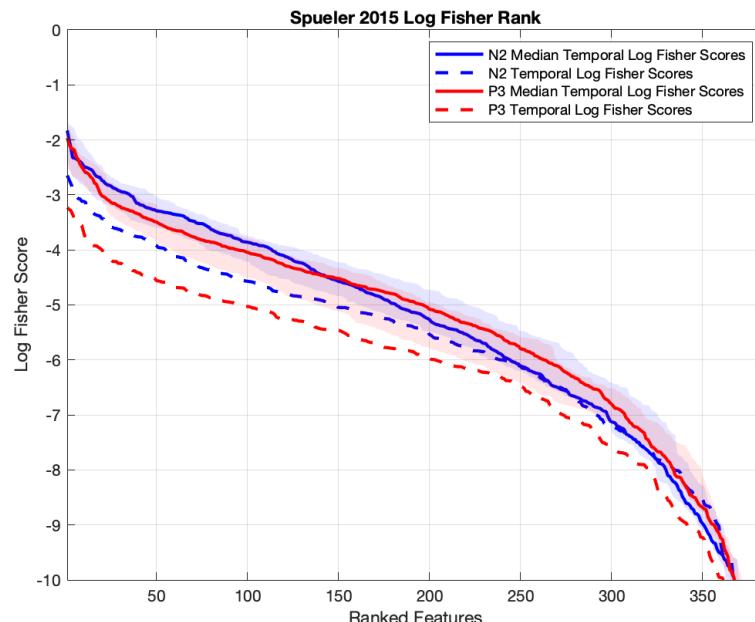
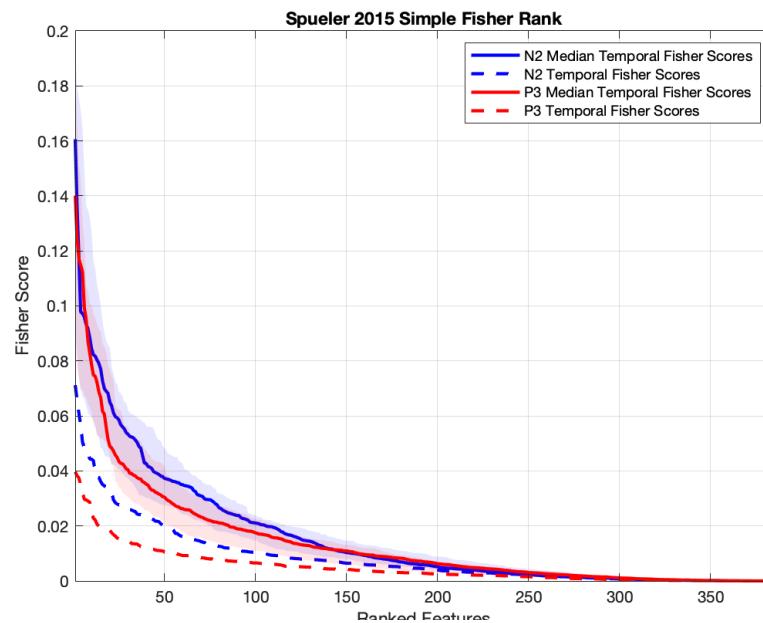
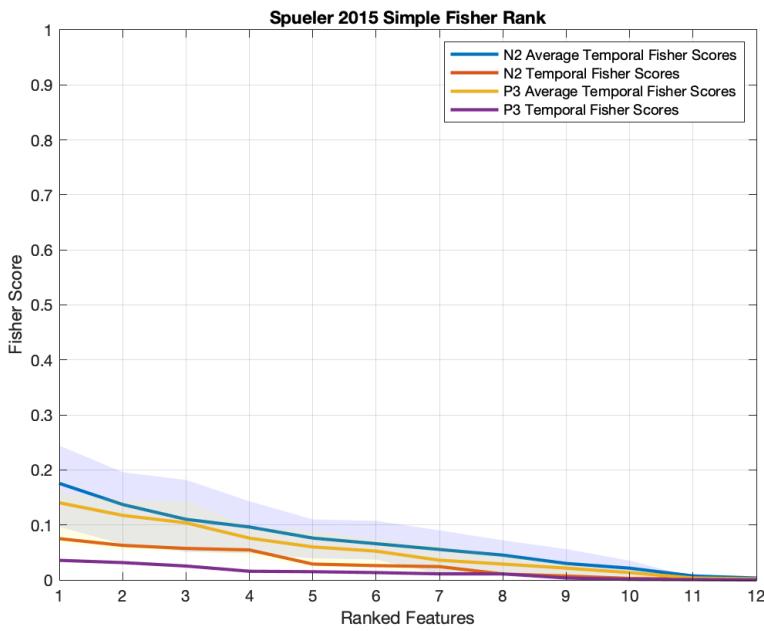
Last time (Cz & FCz), different window



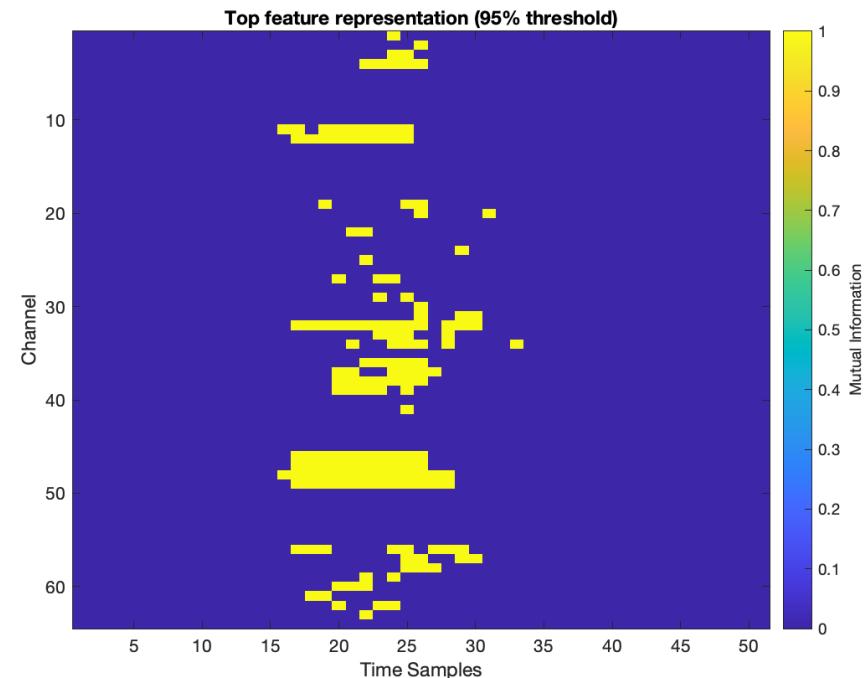
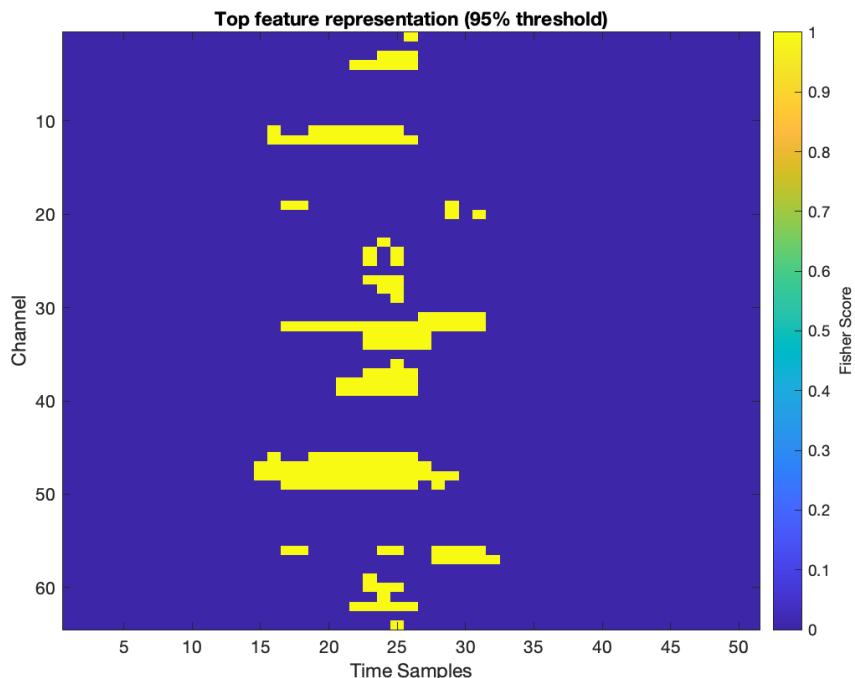
Spueler 2015 – Simple Fisher Rank

N2: 220 - 260ms
P3: 270 – 310ms

Last time (Cz & FCz), different window

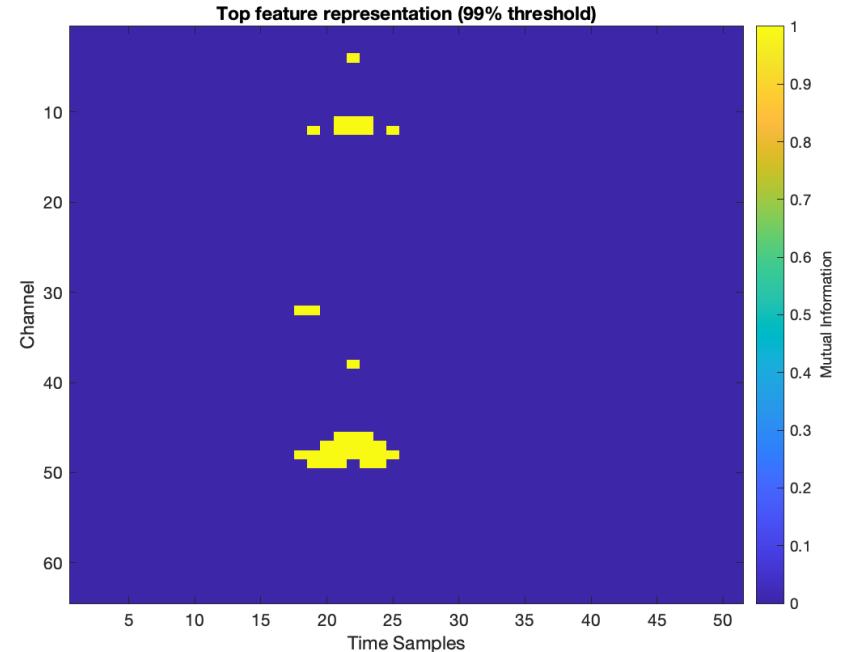
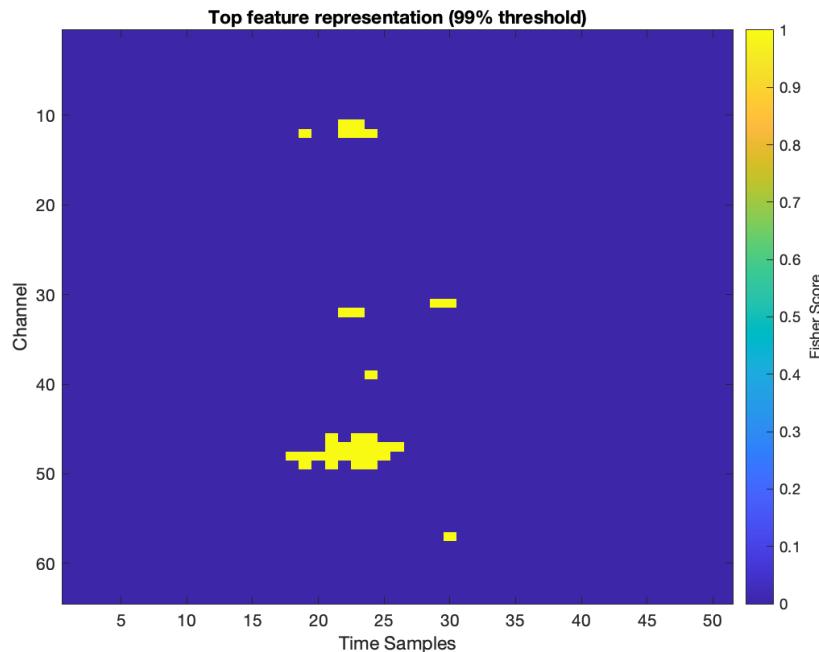


All Subjects – Visual Feature Representation



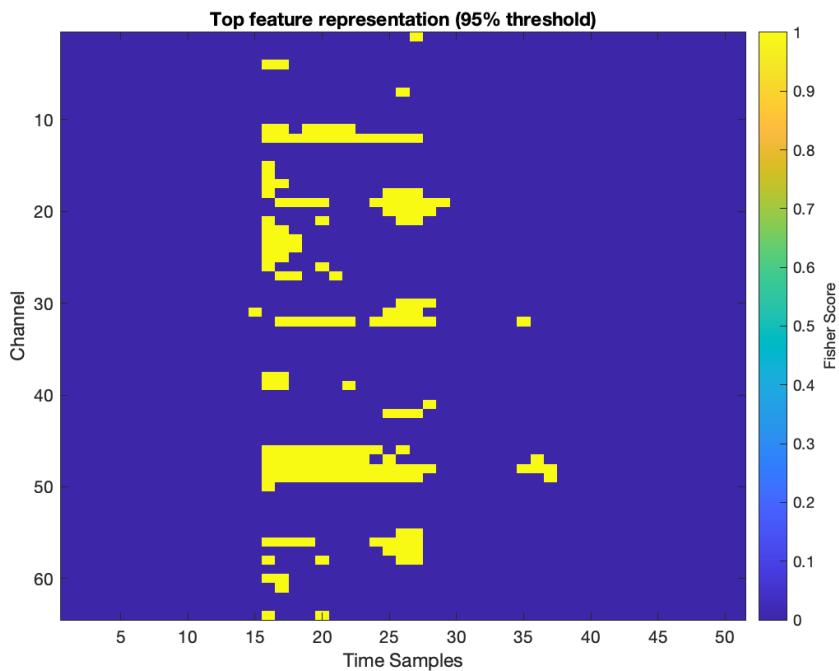
```
score_m = median(score,1); -- Median score (per channel & time sample) over all subjects and datasets
thresh = quantile(score_m,0.95); -- ~0.04 for Fisher & MI
thresh_idx = score_m > thresh;
score_thresh = zeros(length(score_m),1);
score_thresh(thresh_idx) = 1;
score_thresh = reshape(score_thresh, 64,[]);
```

All Subjects – Visual Feature Representation

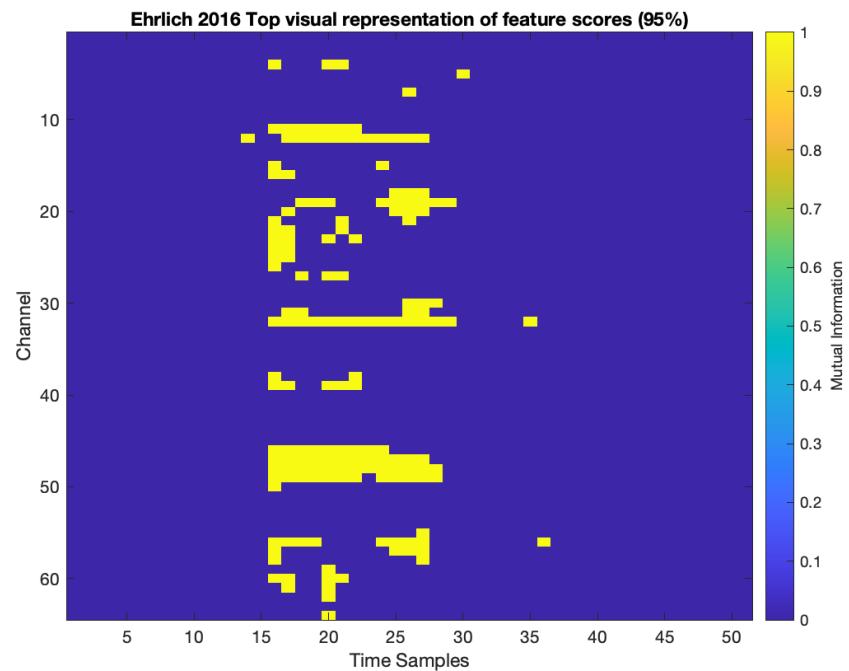


```
score_m = median(score,1); -- Median score (per channel & time sample) over all subjects and datasets
thresh = quantile(score_m,0.99); -- ~0.068 for Fisher & 0.056 for MI
thresh_idx = score_m > thresh;
score_thresh = zeros(length(score_m),1);
score_thresh(thresh_idx) = 1;
score_thresh = reshape(score_thresh, 64,[]);
```

Ehrlich 2016 – Visual Feature Representation

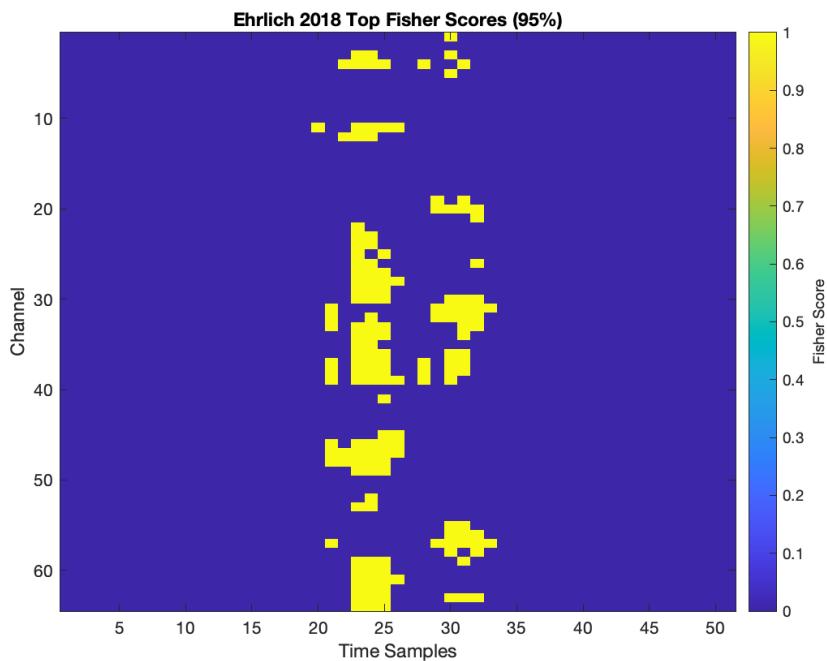


Threshold: 0.0636

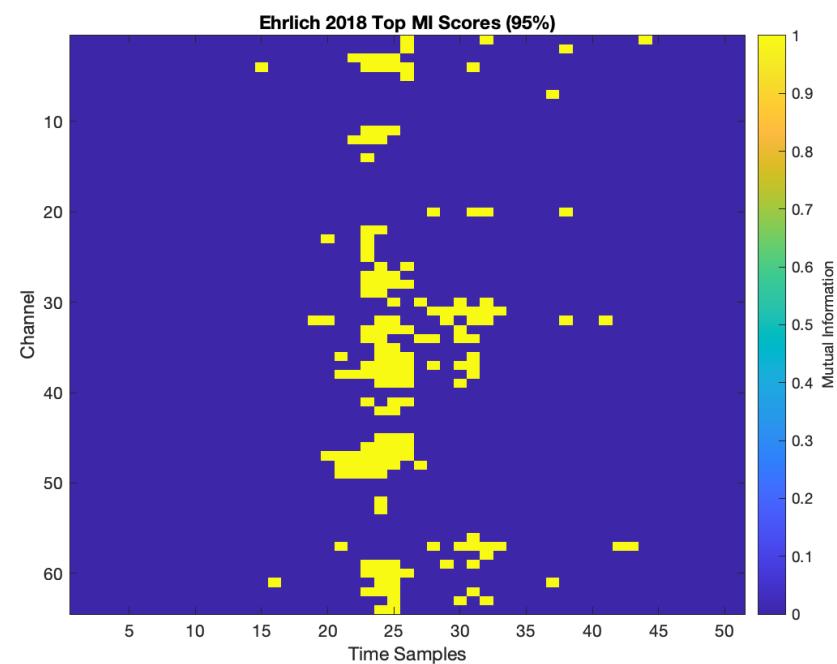


Threshold: 0.0434

Ehrlich 2018 – Visual Feature Representation

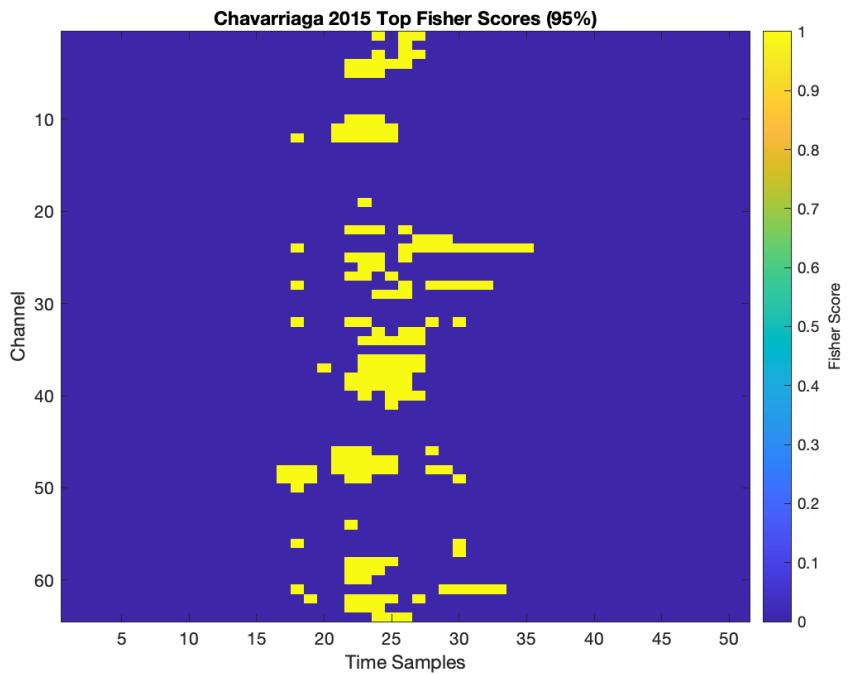


Threshold: 0.0804

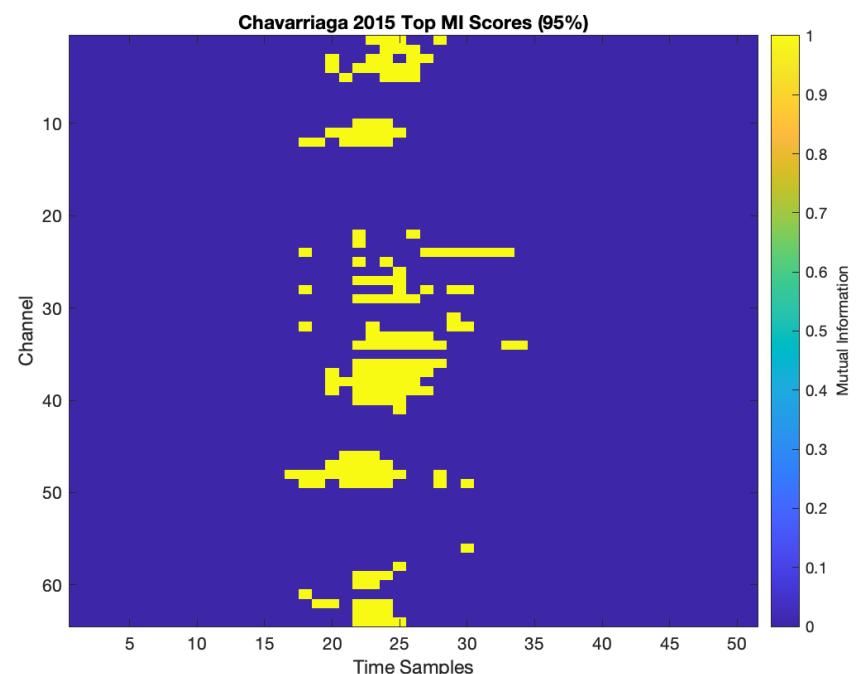


Threshold: 0.0908

Chavarriaga 2015 – Visual Feature Representation

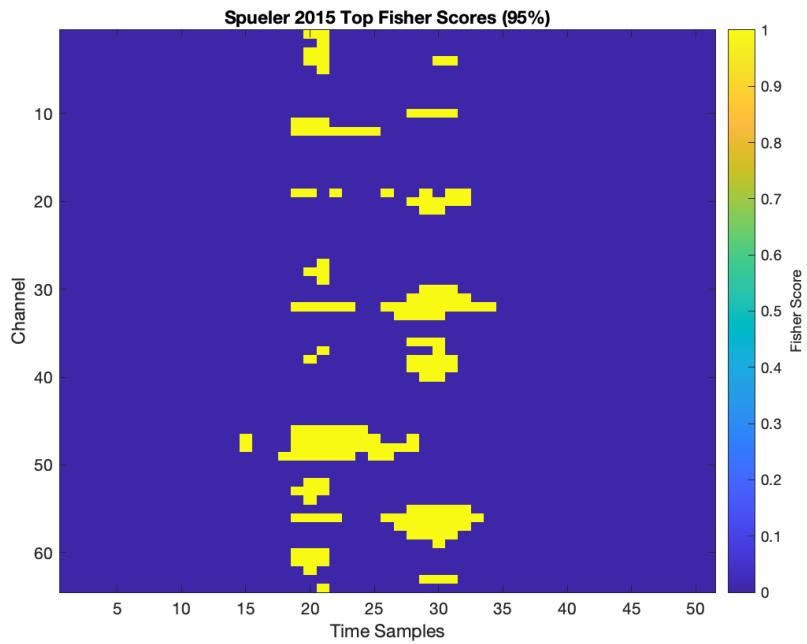


Threshold: 0.0853

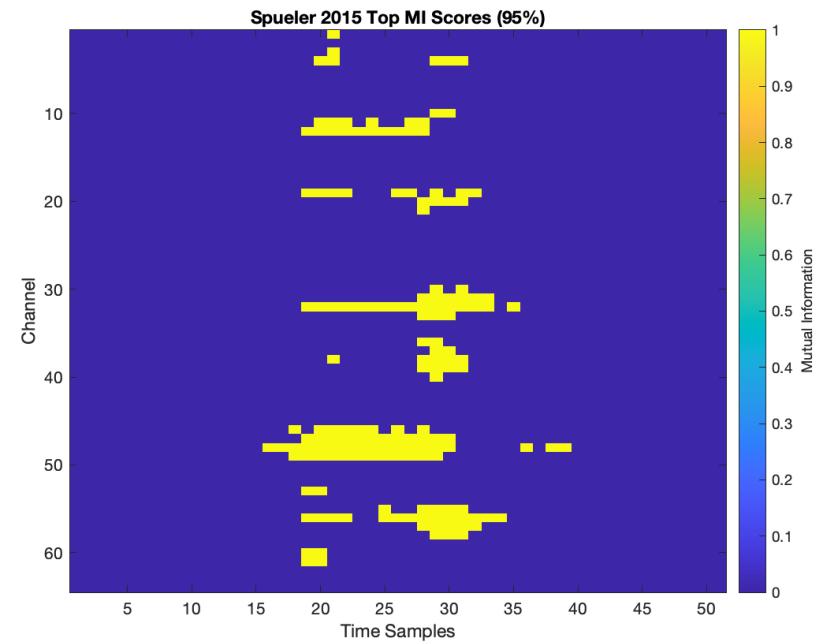


Threshold: 0.0402

Spueler 2015 – Visual Feature Representation



Threshold: 0.0219



Threshold: 0.0190

Feature Selection Methods (Filter-based)

TABLE I. COMMON FILTER METHODS FOR FEATURE SELECTION

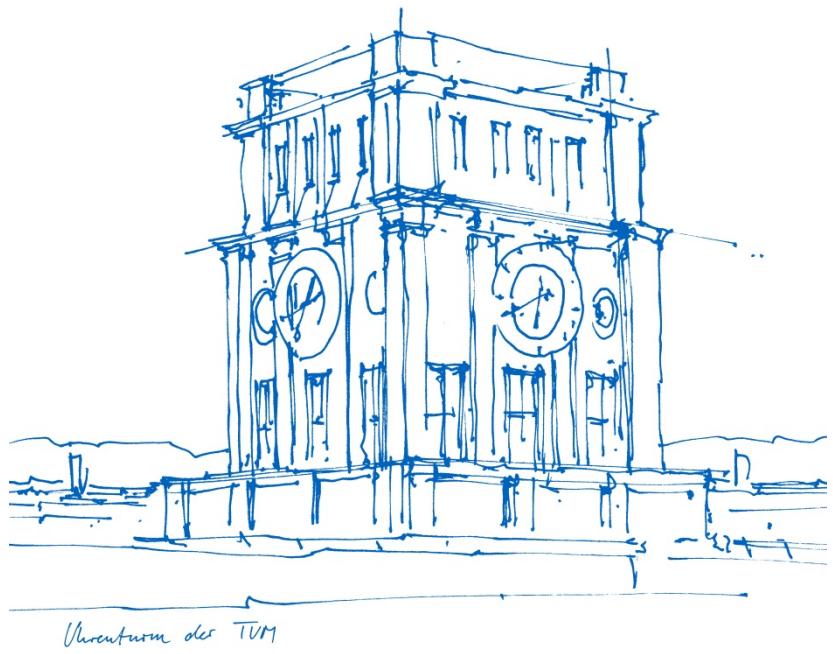
Name	Filter class	Applicable to task	Study
Information gain	univariate, information	classification	[6]
Gain ratio	univariate, information	classification	[7]
Symmetrical uncertainty	univariate, information	classification	[8]
Correlation	univariate, statistical	regression	[8]
Chi-square	univariate, statistical	classification	[7]
Inconsistency criterion	multivariate, consistency	classification	[9]
Minimum redundancy, maximum relevance (mRmR)	multivariate, information	classification, regression	[2]
Correlation-based feature selection (CFS)	multivariate, statistical	classification, regression	[7]
Fast correlation-based filter (FCBF)	multivariate, information	classification	[8]
Fisher score	univariate, statistical	classification	[10]
Relief and ReliefF	univariate, distance	classification, regression	[11]
Spectral feature selection (SPEC) and Laplacian Score (LS)	univariate, similarity	classification, clustering	[4]
Feature selection for sparse clustering	multivariate, similarity	clustering	[12]
Localized Feature Selection Based on Scatter Separability (LFSBSS)	multivariate, statistical	clustering	[13]
Multi-Cluster Feature Selection (MCFS)	multivariate, similarity	clustering	[4]
Feature weighting K-means	multivariate, statistical	clustering	[14]
ReliefC	univariate, distance	clustering	[15]

- Filter methods select features based on a performance measure regardless of the employed data modeling algorithm
- We can roughly classify the developed measures for feature filtering into: **information, distance, consistency, similarity, and statistical measures**
- Univariate feature filters evaluate (and usually rank) a single feature, while multivariate filters evaluate an entire feature subset
- Feature subset generation for multivariate filters depends on the search strategy

Temporal Data Analysis of EEG Sets

Update

May 8, 2020



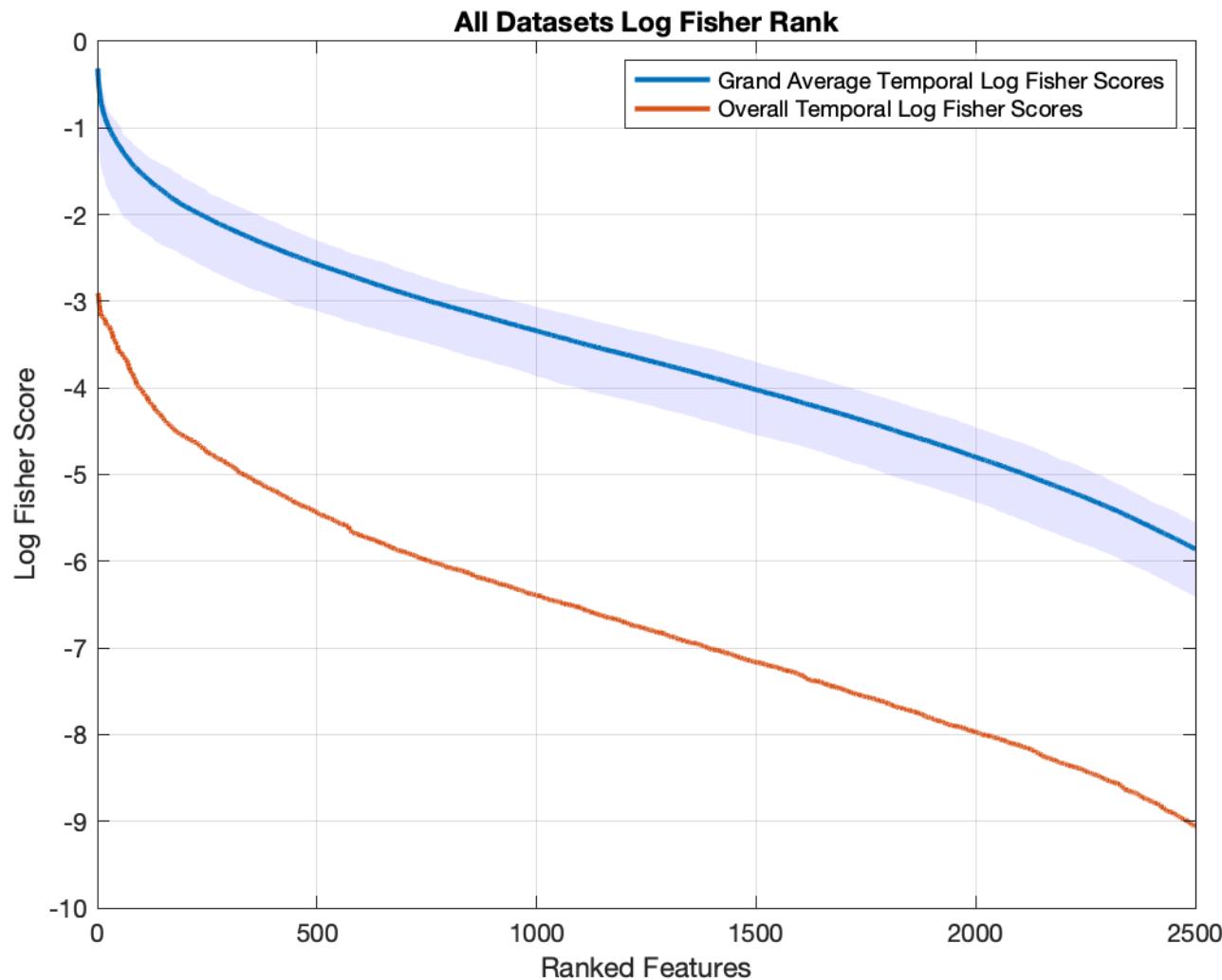
Overview

1. All EEG Data Sets (All Subjects)
2. Ehrlich 2016
3. Ehrlich 2018
4. Chavarriaga 2015
5. Spuler 2015

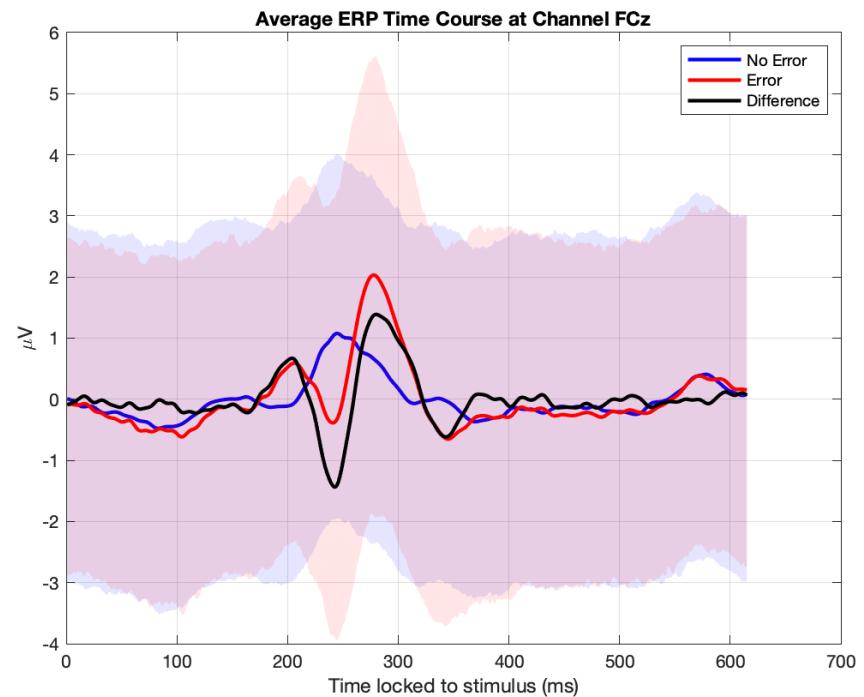
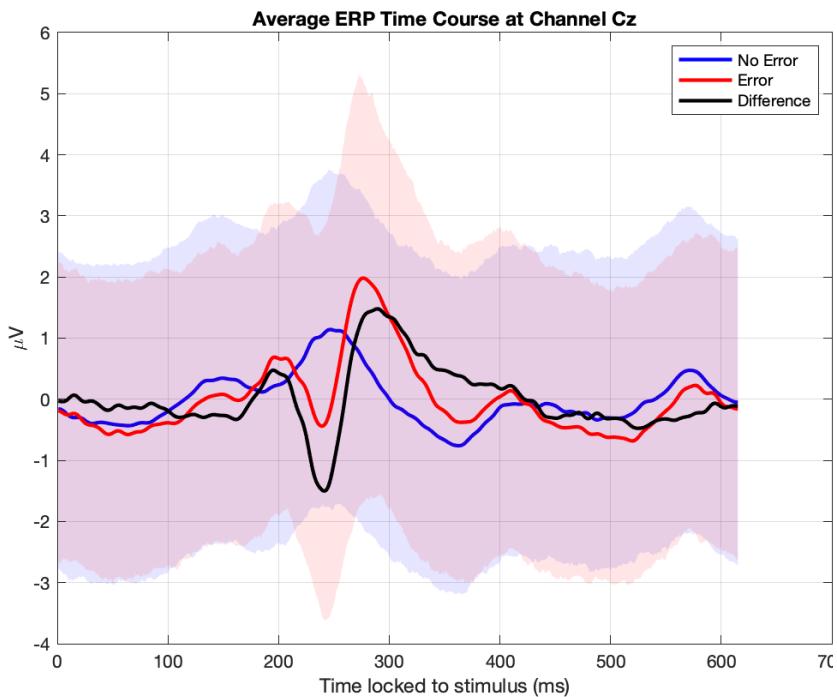
Each section:

- i. Log-plot Fisher Rank
- ii. All Subjects ERP
- iii. N2 vs P3 Features (simple)
- iv. MI vs Fisher Rank

All Subjects – Log Plot Fisher Rank



All Subjects – ERP



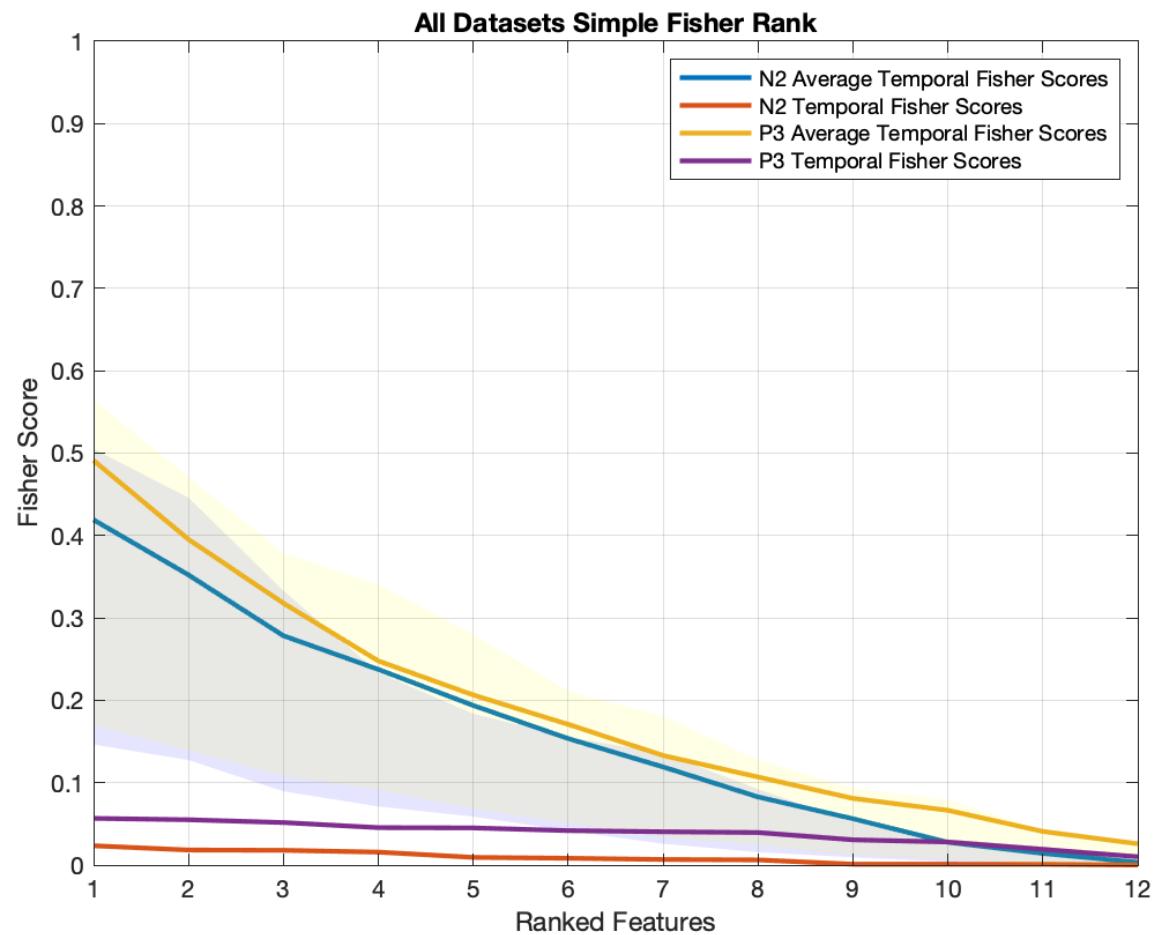
Confidence Interval: 0.25-0.75 quantiles

All Subjects – Simple Fisher Rank

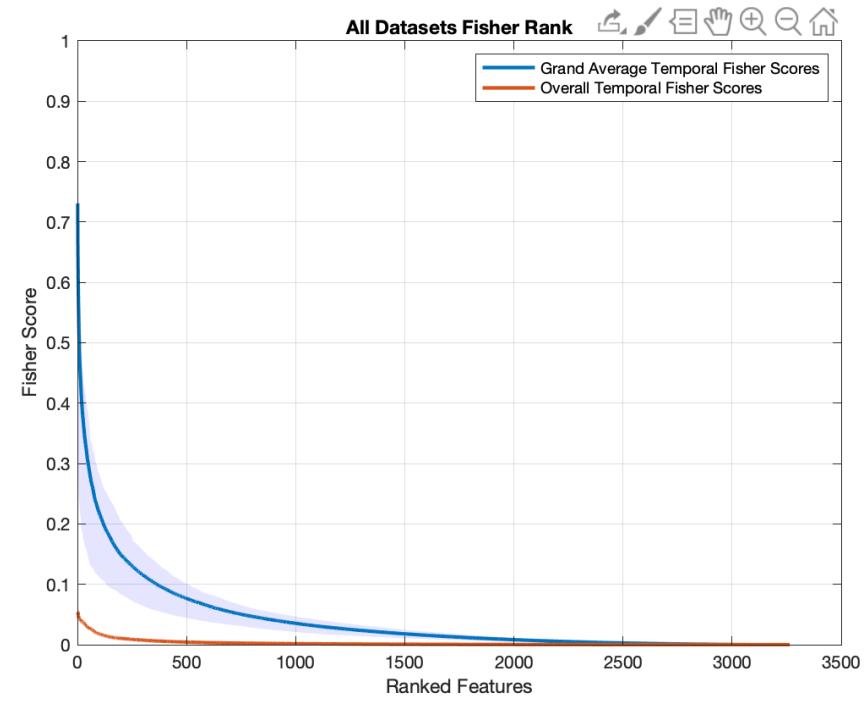
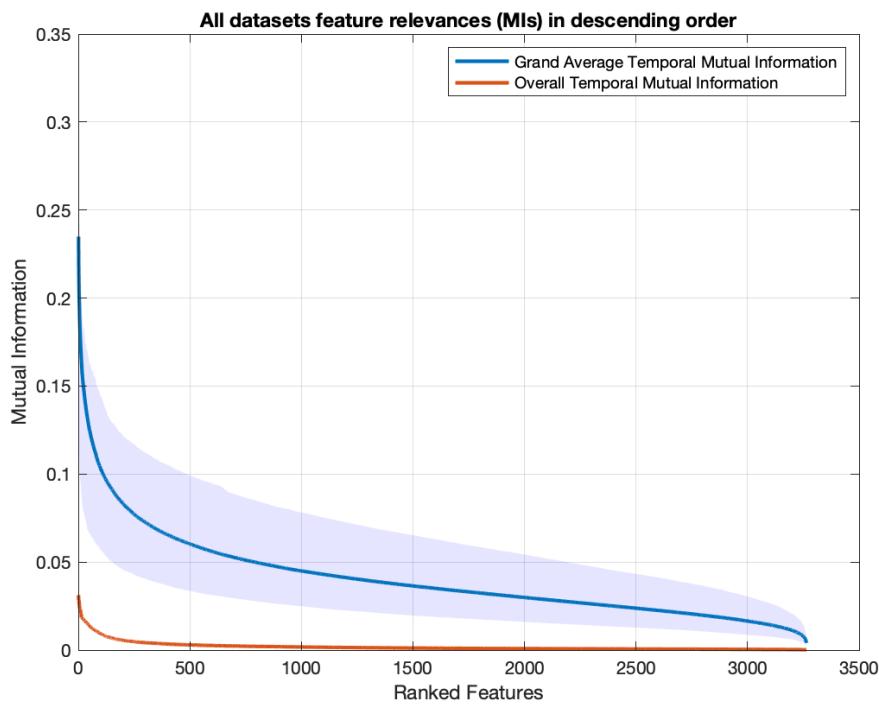
N2 (240) ± 20 ms

P3 (290) ± 20 ms

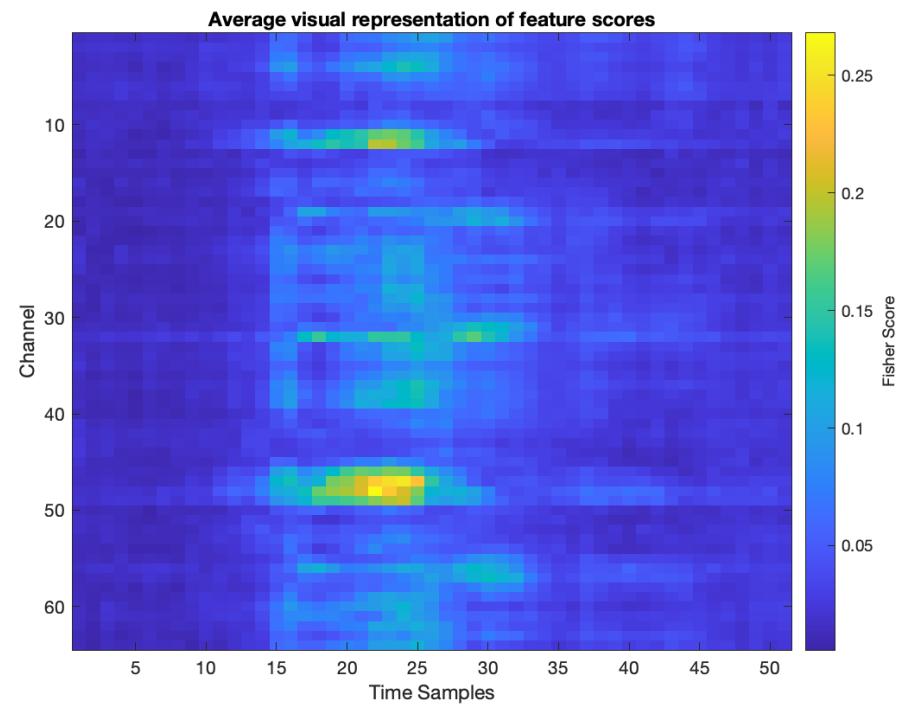
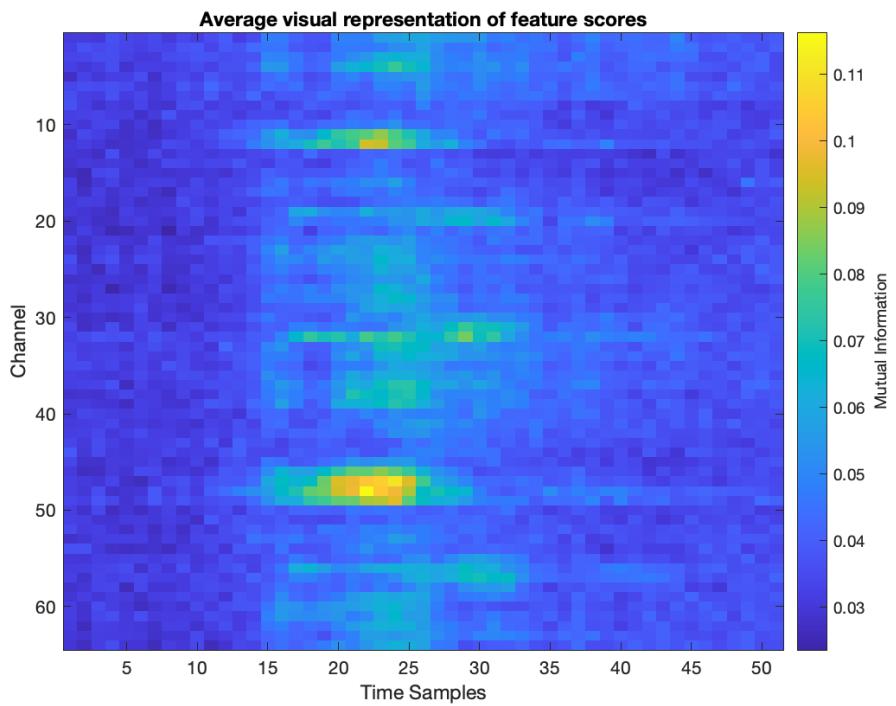
Cz & FCz



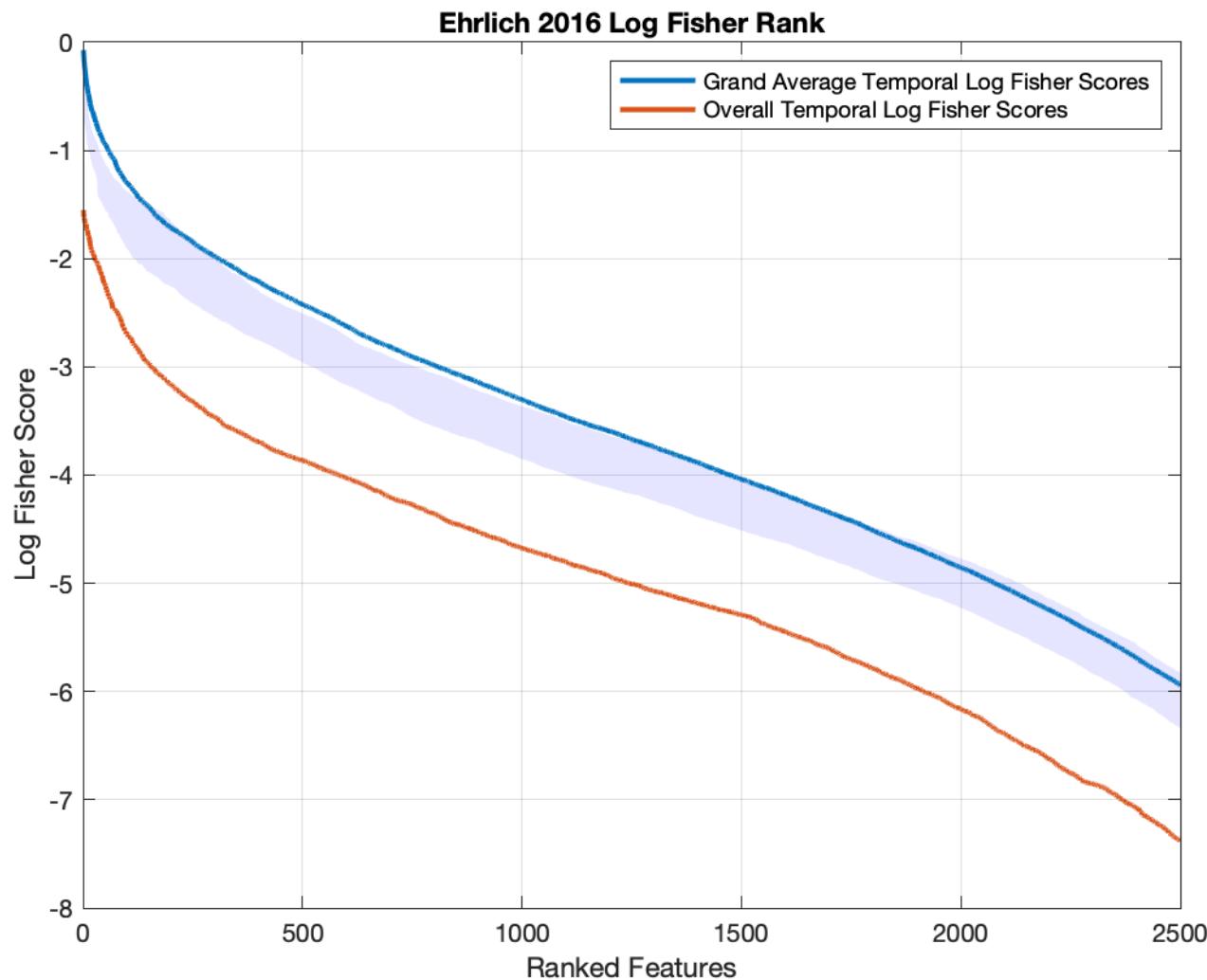
All Subjects – MI vs Fisher Rank



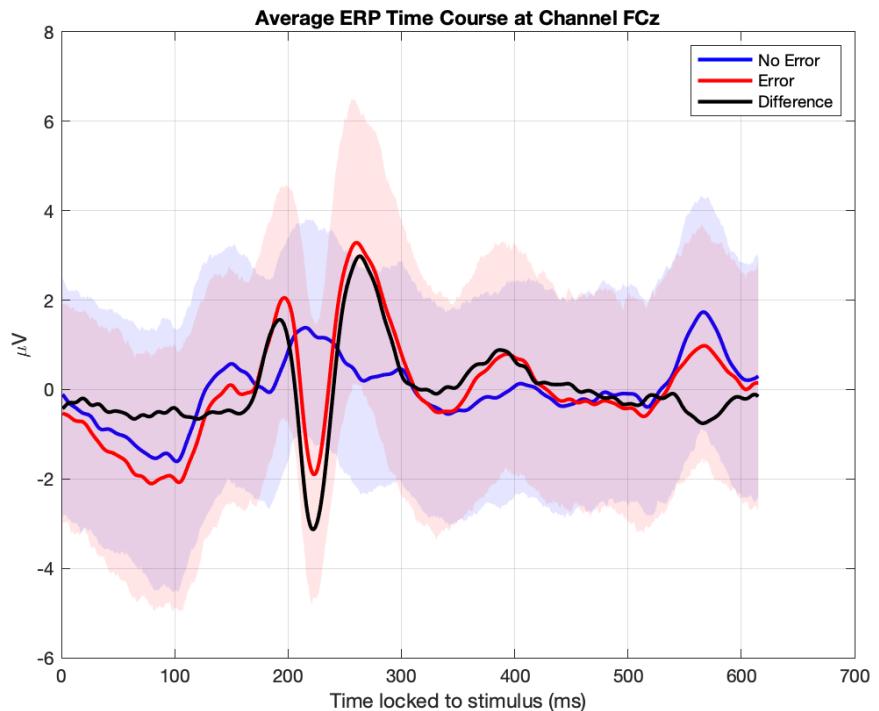
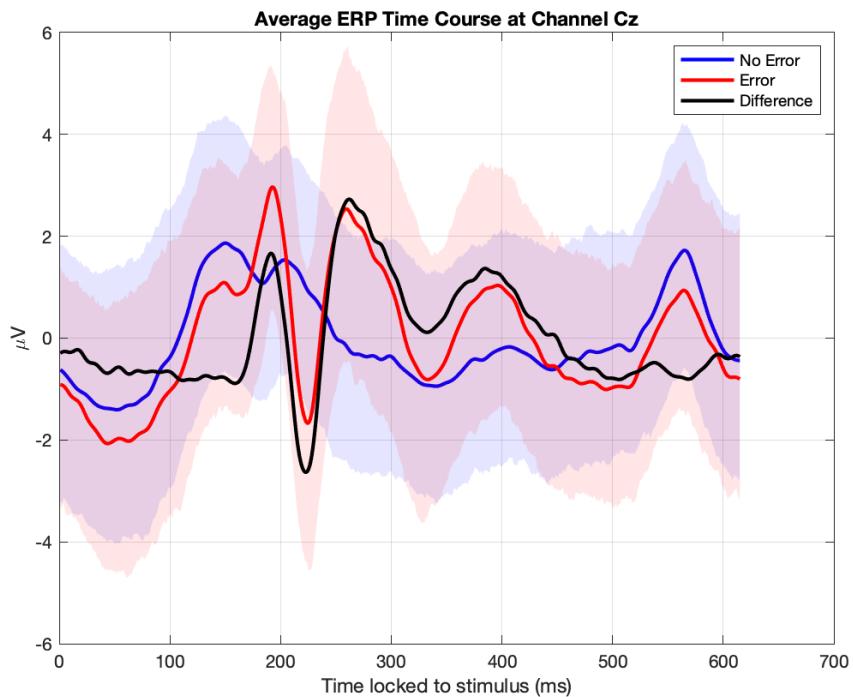
All Subjects – MI vs Fisher Rank



Ehrlich 2016 – Log Plot Fisher Rank



Ehrlich 2016 – ERP

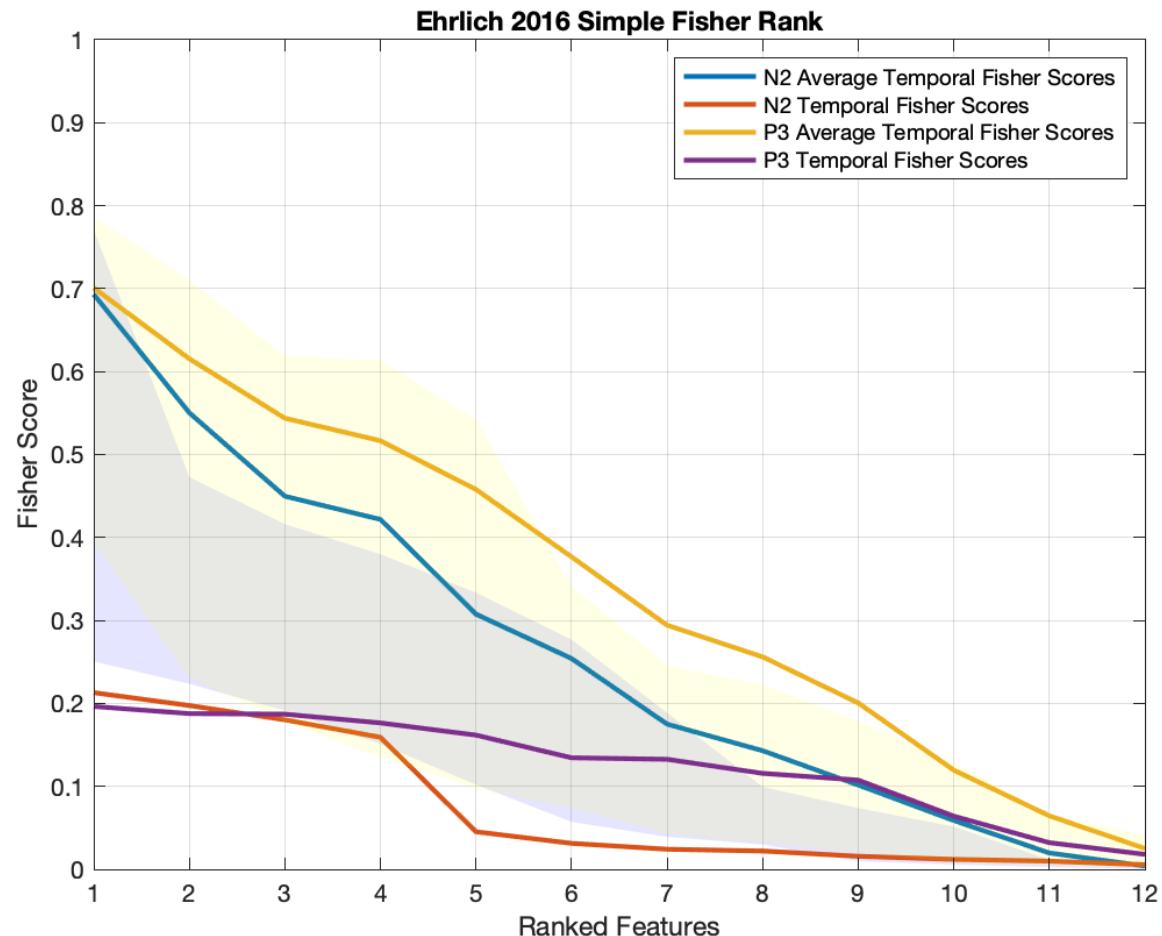


Confidence Interval: 0.25-0.75 quantiles

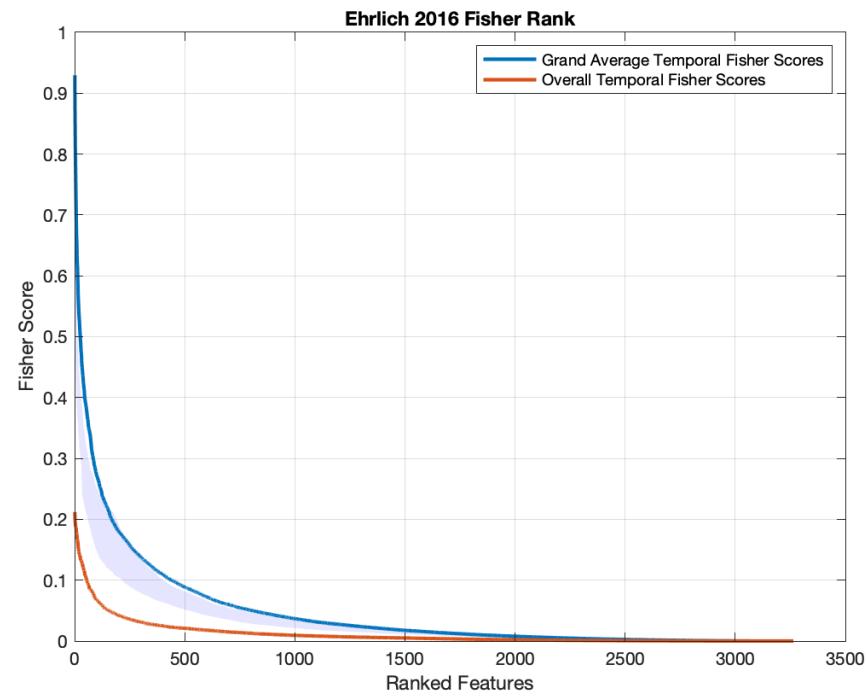
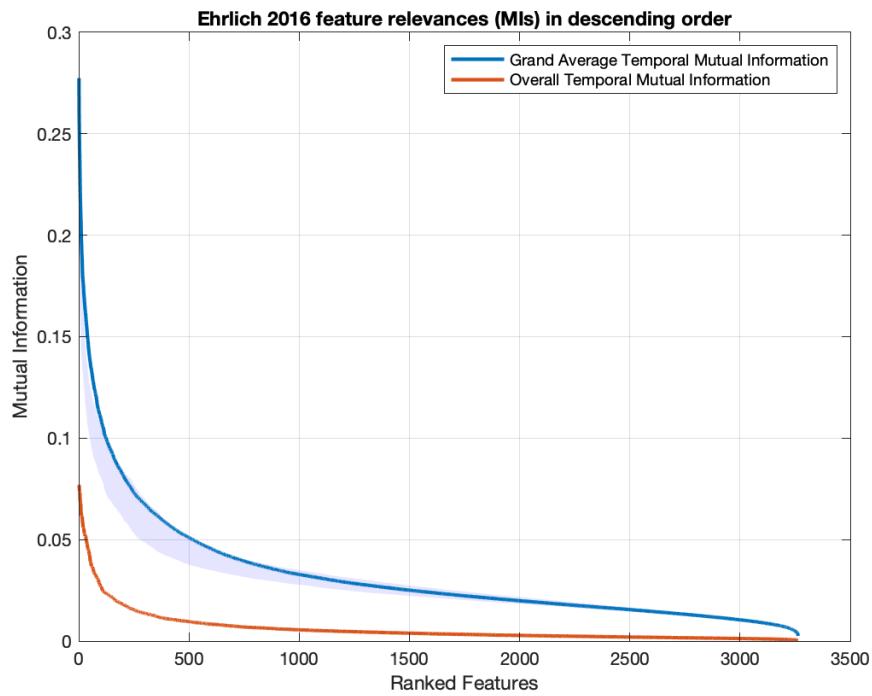
Ehrlich 2016 – Simple Fisher Rank

N2 (223) ± 20 ms
P3 (264) ± 20 ms

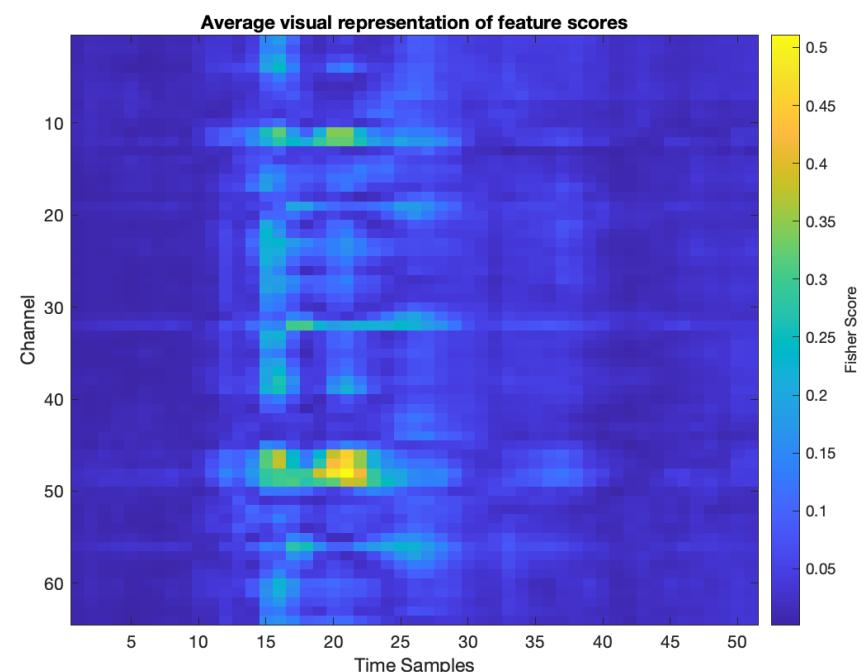
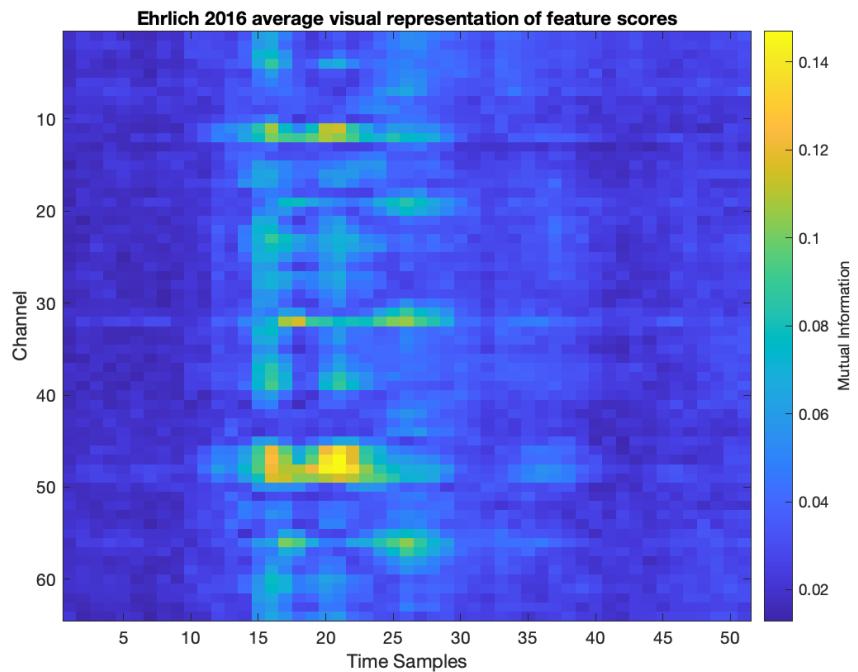
Cz & FCz



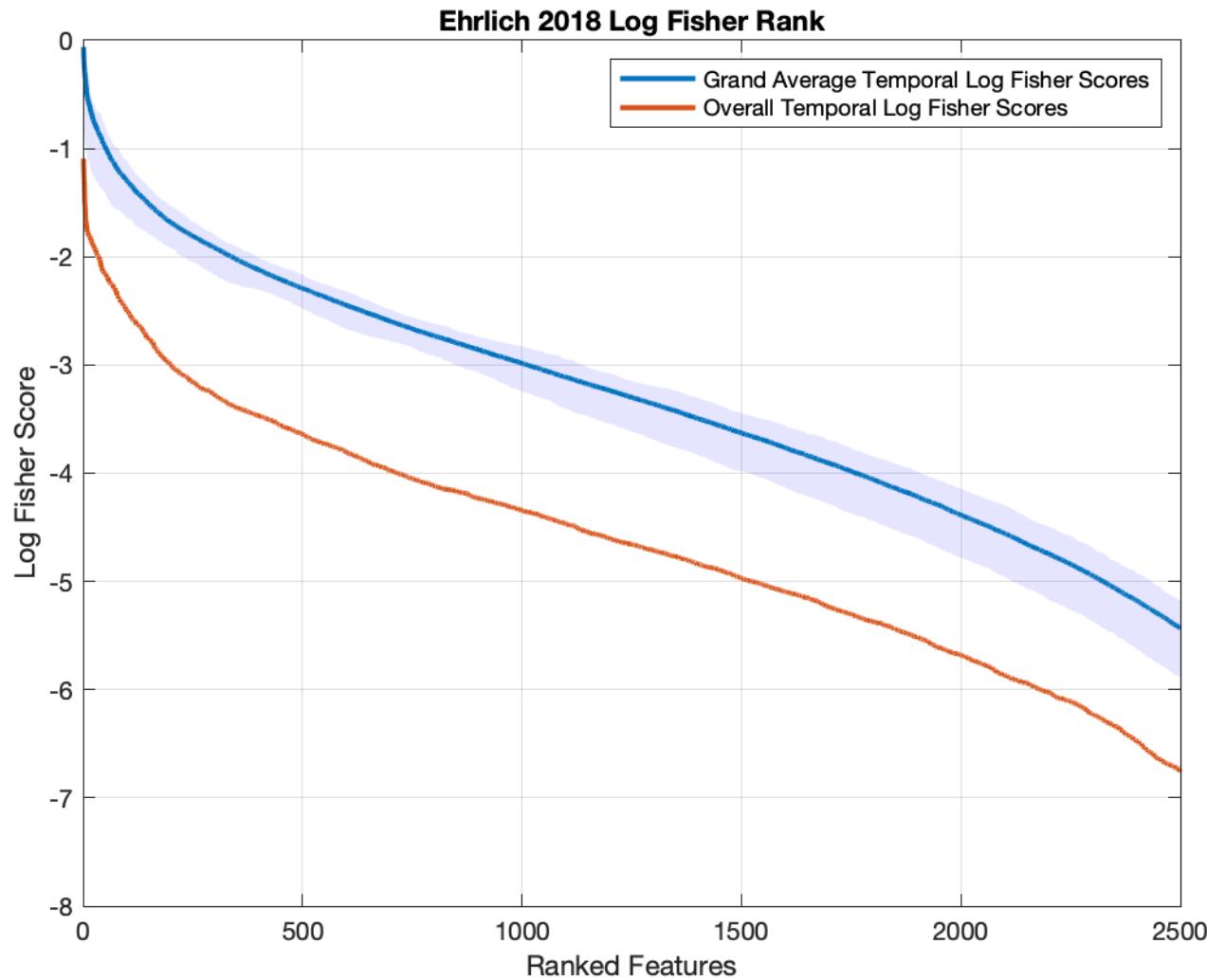
Ehrlich 2016 – MI vs Fisher Rank



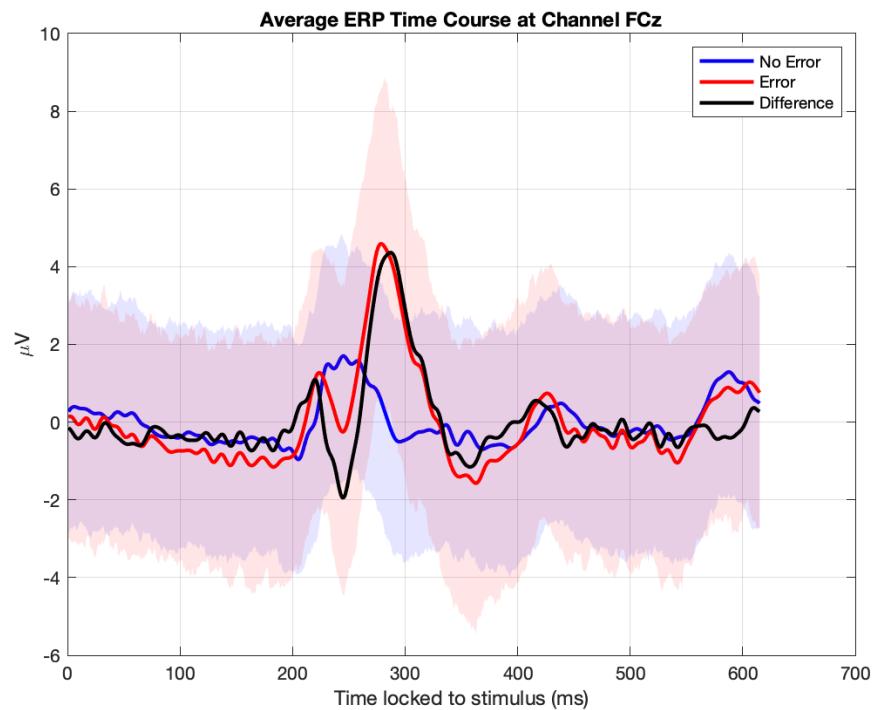
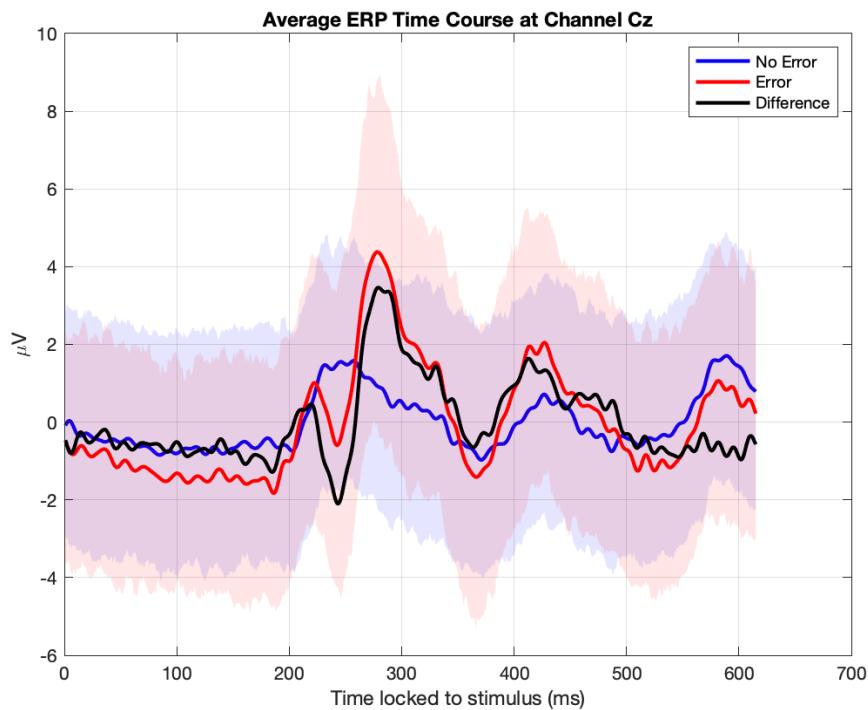
Ehrlich 2016 – MI vs Fisher Rank



Ehrlich 2018 – Log Plot Fisher Rank



Ehrlich 2018 – ERP



Confidence Interval: 0.25-0.75 quantiles

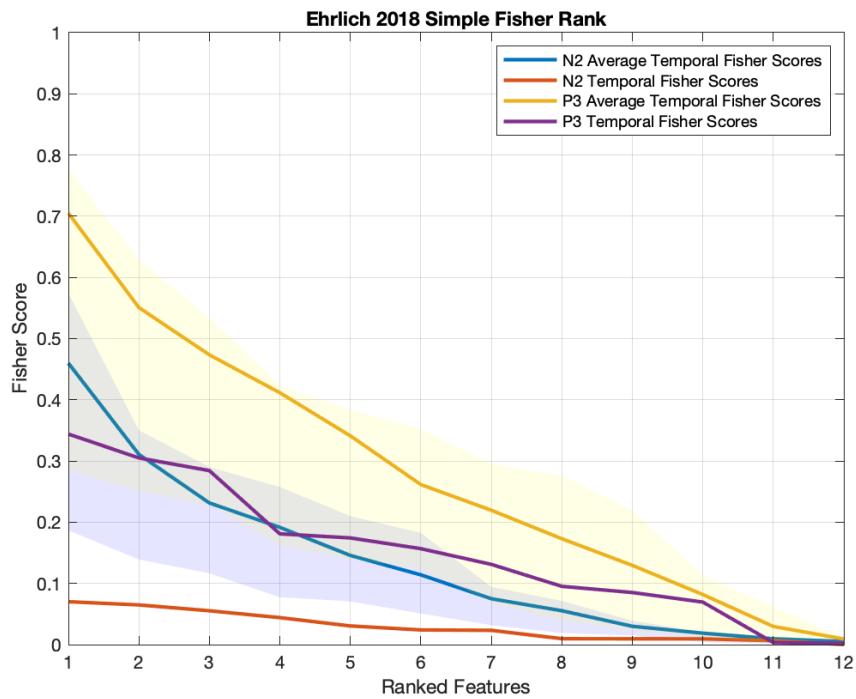
Ehrlich 2018 – Simple Fisher Rank Comparison

N2 (243) \pm 20 ms

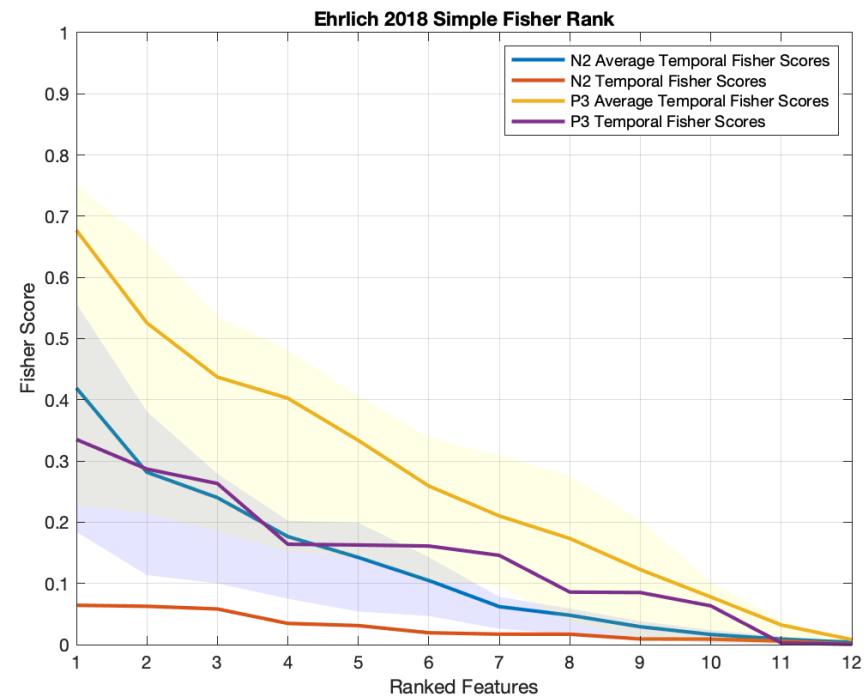
P3 (280) \pm 20 ms

Cz & FCz

balanced

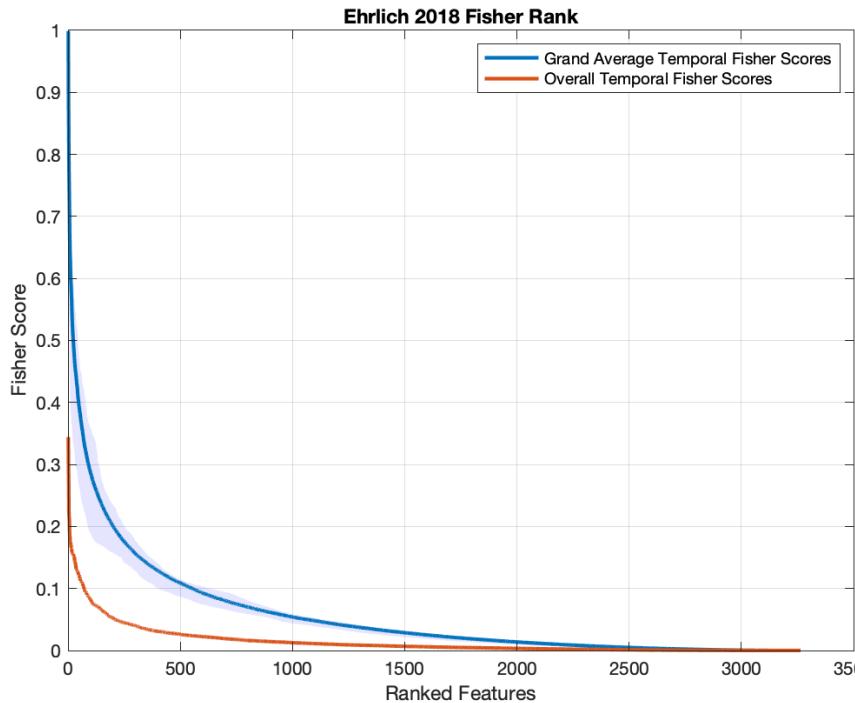


Not balanced

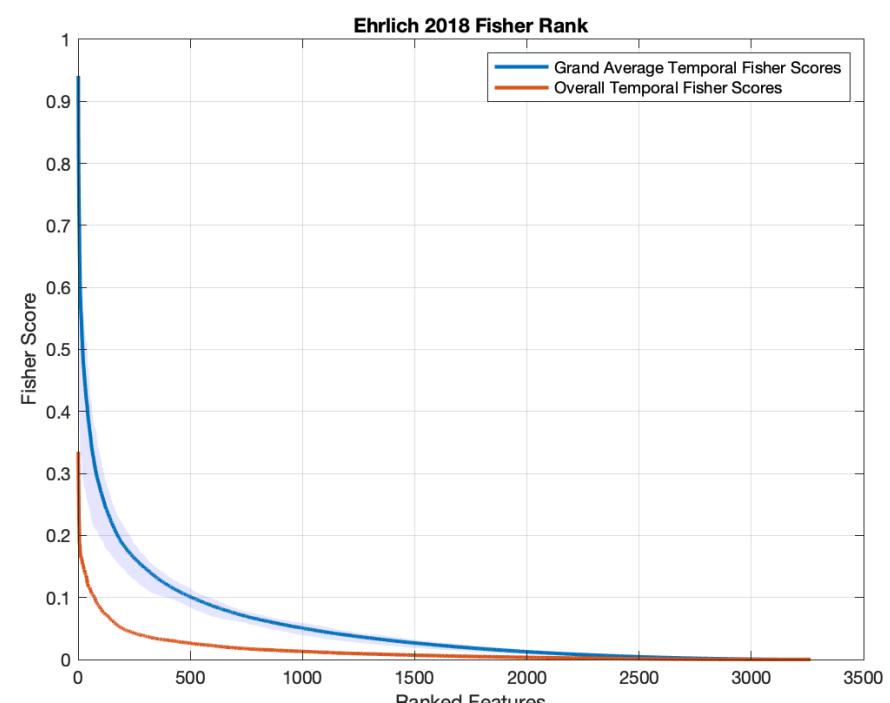


Ehrlich 2018 – Fisher Rank Comparison

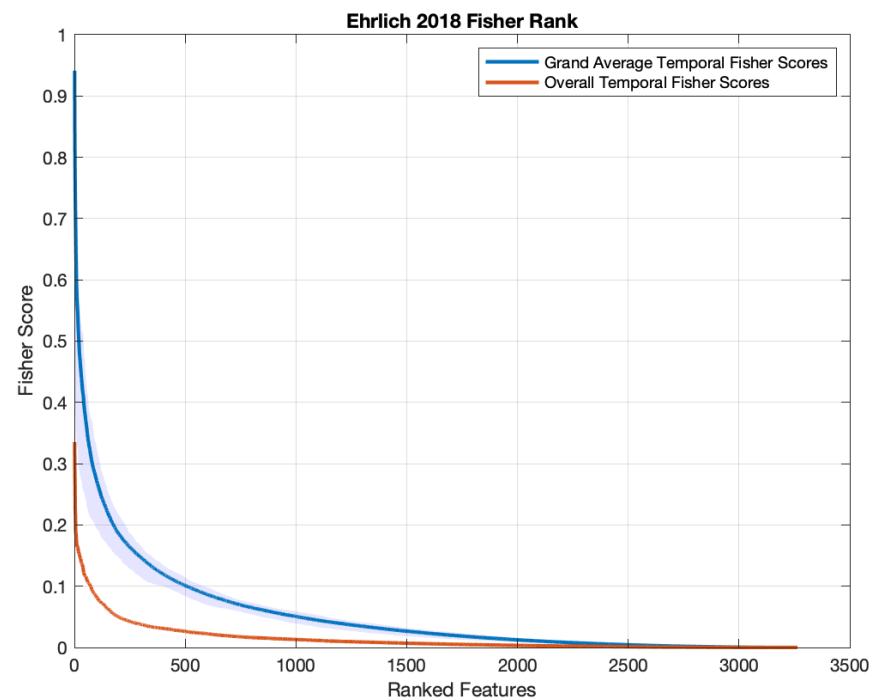
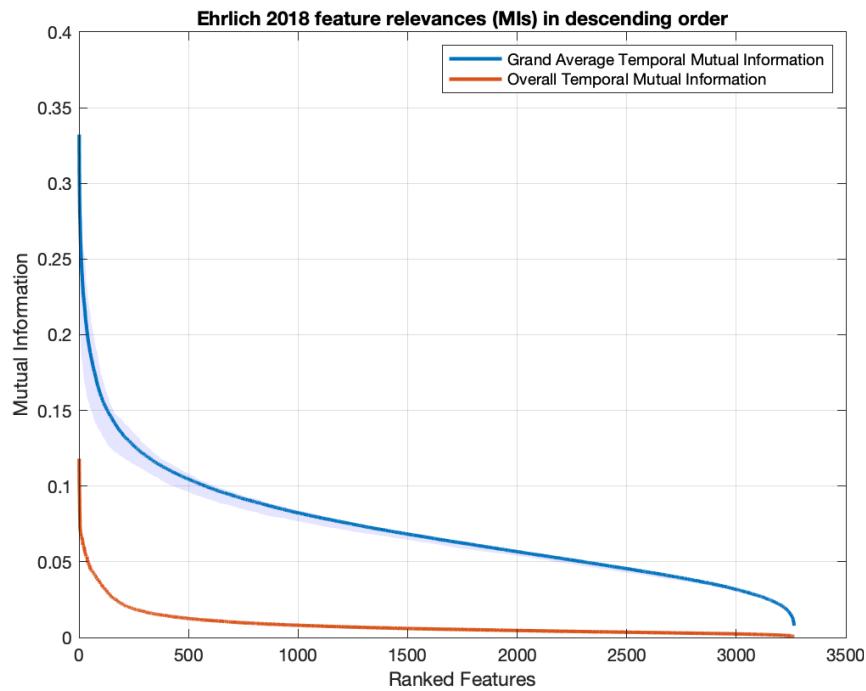
balanced



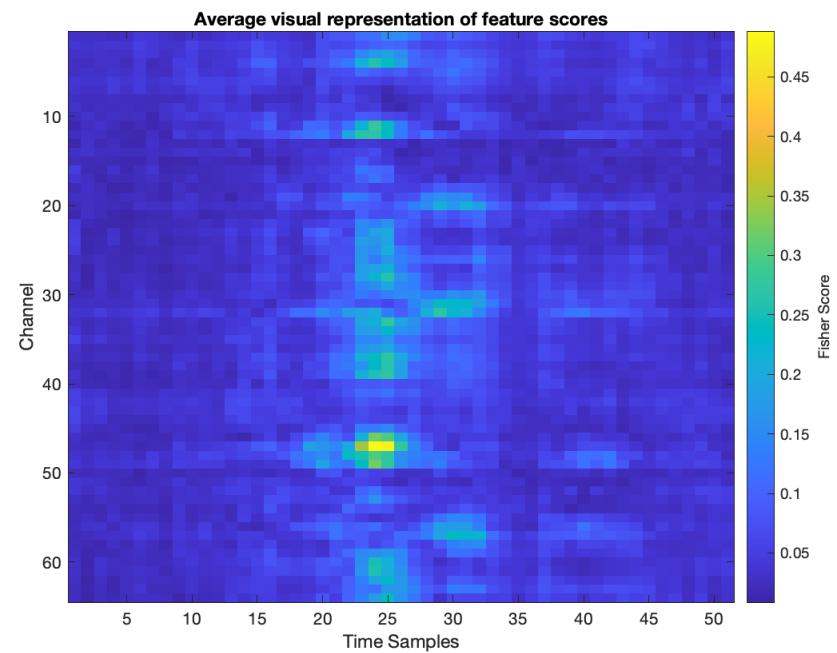
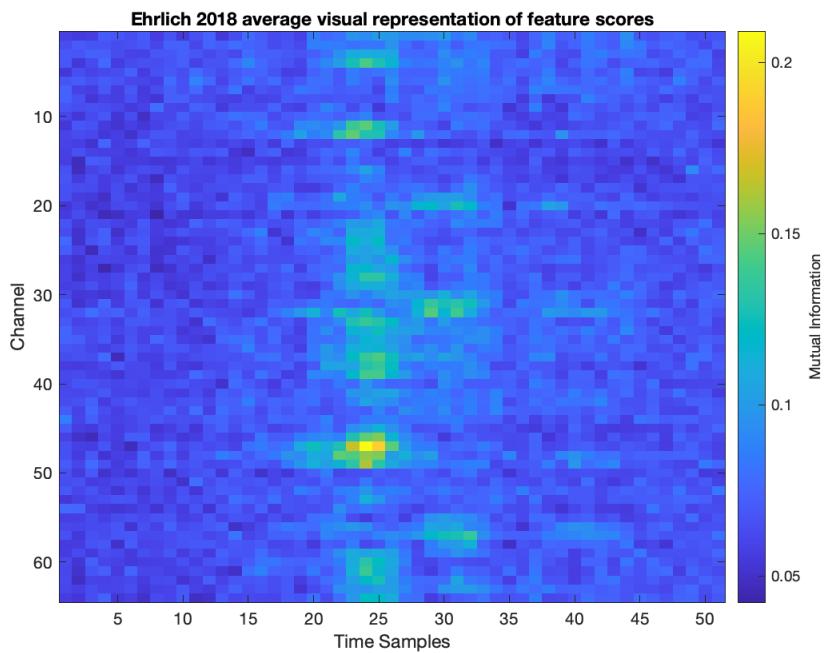
Not balanced



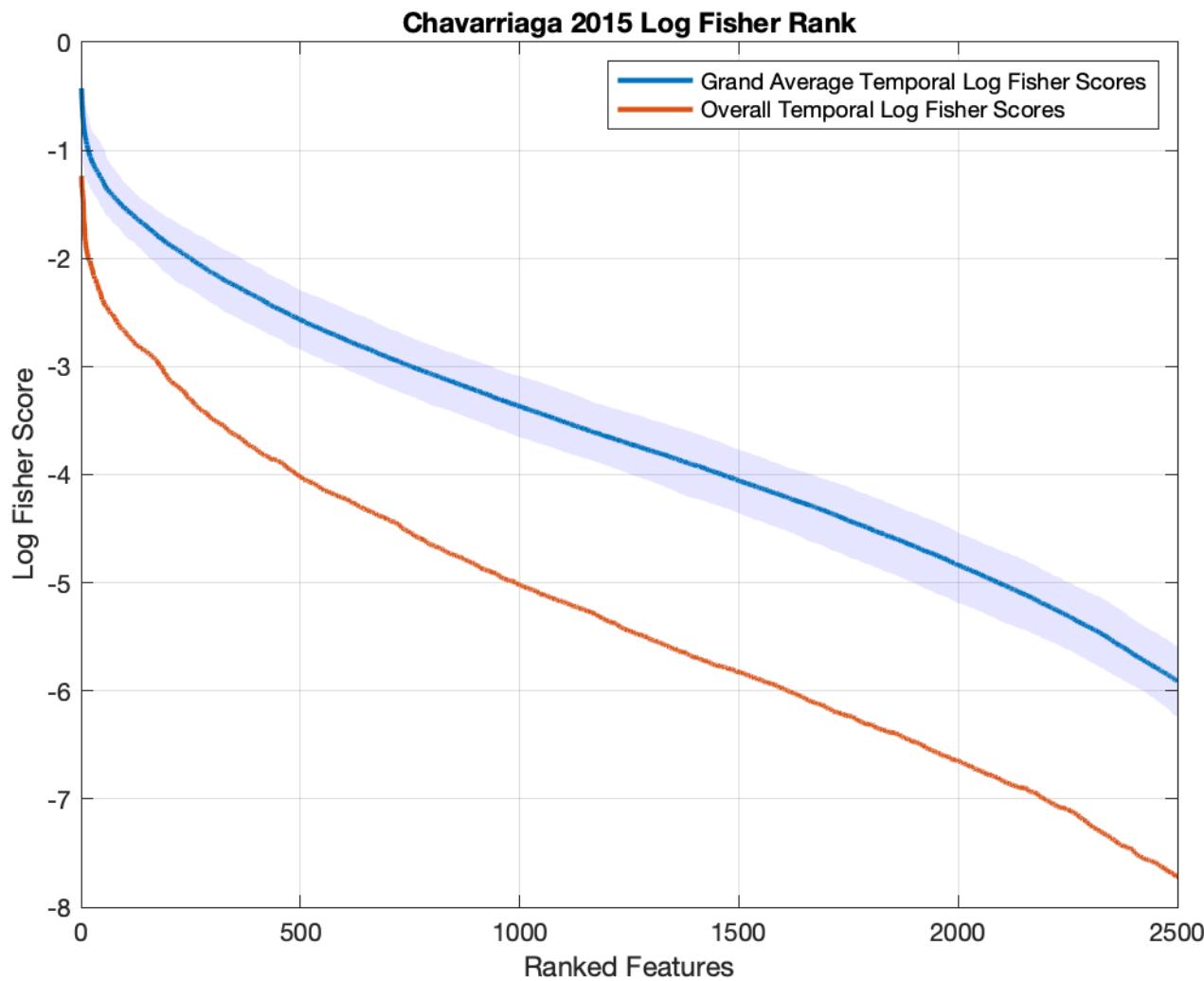
Ehrlich 2018 – MI vs Fisher Rank



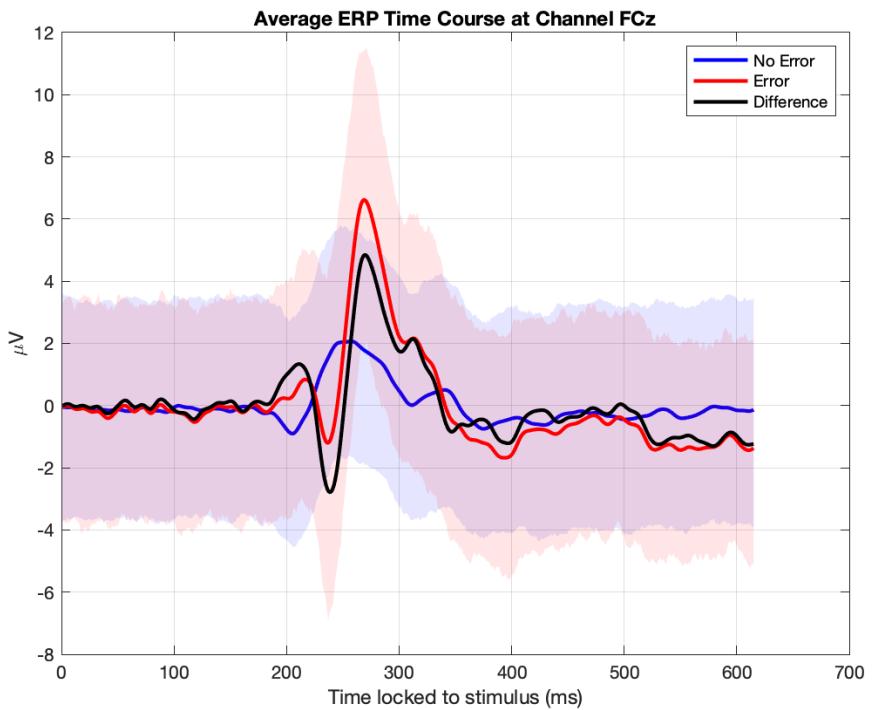
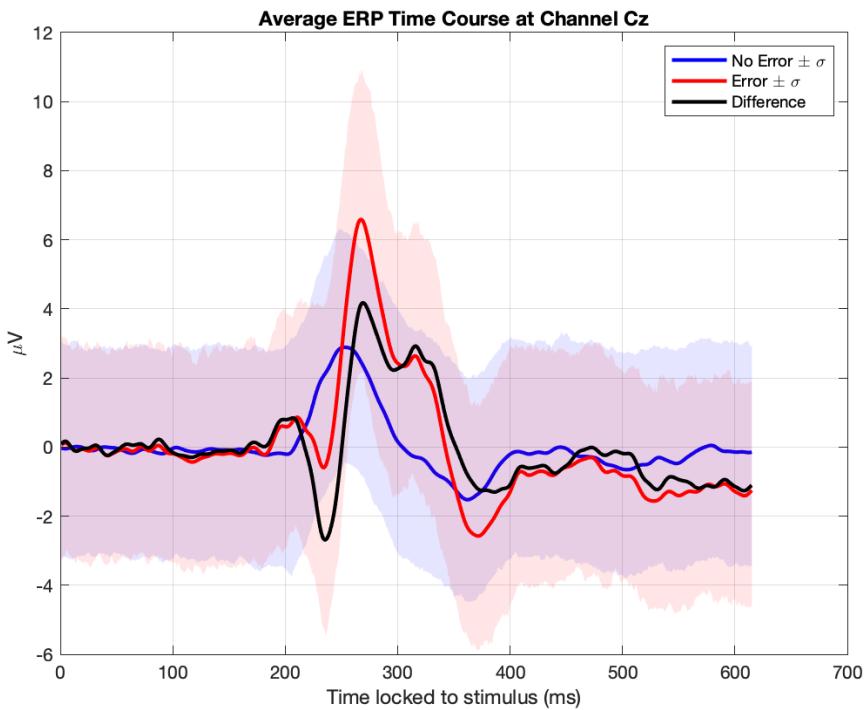
Ehrlich 2018 – MI vs Fisher Rank



Chavarriaga 2015 – Log Plot Fisher Rank



Chavarriaga 2015 – ERP

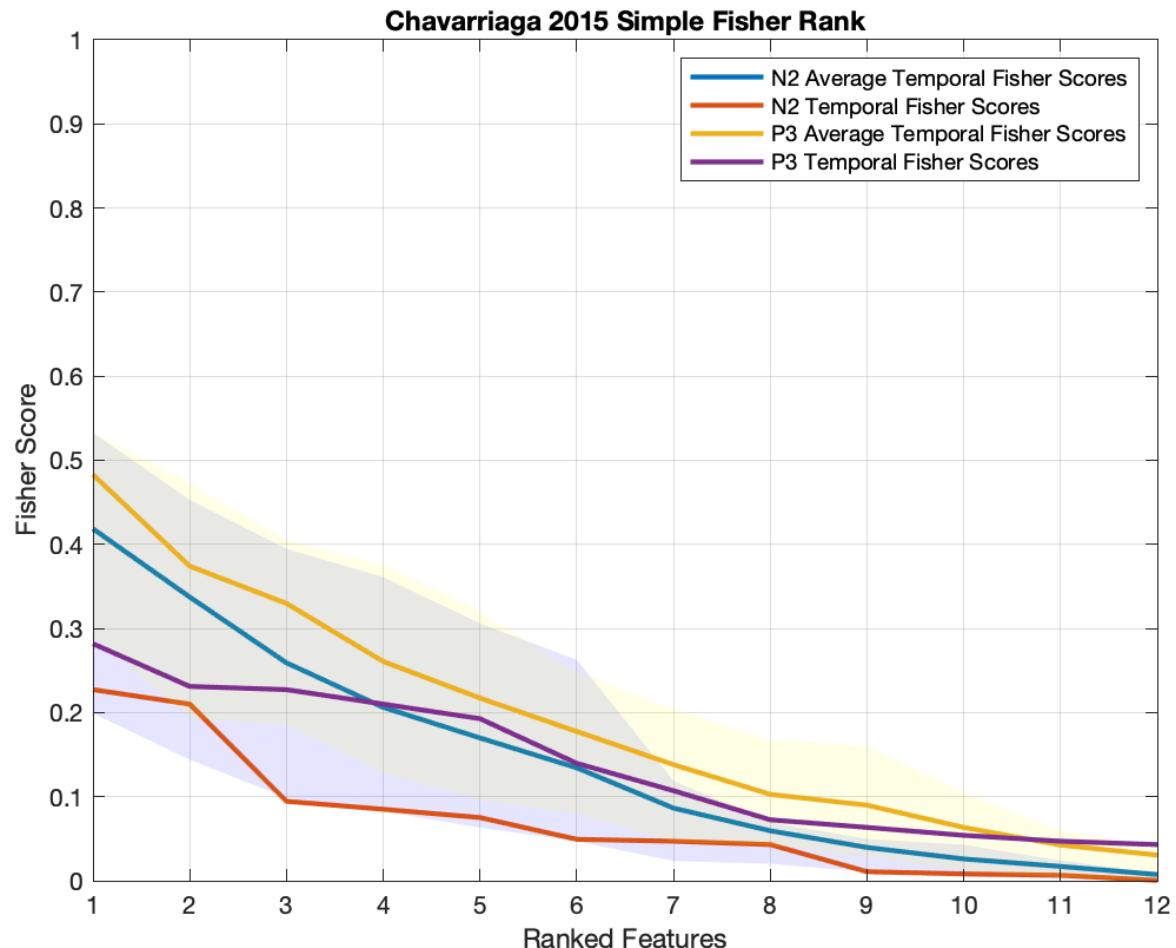


Confidence Interval: 0.25-0.75 quantiles

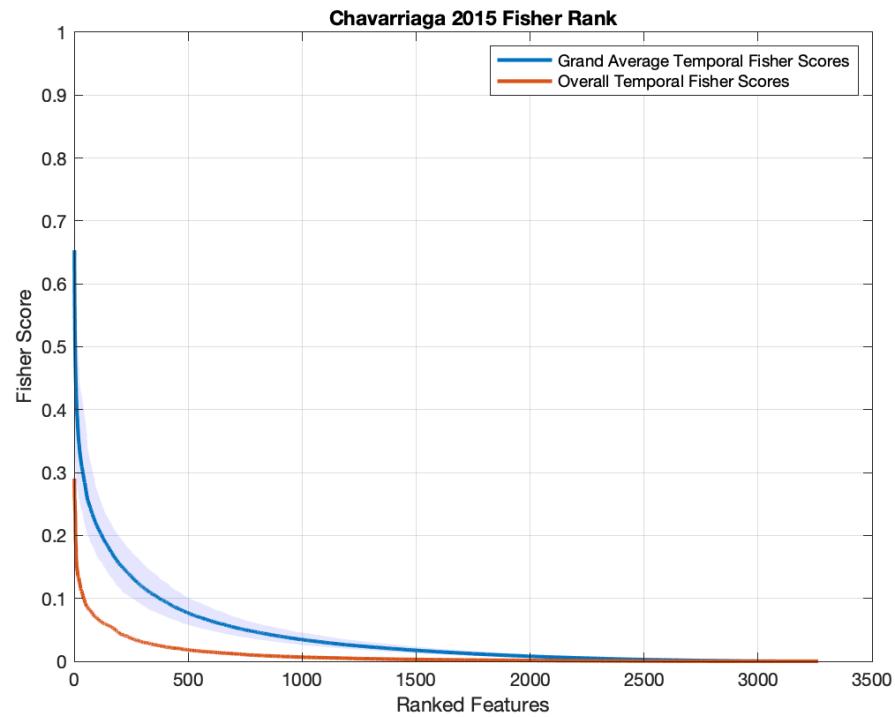
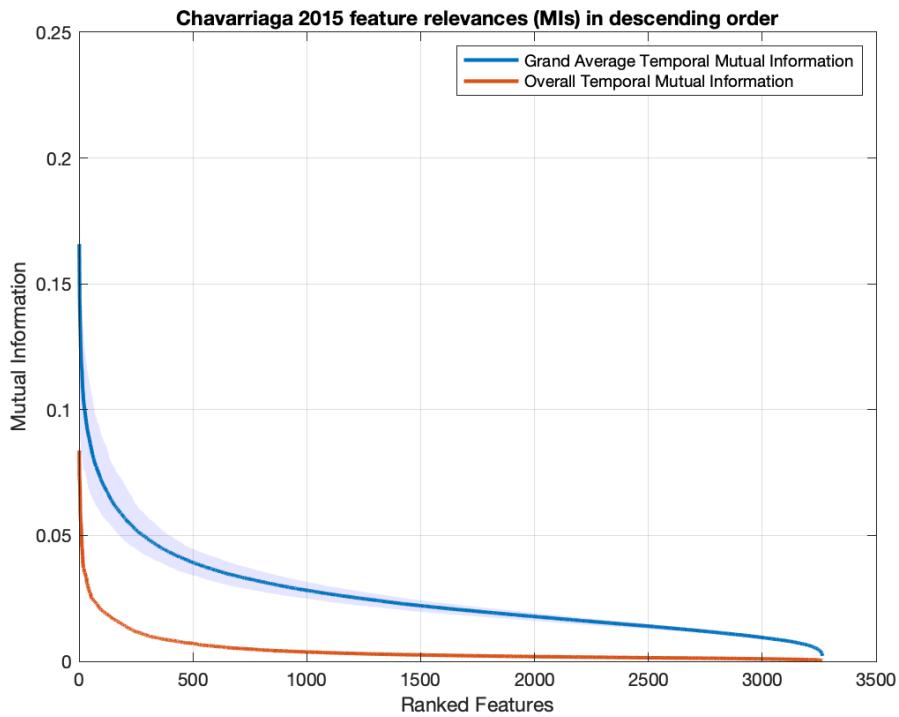
Chavarriaga 2015 – Simple Fisher Rank

N2 (244) ± 20 ms
P3 (276) ± 20 ms

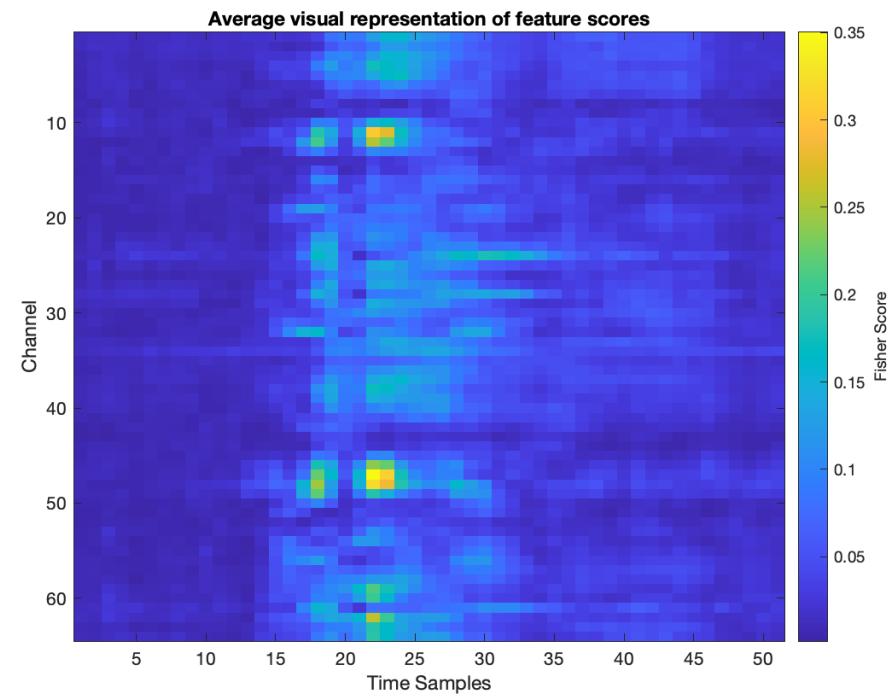
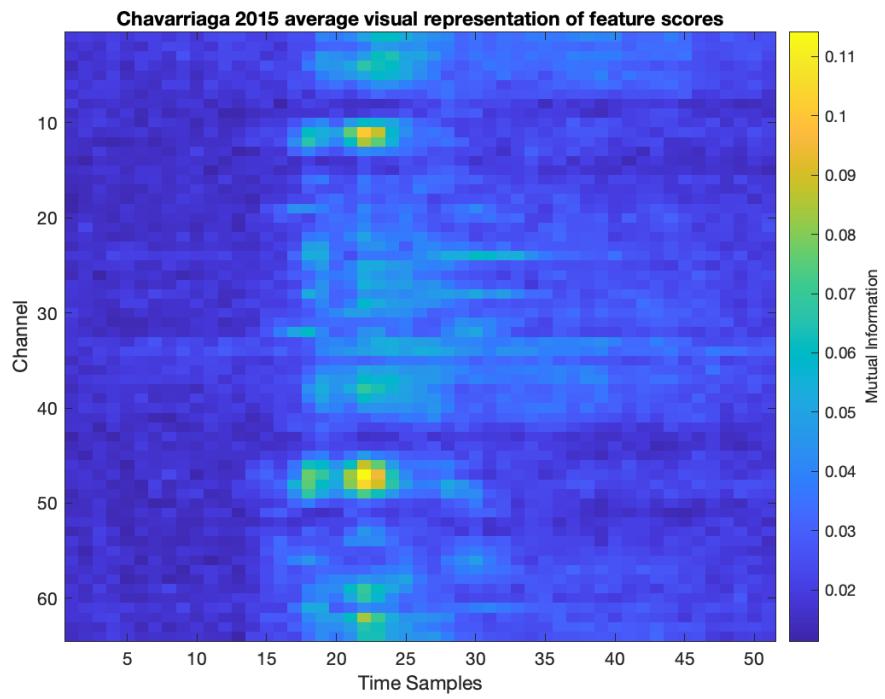
Cz & FCz



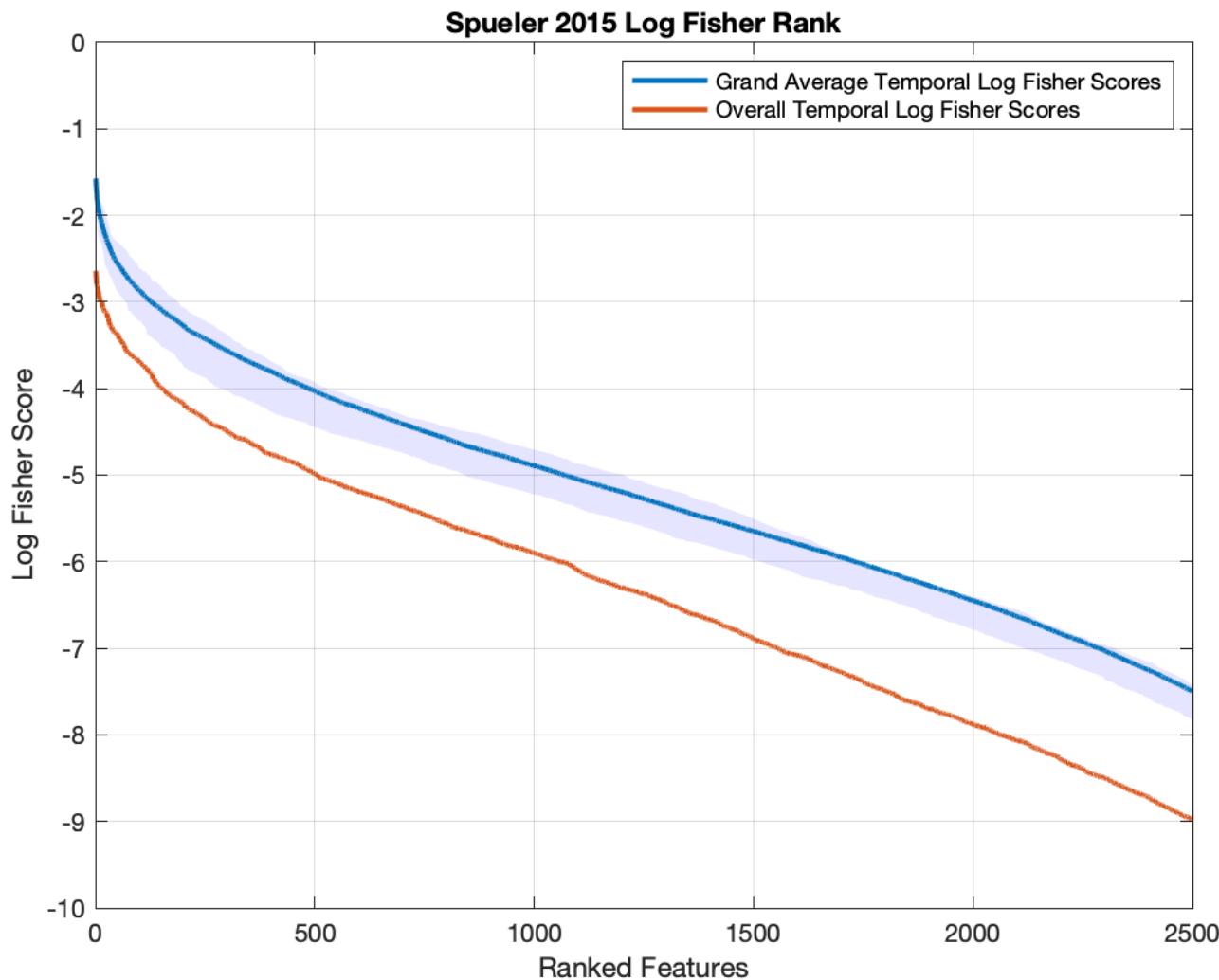
Chavarriaga 2015 – MI vs Fisher Rank



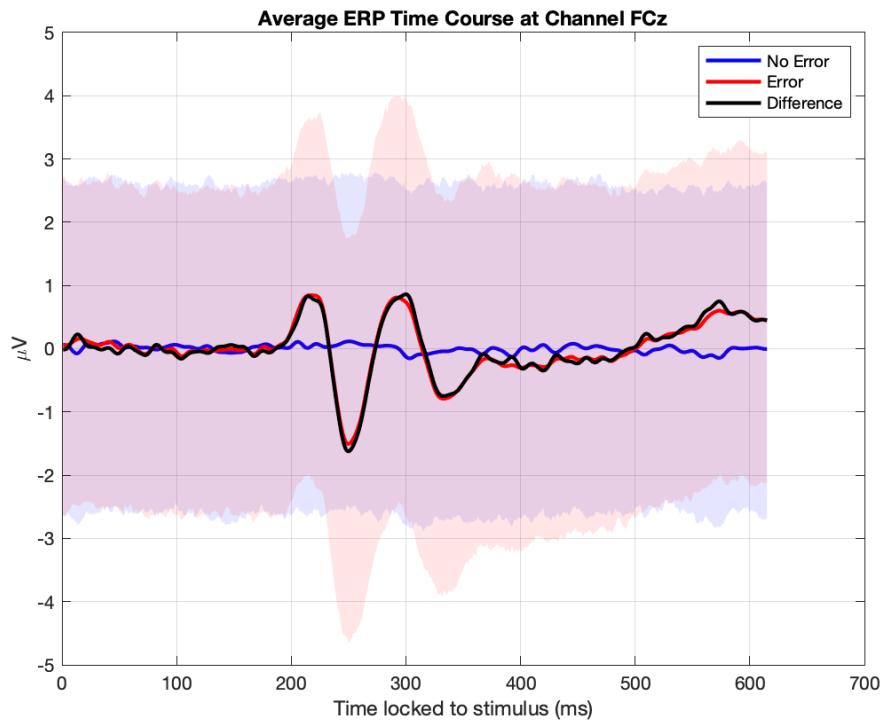
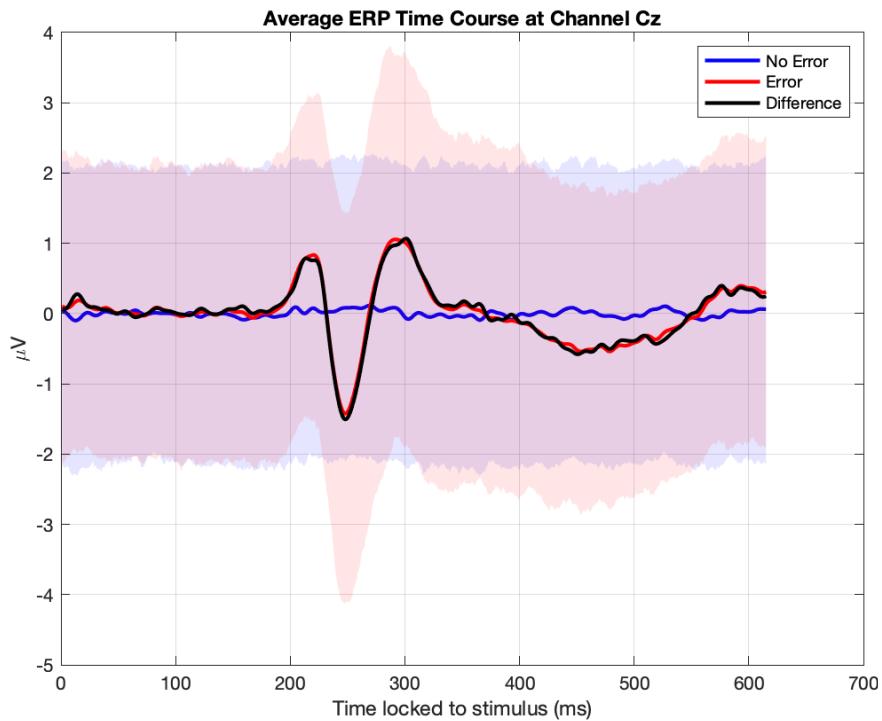
Chavarriaga 2015 – MI vs Fisher Rank



Spueler 2015 – Log Plot Fisher Rank



Spueler 2015 – ERP

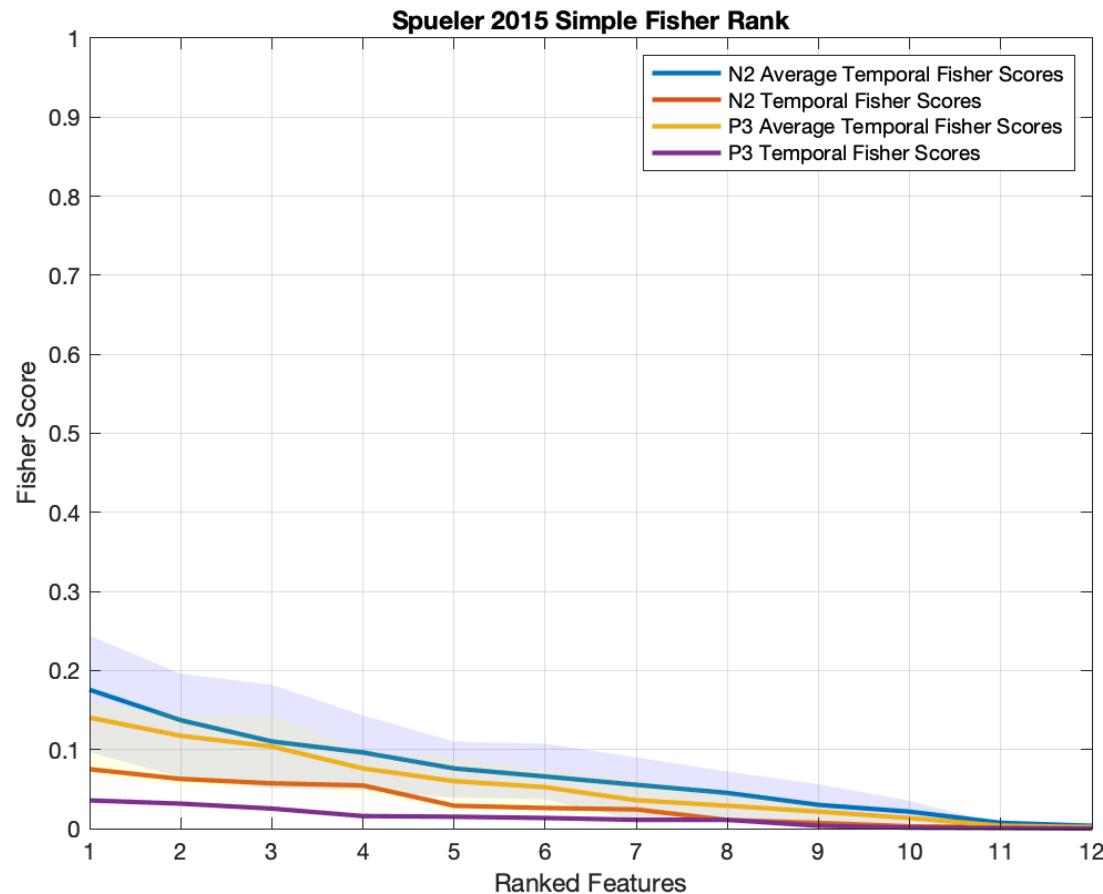


Confidence Interval: 0.25-0.75 quantiles

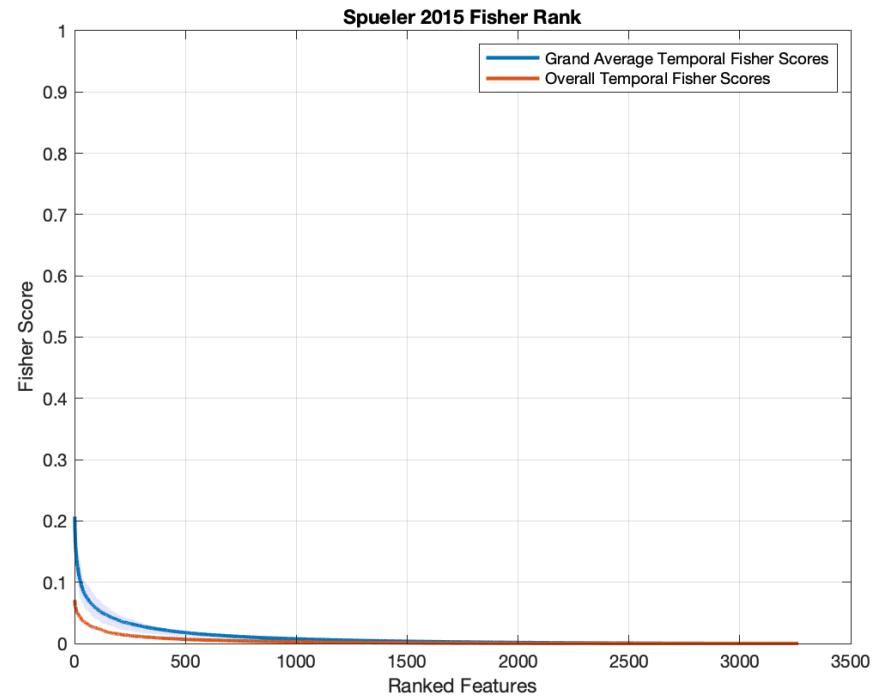
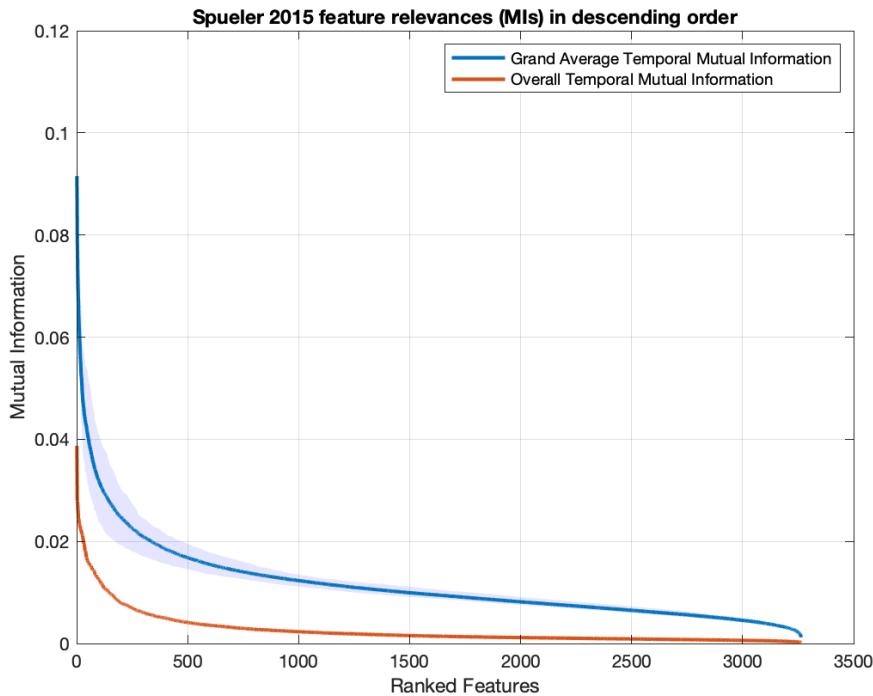
Spueler 2015 – Simple Fisher Rank

N2 (258) ± 20 ms
P3 (292) ± 20 ms

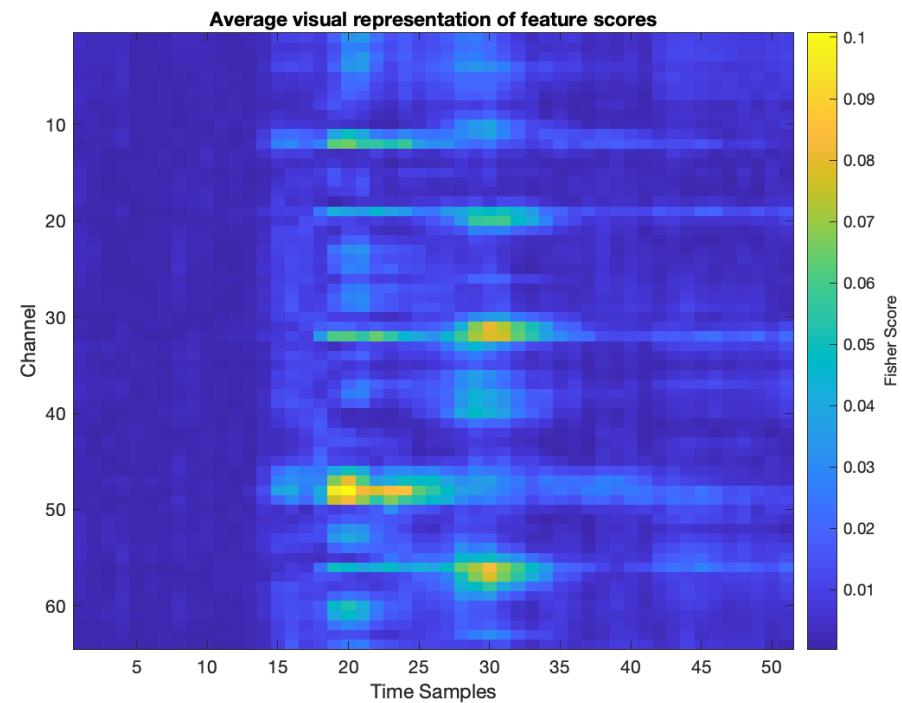
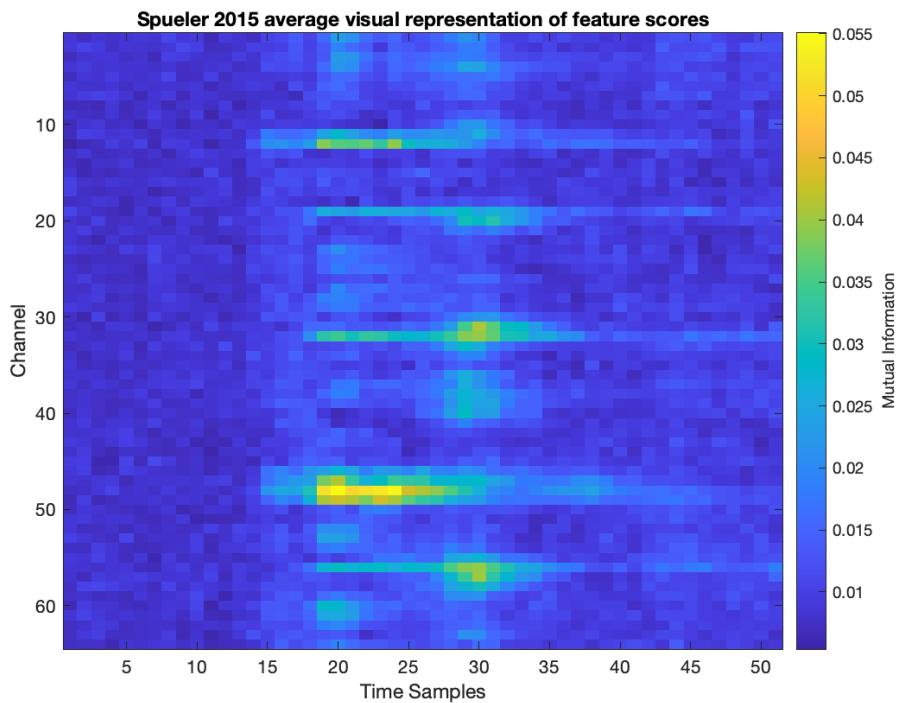
Cz & FCz



Spueler 2015 – MI vs Fisher Rank



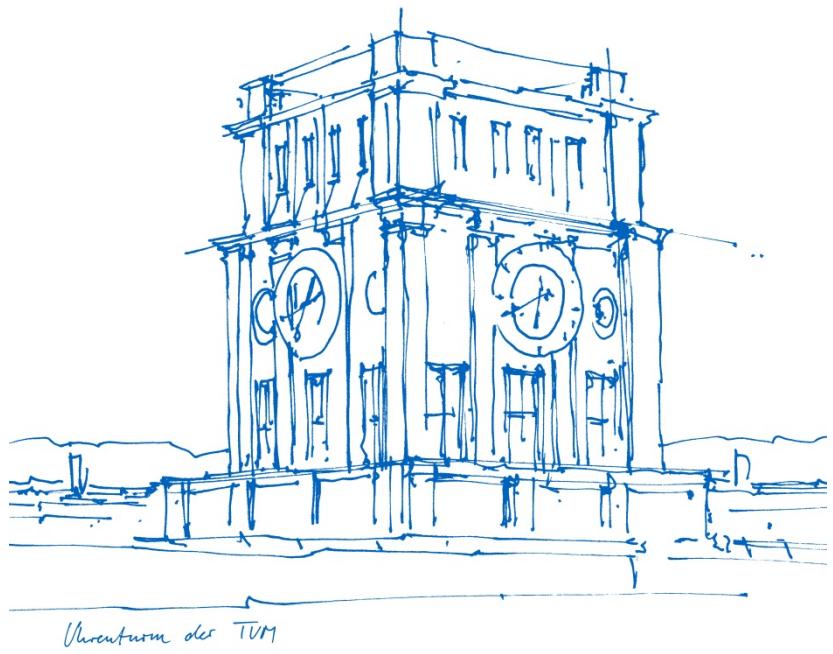
Spueler 2015 – MI vs Fisher Rank



Temporal Data Analysis of EEG Sets

Update

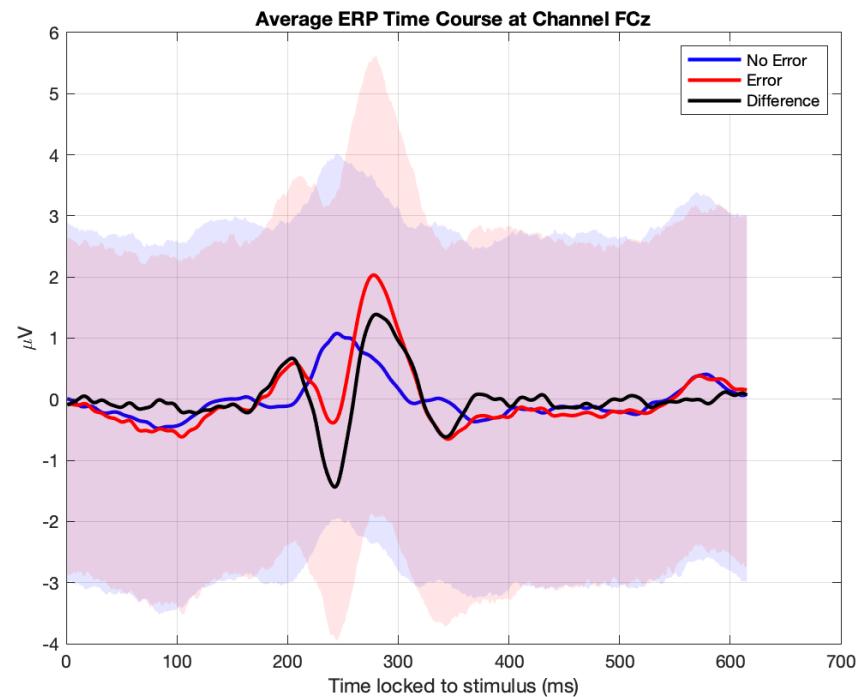
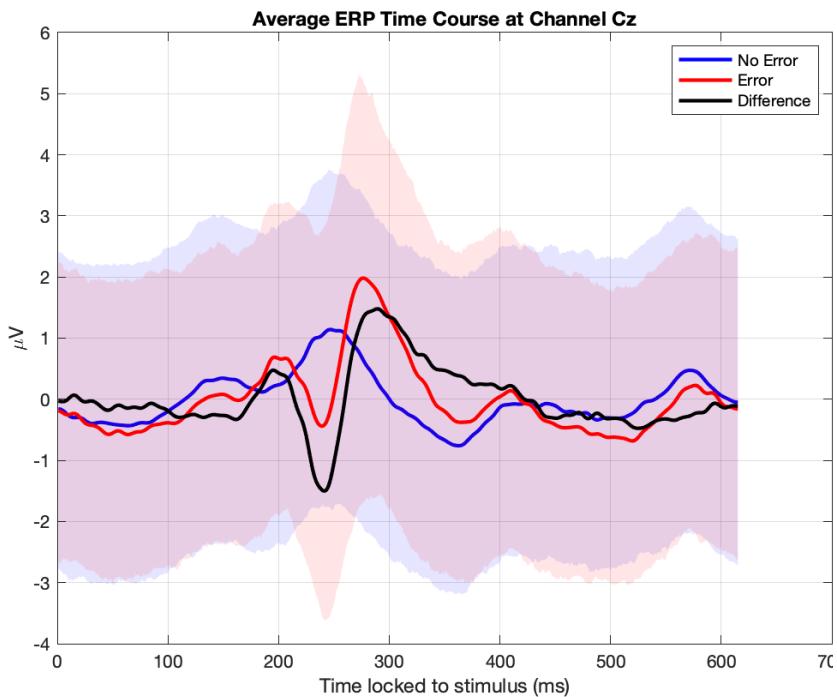
April 24, 2020



Overview

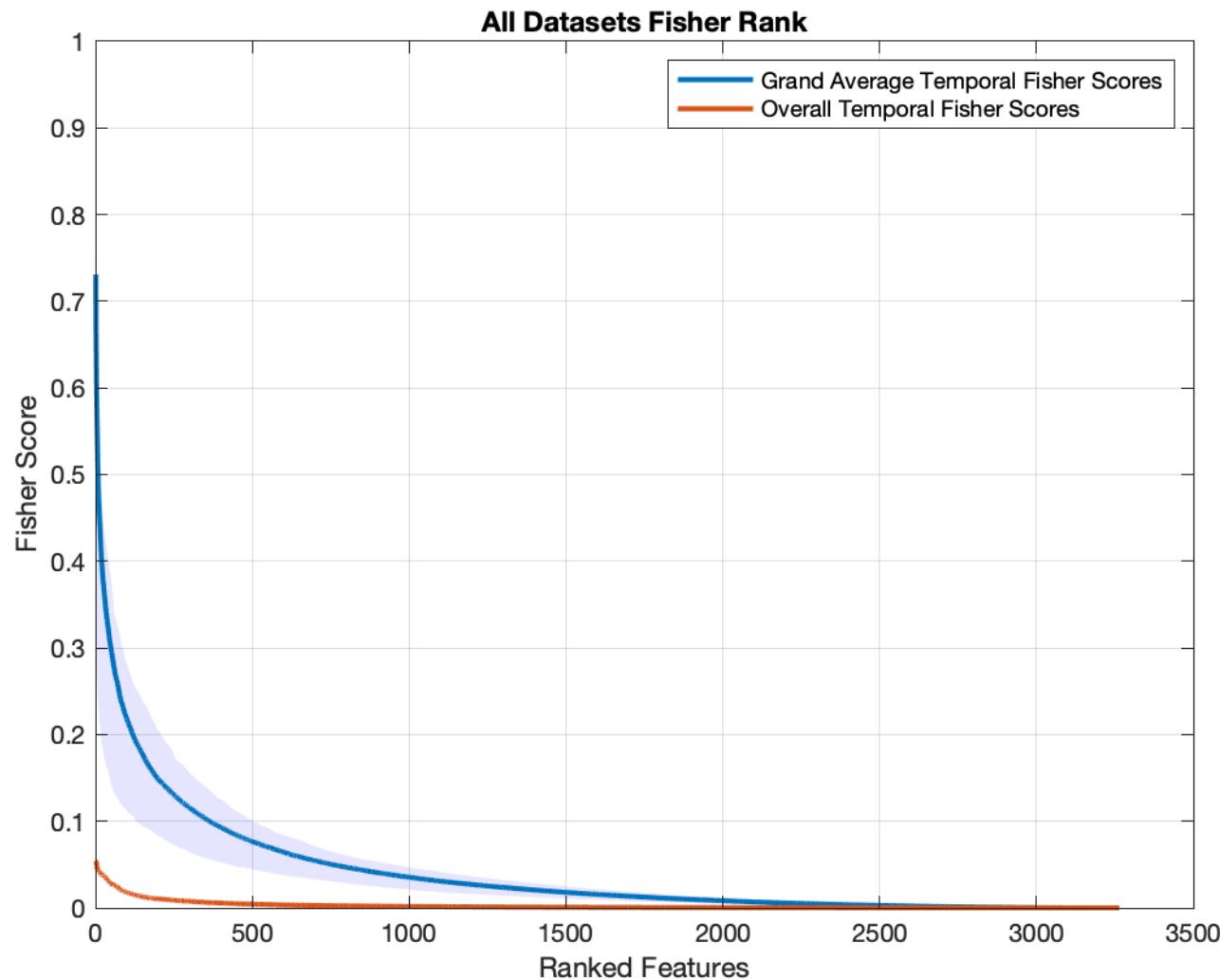
1. All EEG Data Sets (All Subjects)
 - i. ERP All Subjects
 - ii. Average Feature Results
 - iii. Windowed ERP
2. Ehrlich 2016
 - i. Average Feature Results
3. Ehrlich 2018
 - i. Average Feature Results
4. Chavarriaga 2015
 - i. Average Feature Results
5. Spueler 2015
 - i. Average Feature Results

All Subjects – ERP

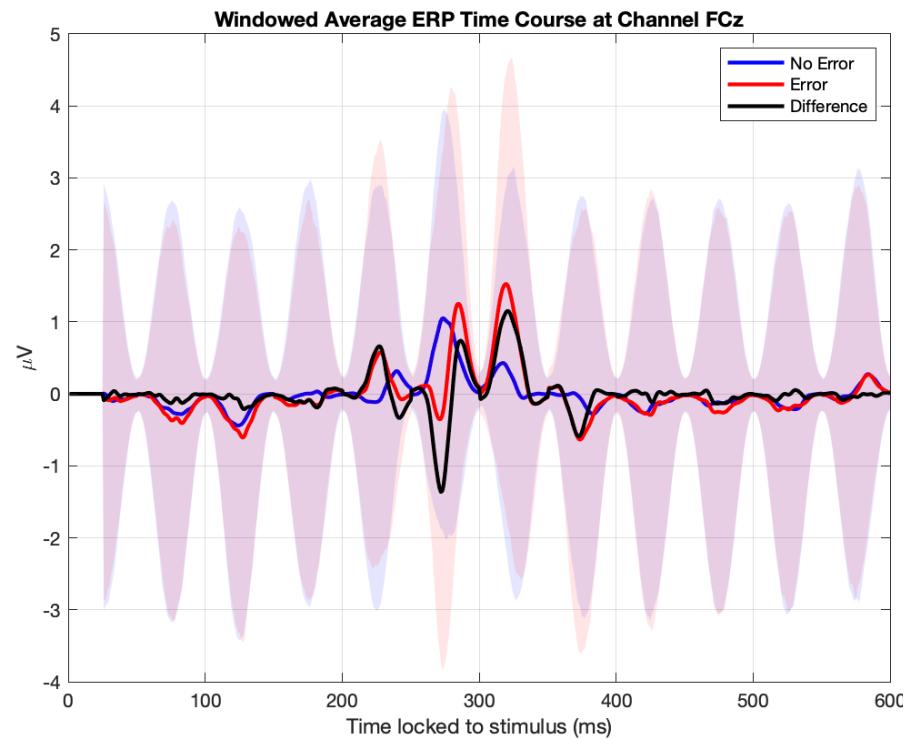
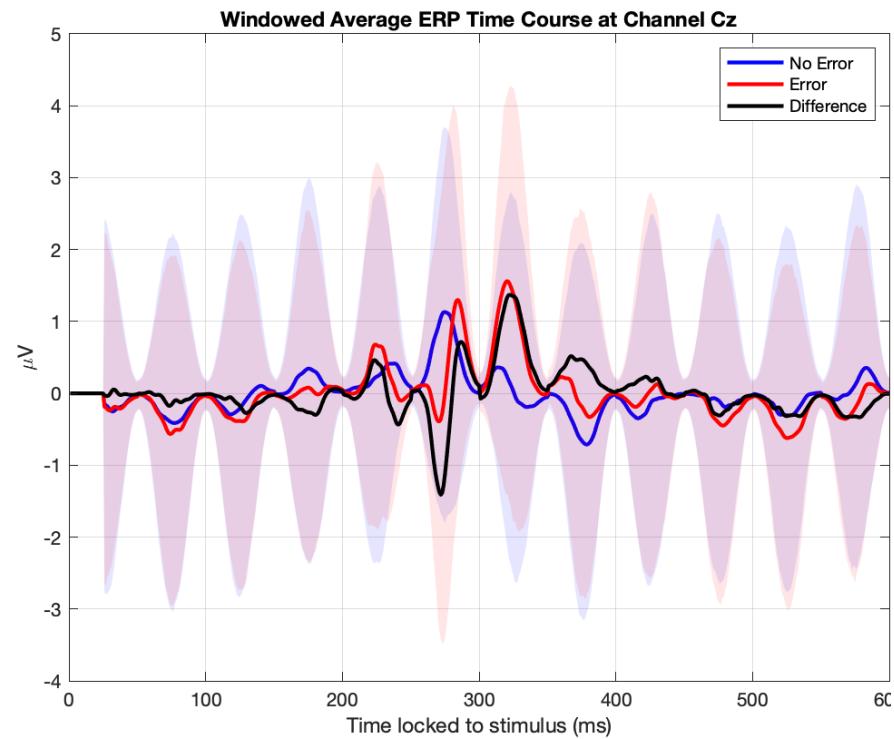


Confidence Interval: 0.25-0.75 quantiles

All Subjects – Average Feature Results



All Subjects – Windowed ERP



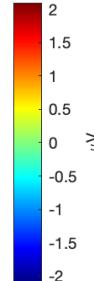
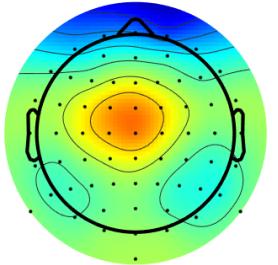
Hamming window – size 100

Sliding step = 50

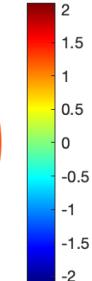
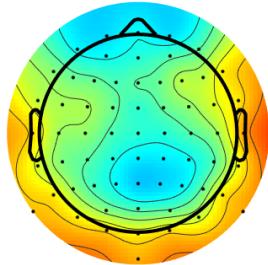
Confidence Interval: 0.25-0.75 quantiles

All Subjects – Windowed ERP

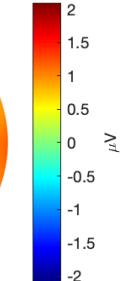
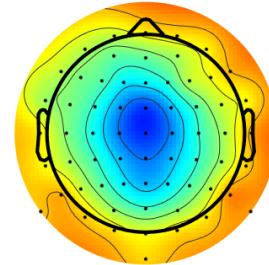
Windowed Average No Error Activation at t=272ms



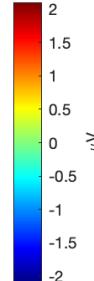
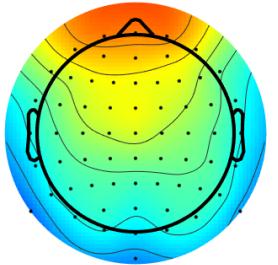
Windowed Average Error Activation at t=272ms



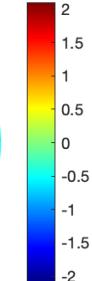
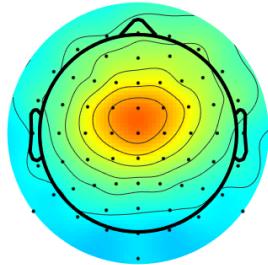
Windowed Average Difference Activation at t=272ms



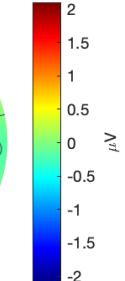
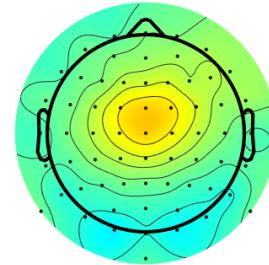
Windowed Average No Error Activation at t=288ms



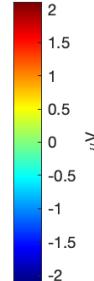
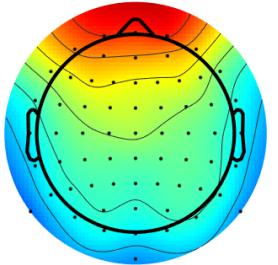
Windowed Average Error Activation at t=288ms



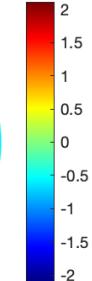
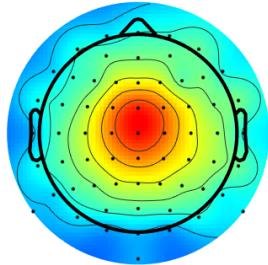
Windowed Average Activation Difference at t=288ms



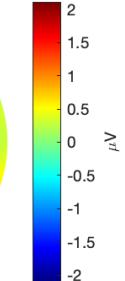
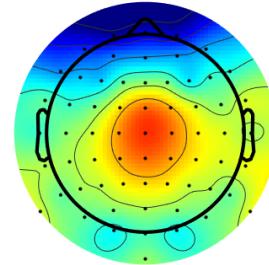
Windowed Average No Error Activation at t=272ms



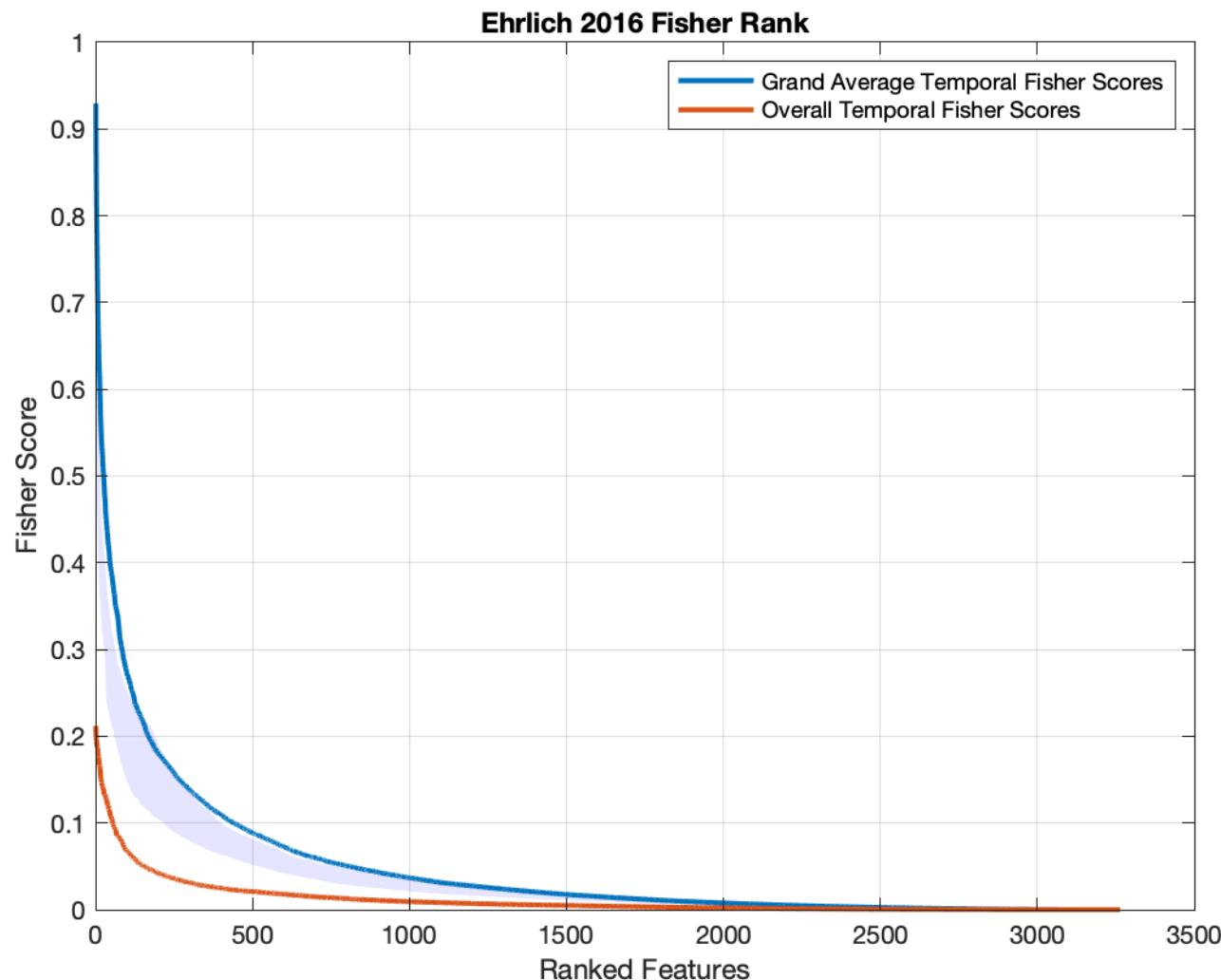
Windowed Average Error Activation at t=322ms



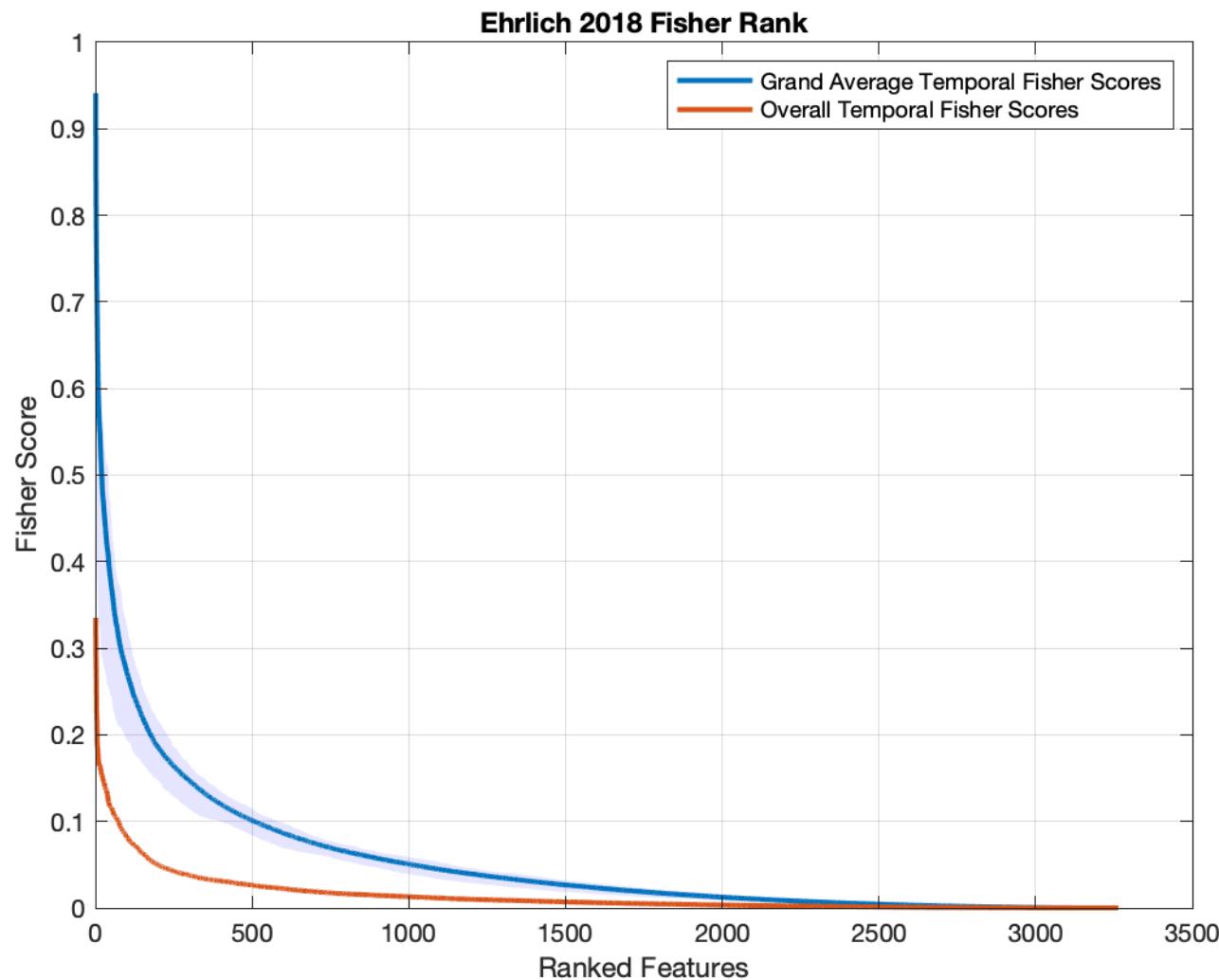
Windowed Average Activation Difference at t=322ms



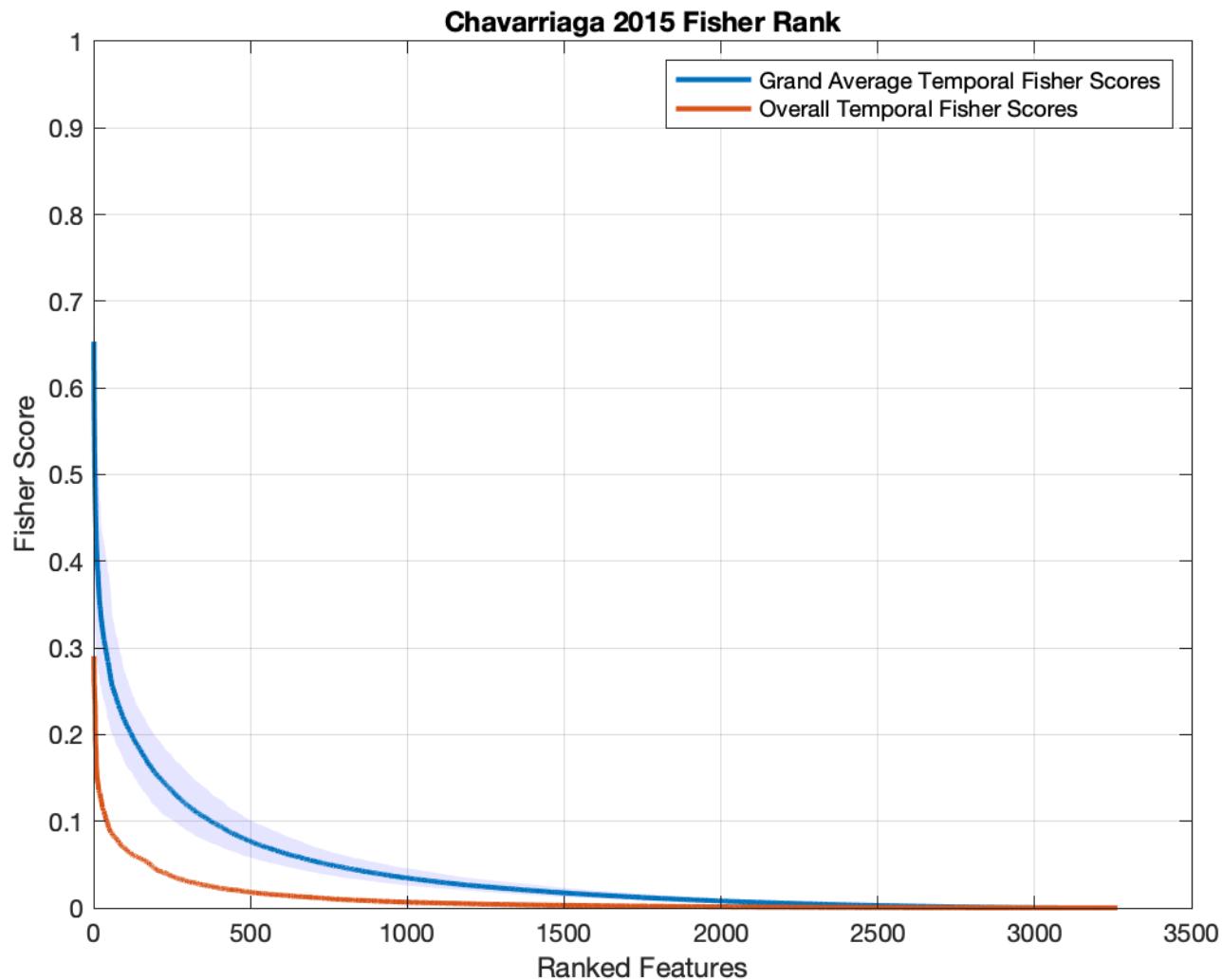
Ehrlich 2016 – Average Feature Results



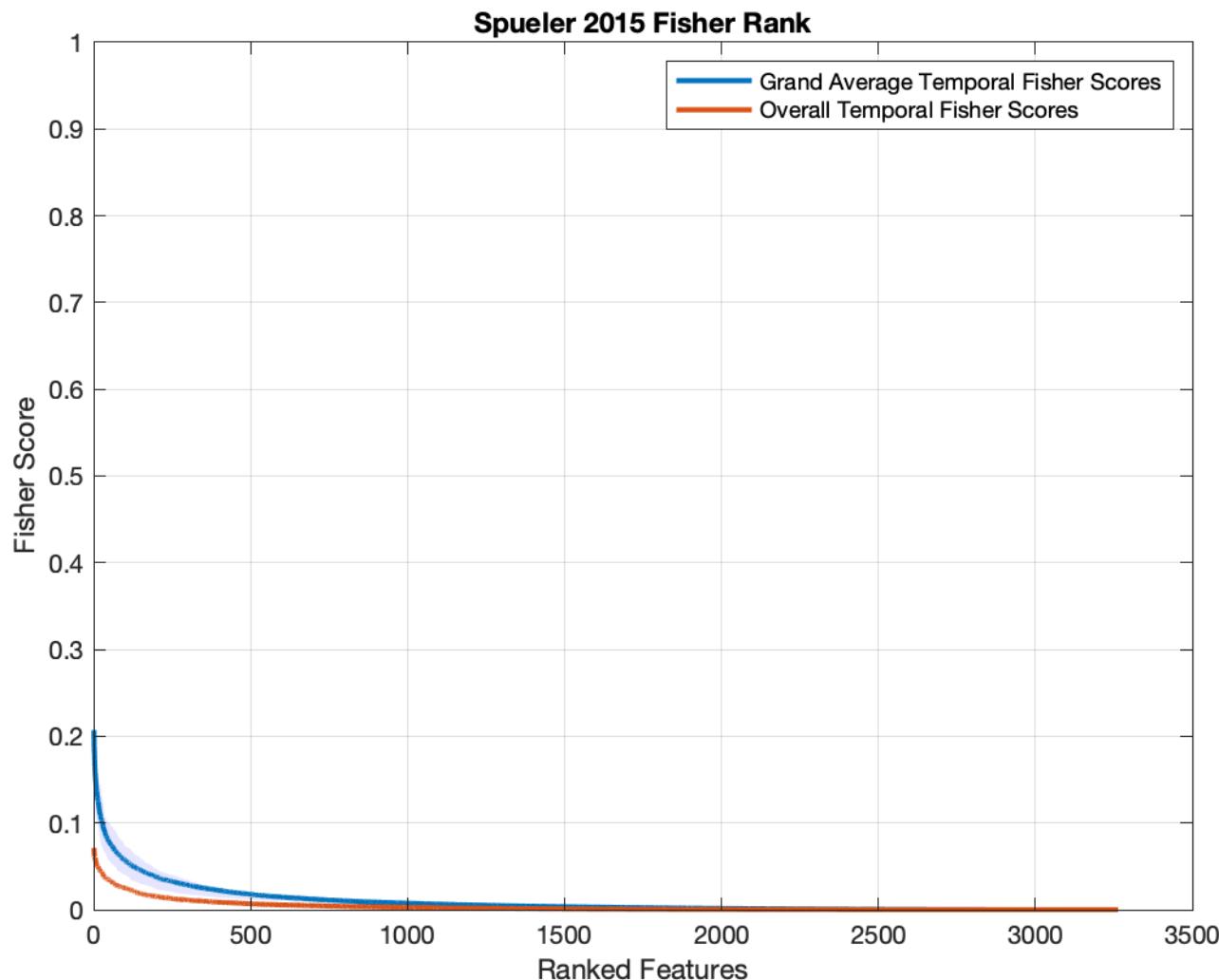
Ehrlich 2018 – Average Feature Results



Chavarriaga 2015 – Average Feature Results



Spueler 2015 – Average Feature Results



Temporal Data Analysis of EEG Sets

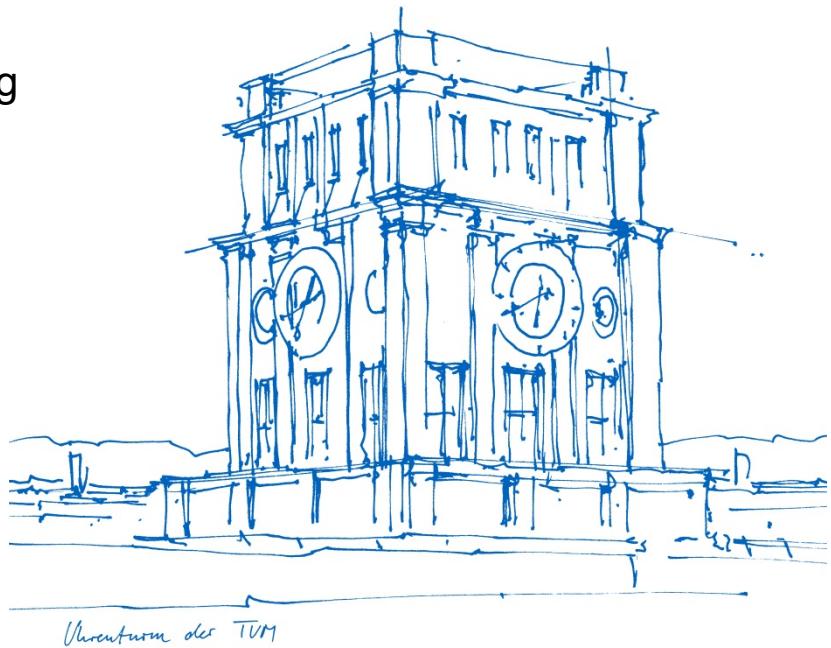
Nick Tacca

Elite Master of Science in Neuroengineering

Department of Electrical and Computer Engineering

Technical University of Munich

April 9, 2020



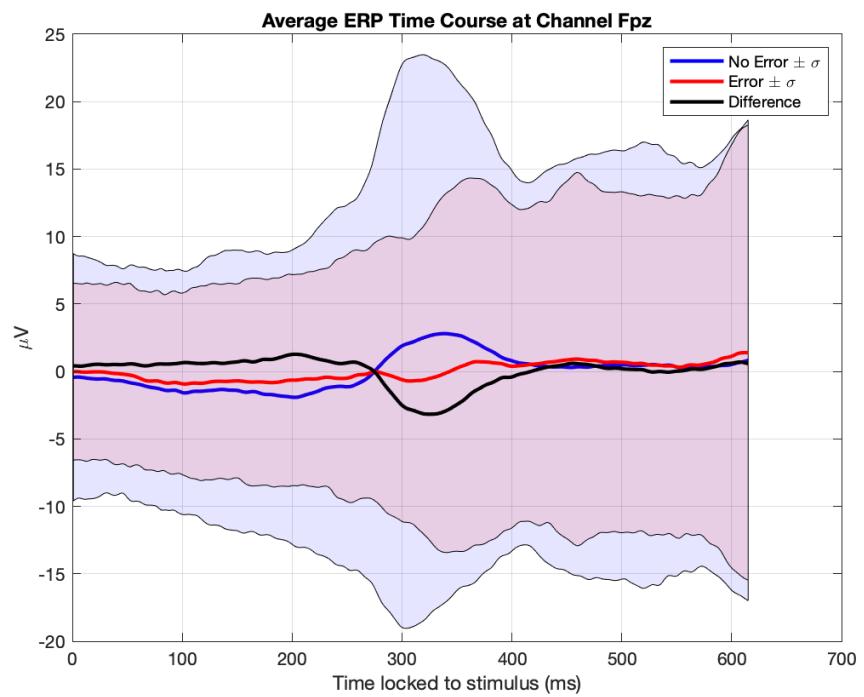
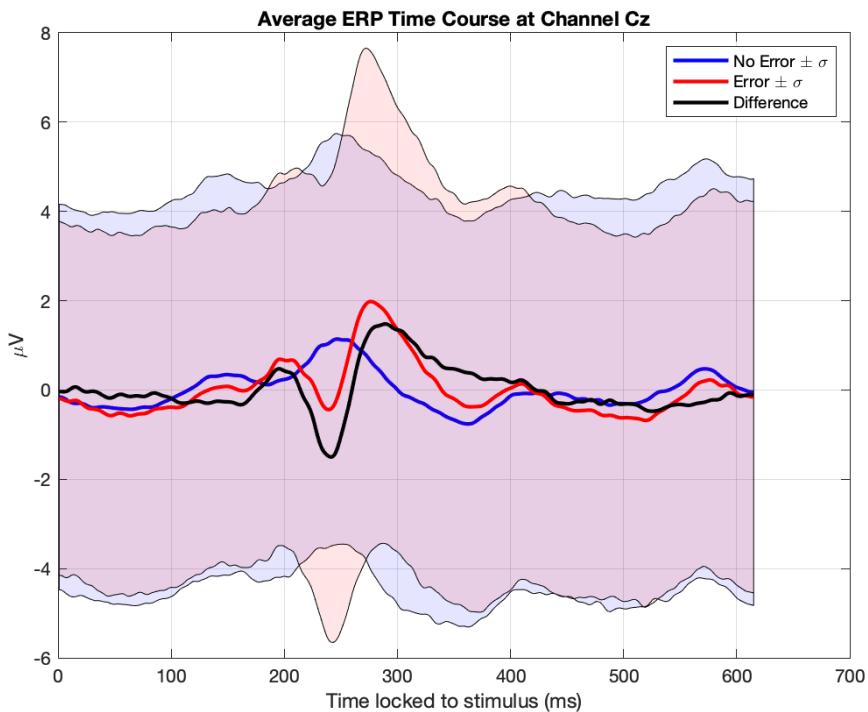
Overview

1. All EEG Data Sets (All Subjects)
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3. Ehrlich 2018
4. Chavarriaga 2015
5. Spueler 2015

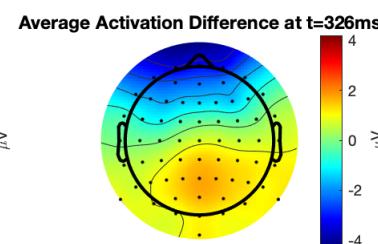
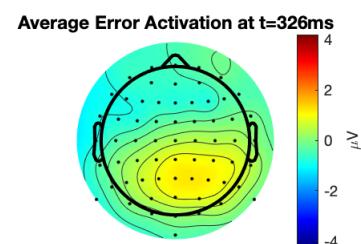
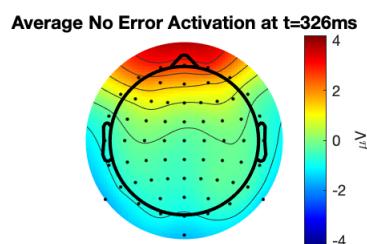
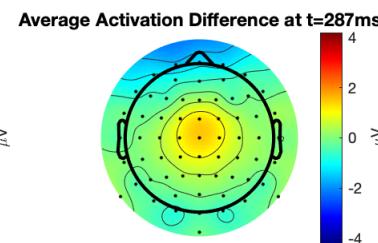
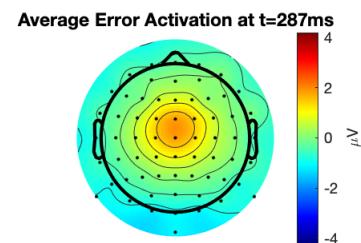
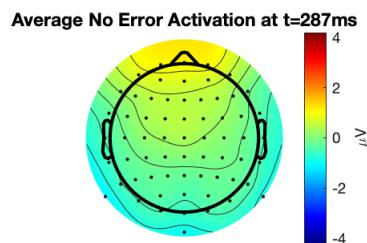
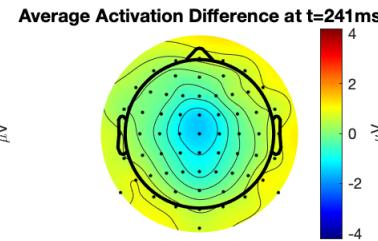
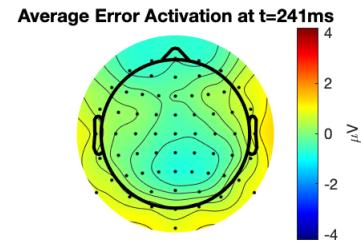
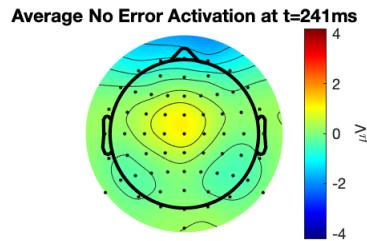
Within each Section:

- i. ERP All Subjects
- ii. Average Feature Results
- iii. All Together Feature Results

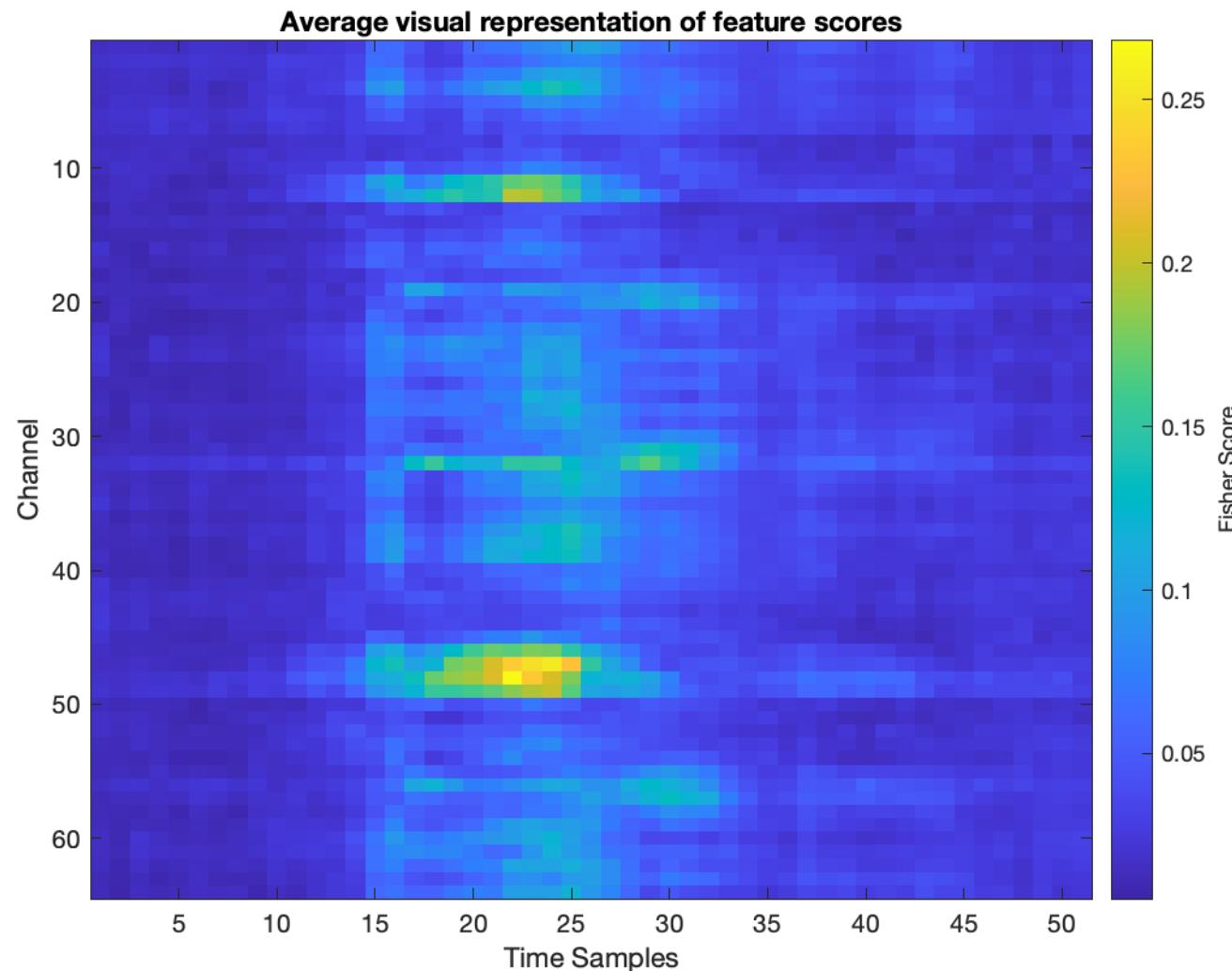
All Subjects – ERP



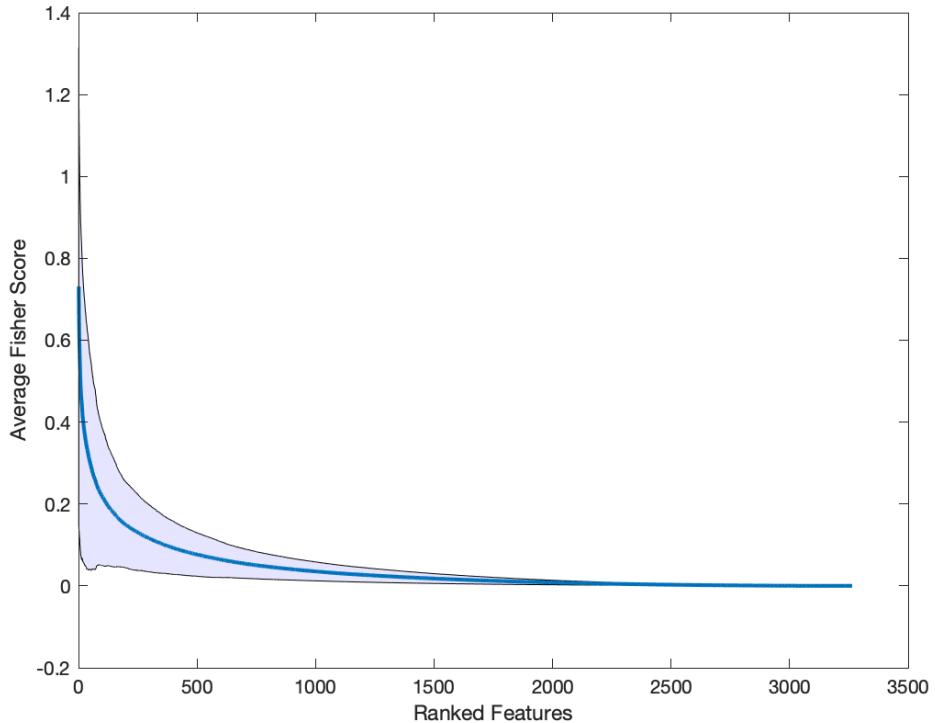
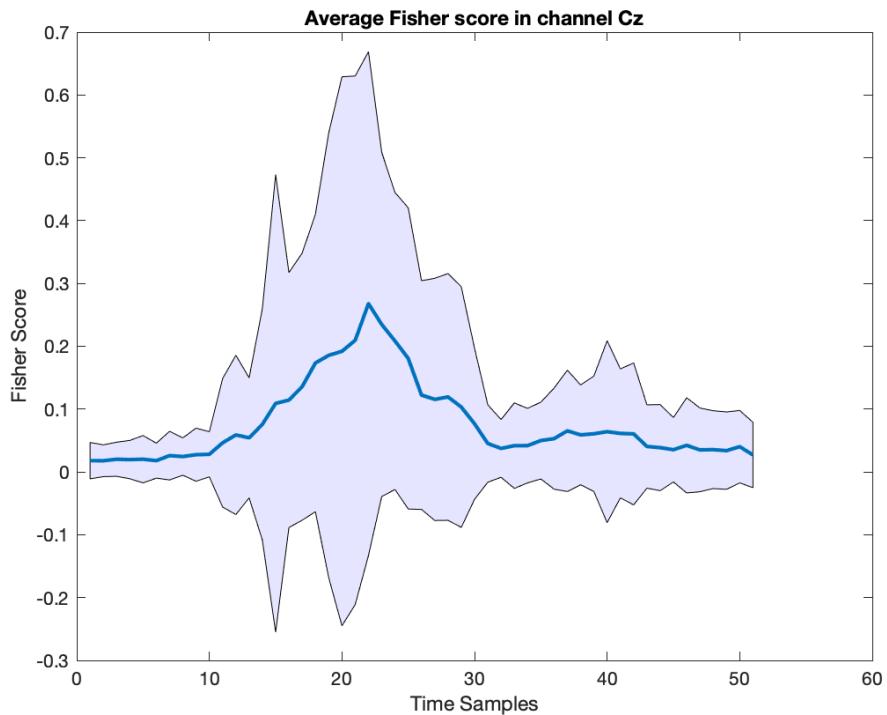
All Subjects – ERP



All Subjects – Average Feature Results

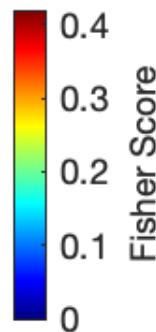
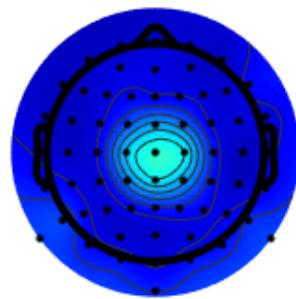


All Subjects – Average Feature Results

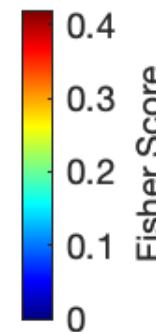
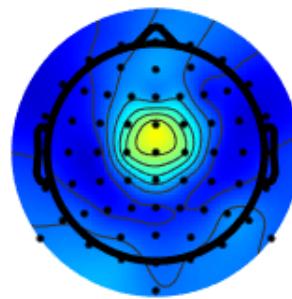


All Subjects – Average Feature Results

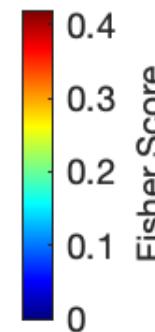
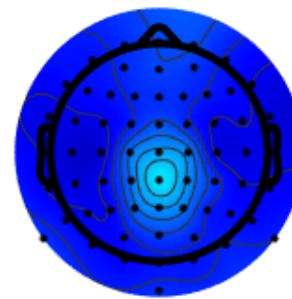
N200 (t=241ms)



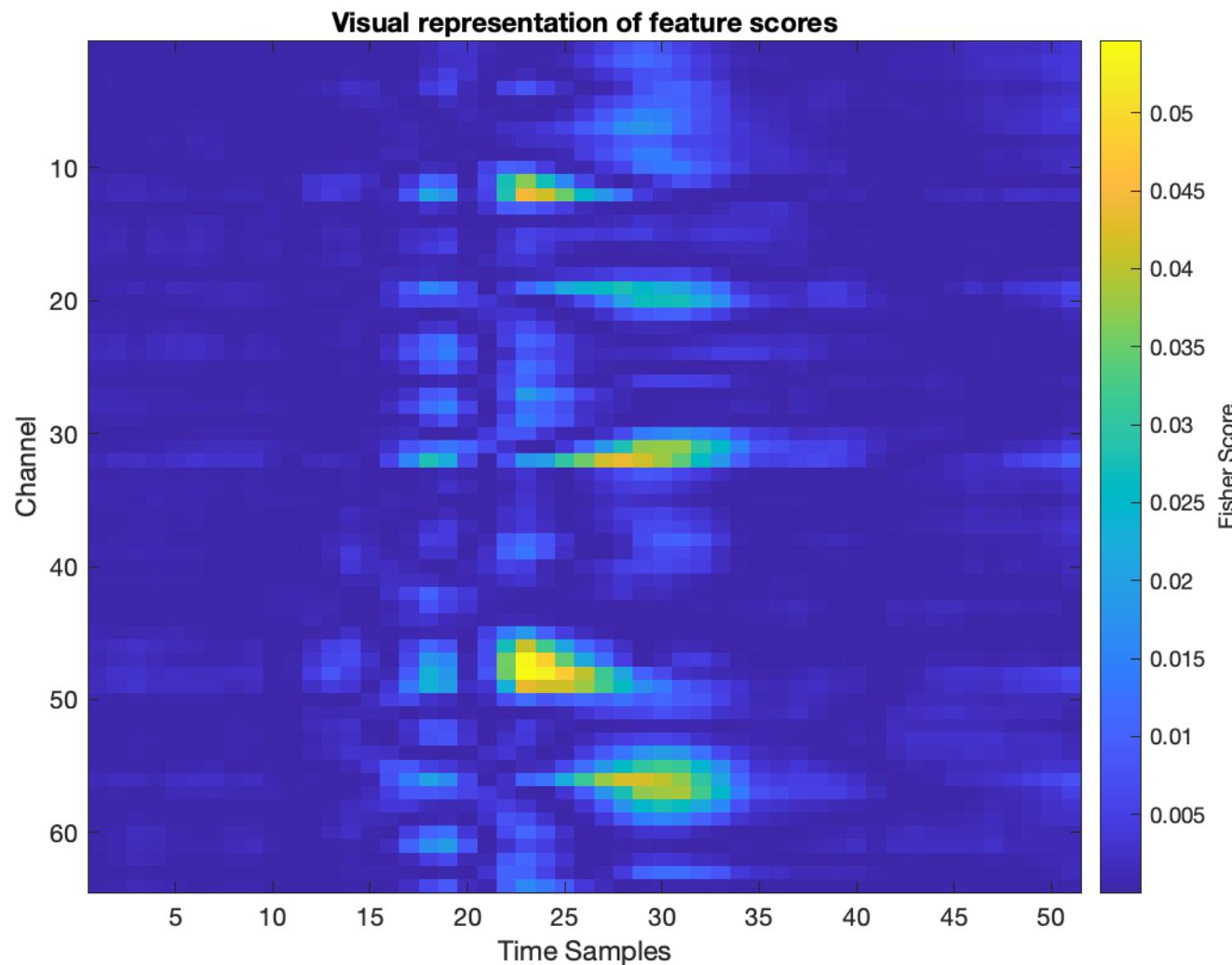
P300 (t=287ms)



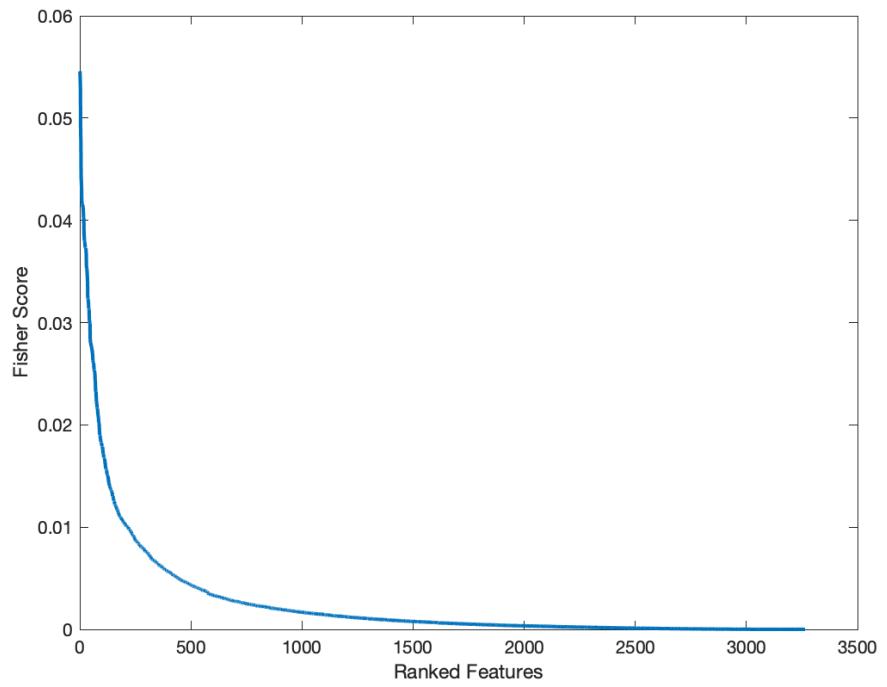
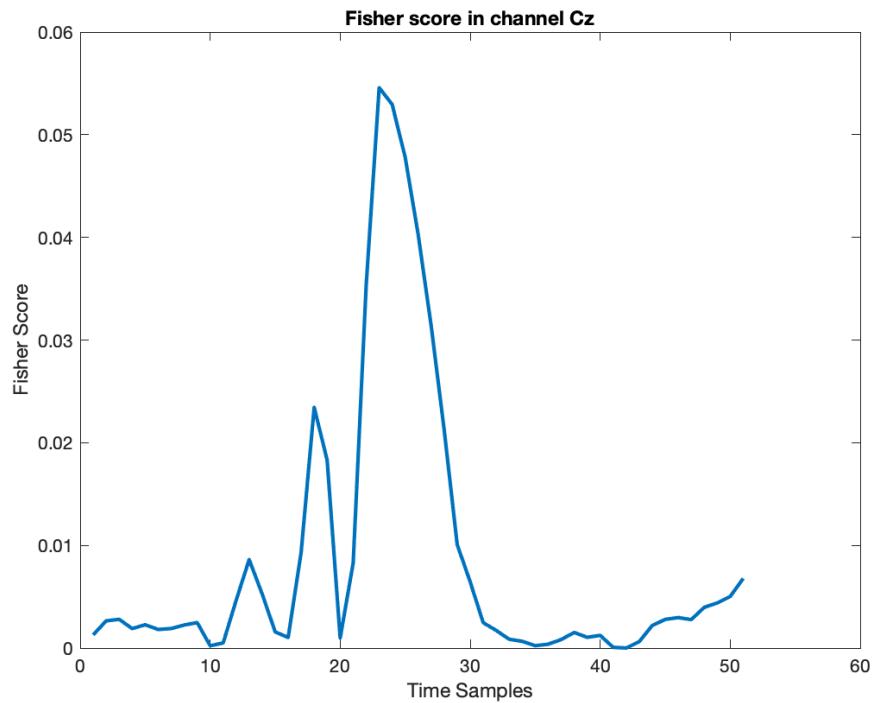
N400 (t=326ms)



All Subjects – All Together Feature Results

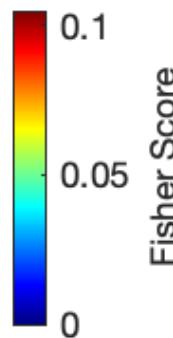
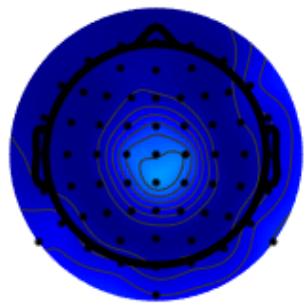


All Subjects – All Together Feature Results

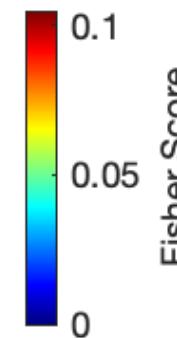
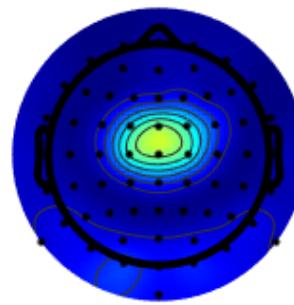


All Subjects – All Together Feature Results

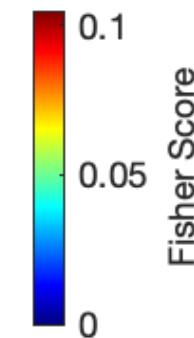
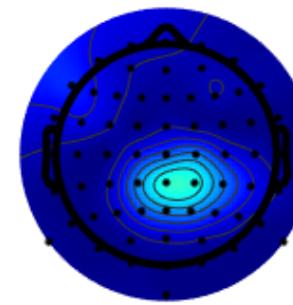
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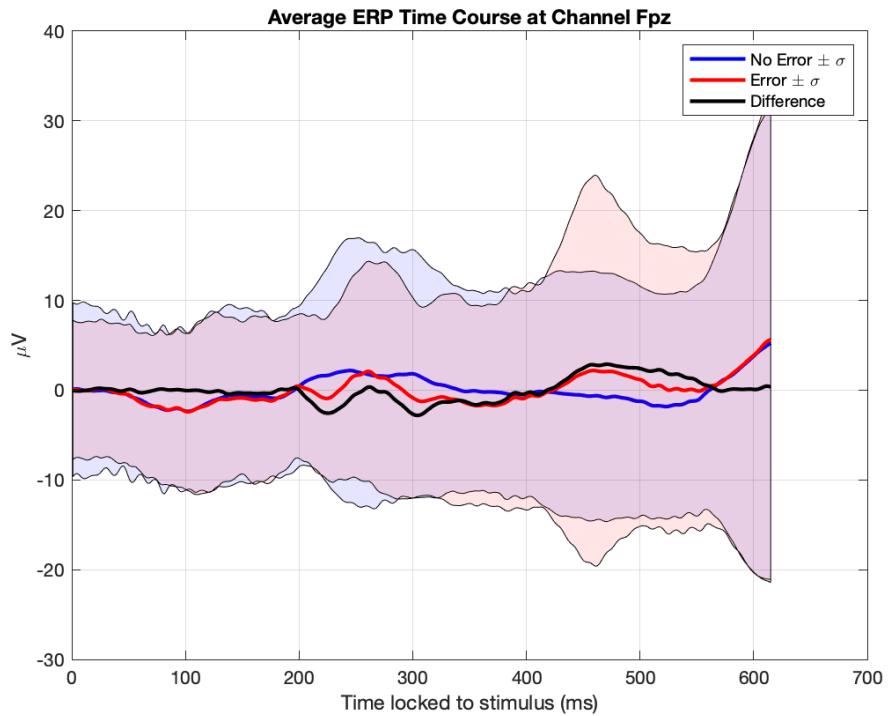
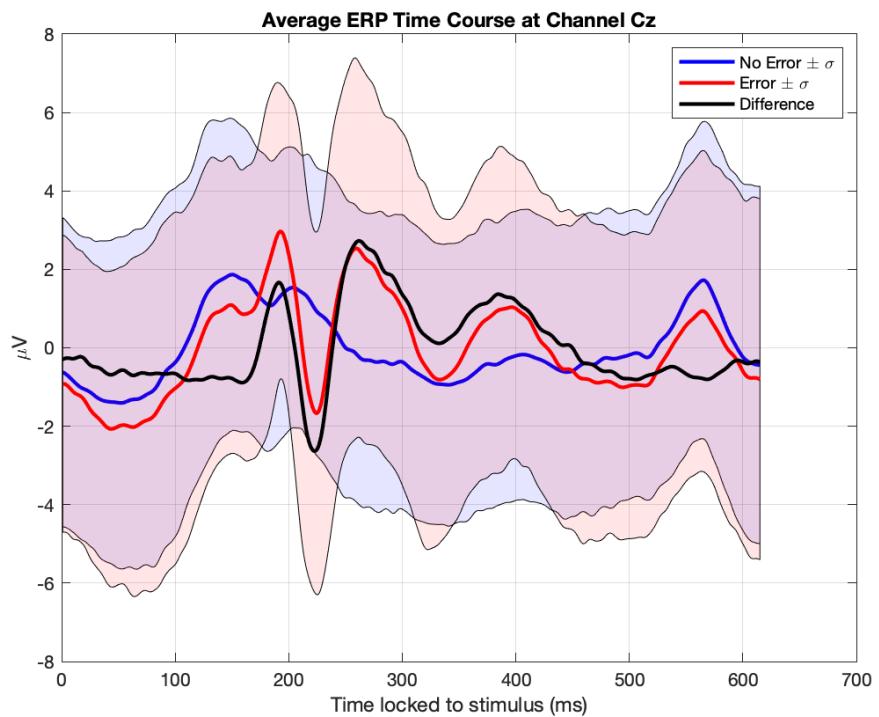
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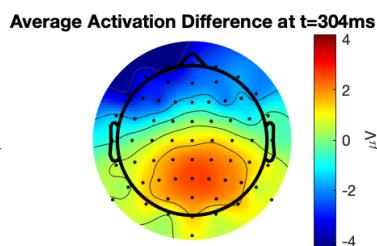
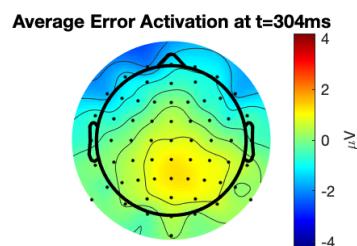
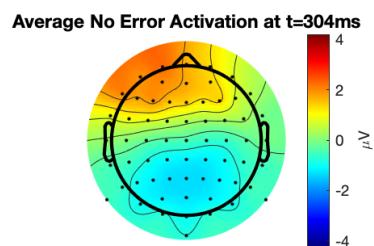
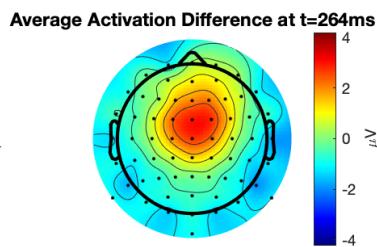
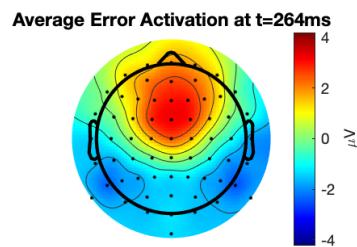
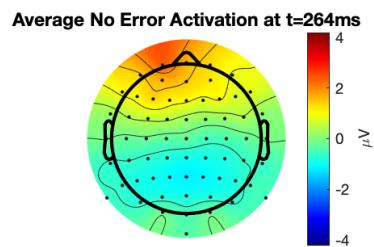
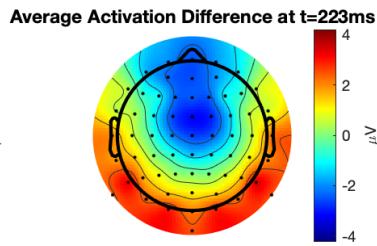
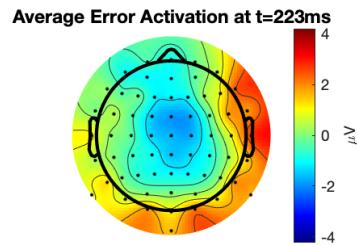
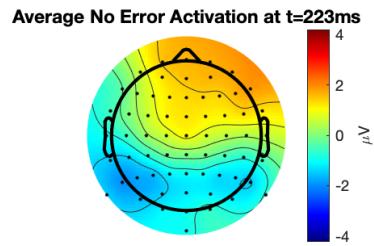
N400 (t=326ms)



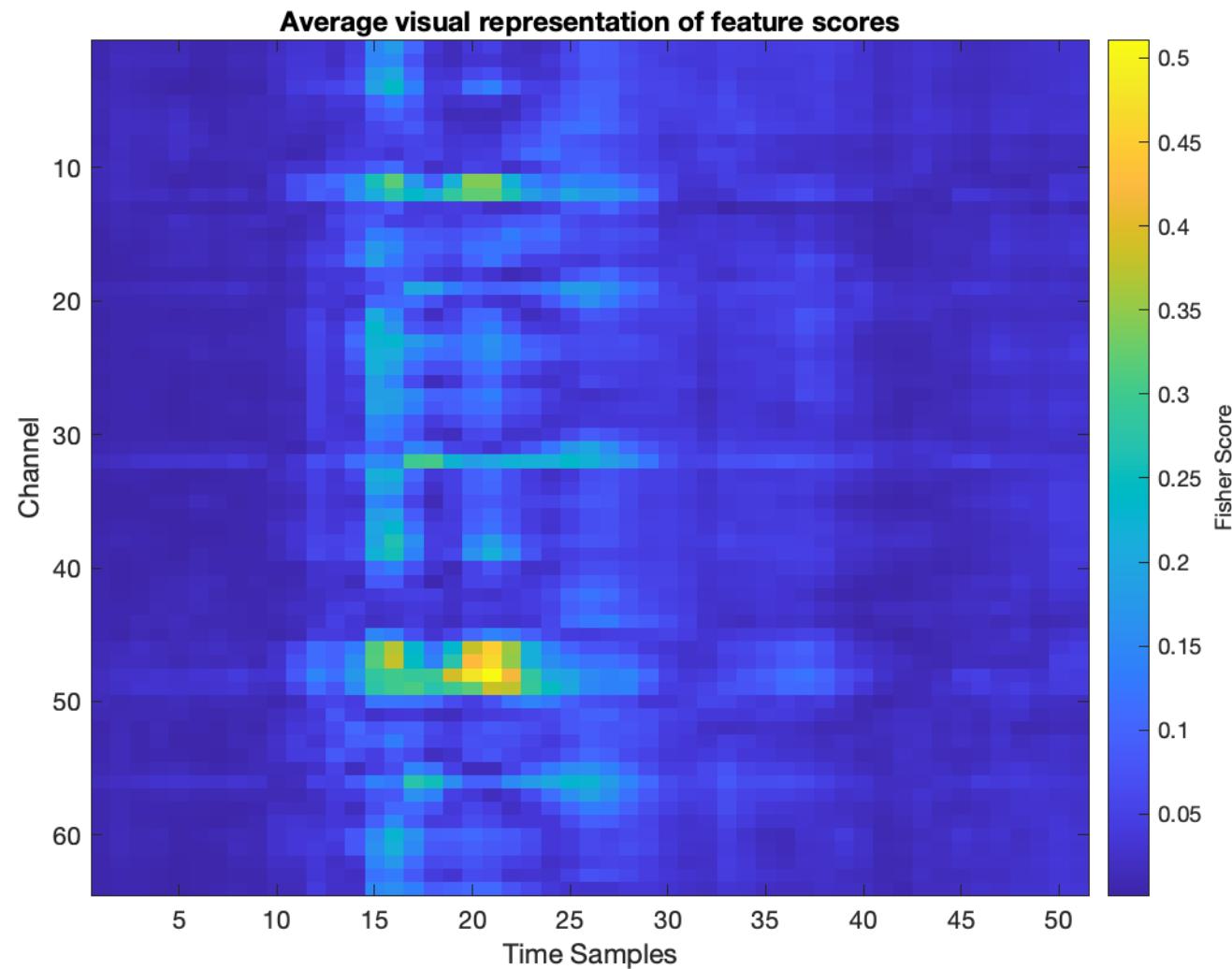
Ehrlich 2016 – ERP



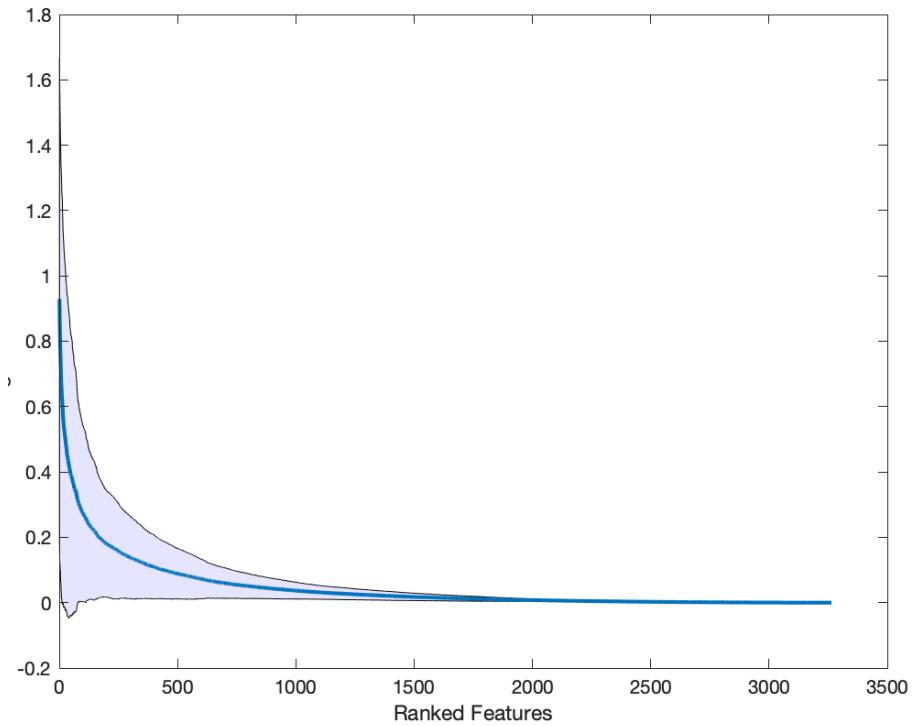
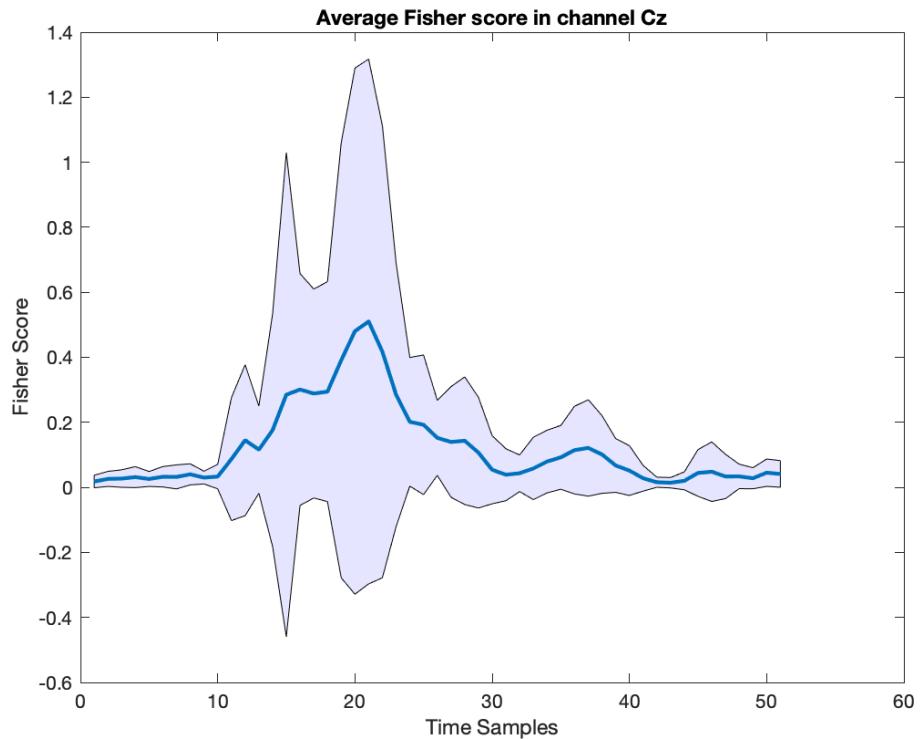
Ehrlich 2016 – ERP



Ehrlich 2016 – Average Feature Results

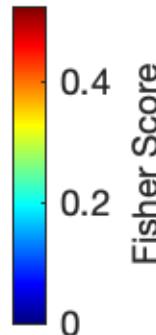
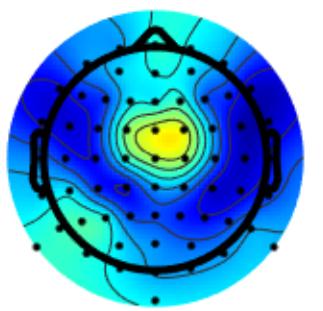


Ehrlich 2016 – Average Feature Results

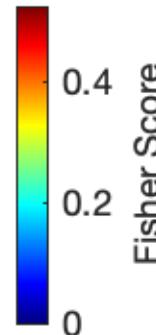
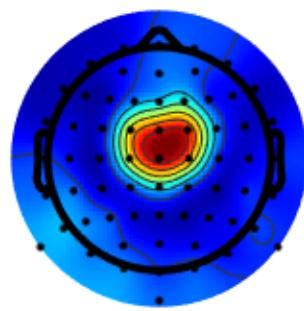


Ehrlich 2016 – Average Feature Results

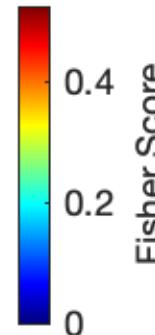
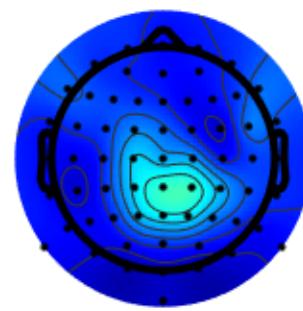
N200 (t=223ms)



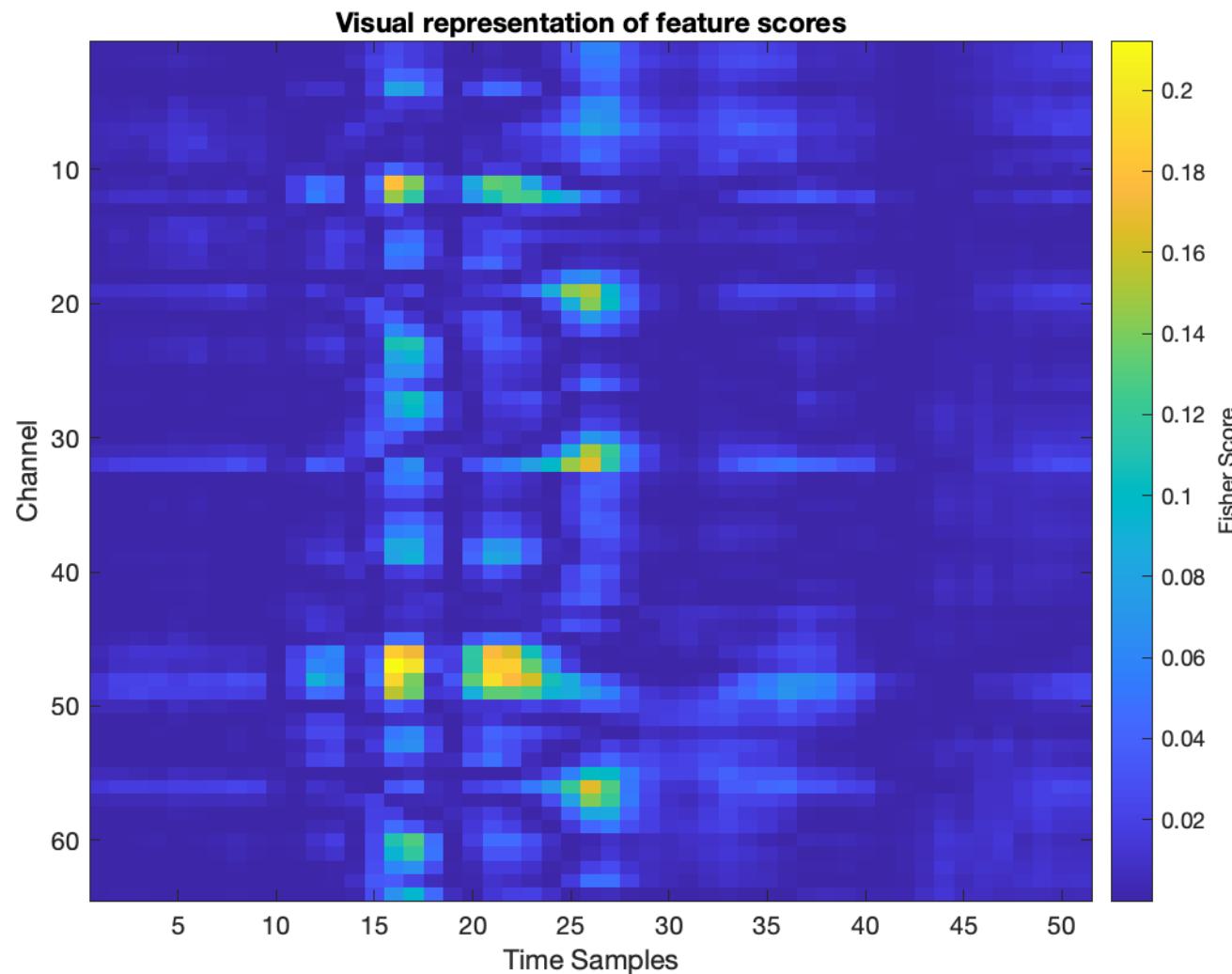
P300 (t=264ms)



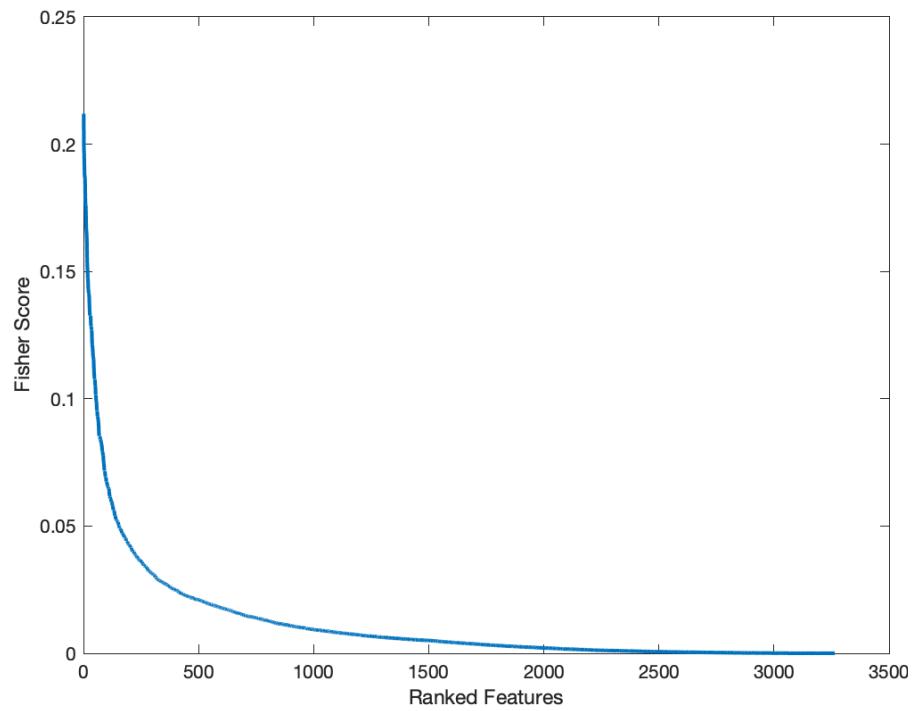
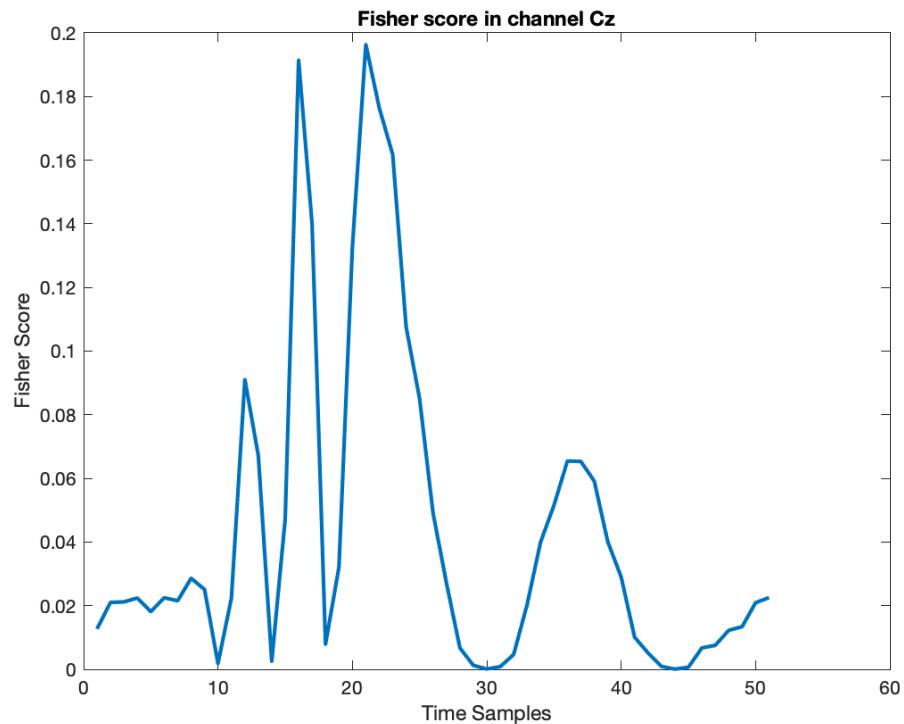
N400 (t=304ms)



Ehrlich 2016 – All Together Feature Results

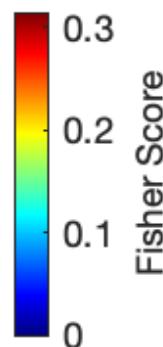
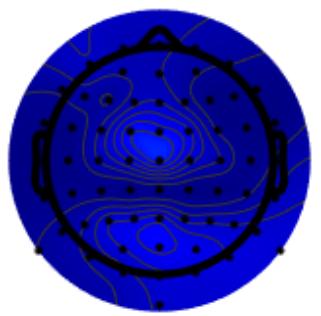


Ehrlich 2016 – All Together Feature Results

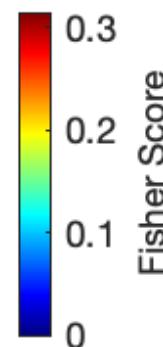
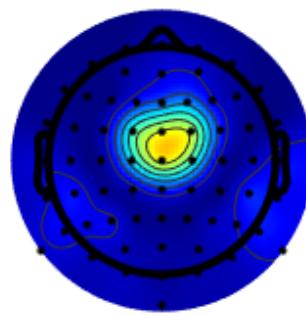


Ehrlich 2016 – All Together Feature Results

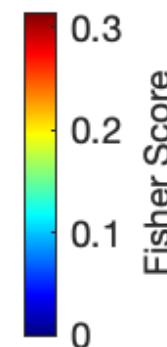
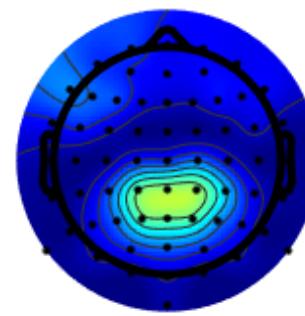
N200 (t=223ms)



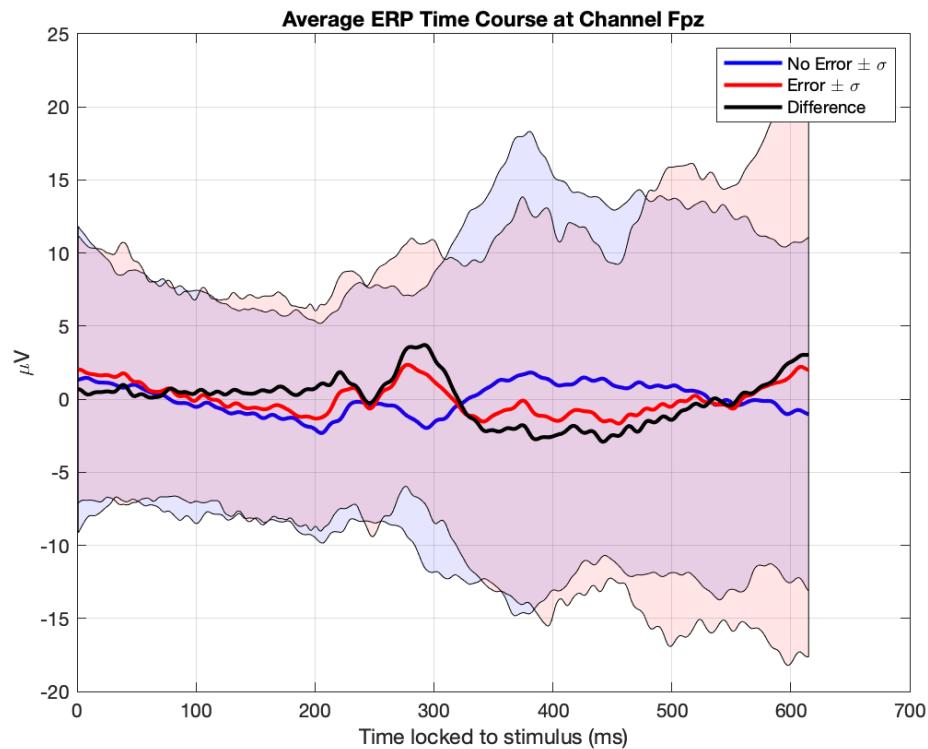
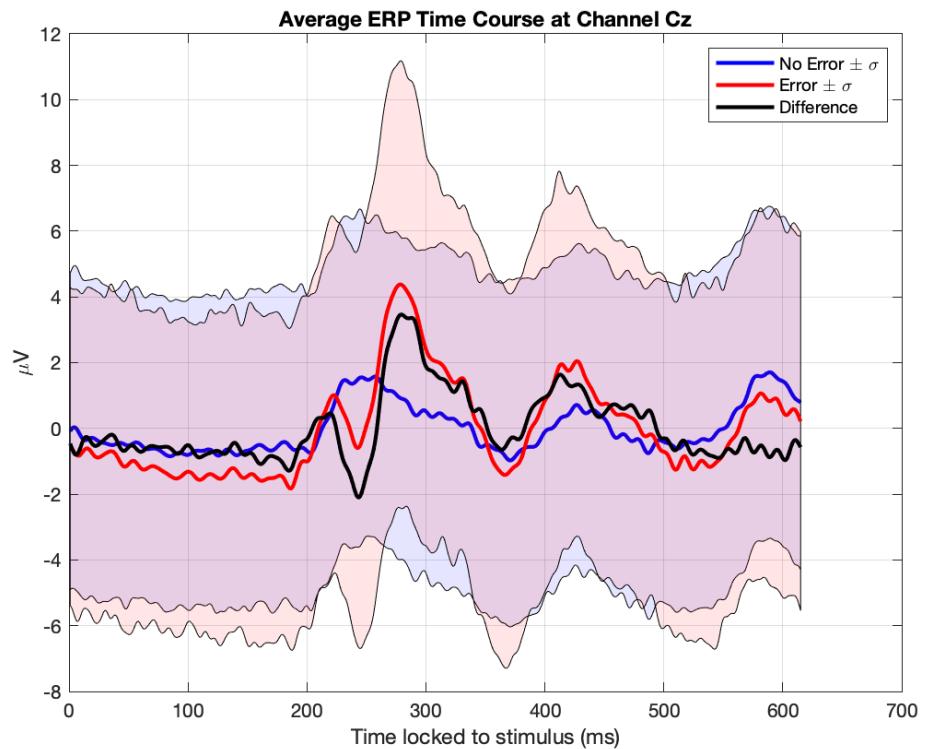
P300 (t=264ms)



N400 (t=304ms)

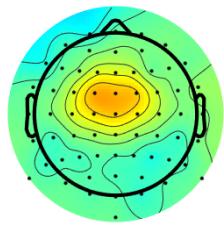


Ehrlich 2018 – ERP

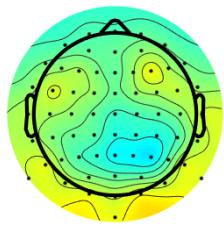


Ehrlich 2018 – ERP

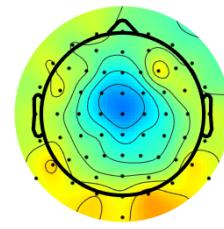
Average No Error Activation at t=243ms



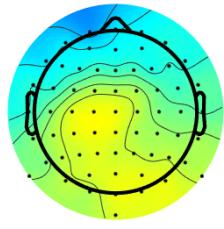
Average Error Activation at t=243ms



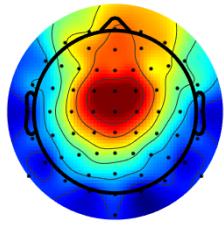
Average Activation Difference at t=243ms



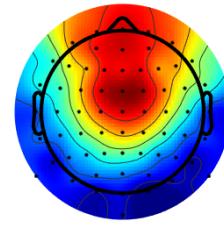
Average No Error Activation at t=280ms



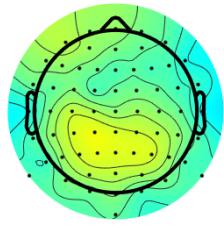
Average Error Activation at t=280ms



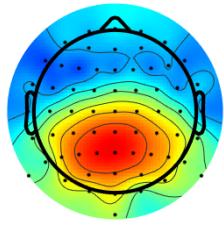
Average Activation Difference at t=280ms



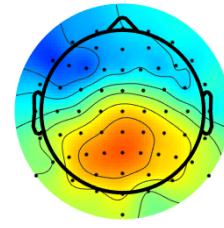
Average No Error Activation at t=332ms



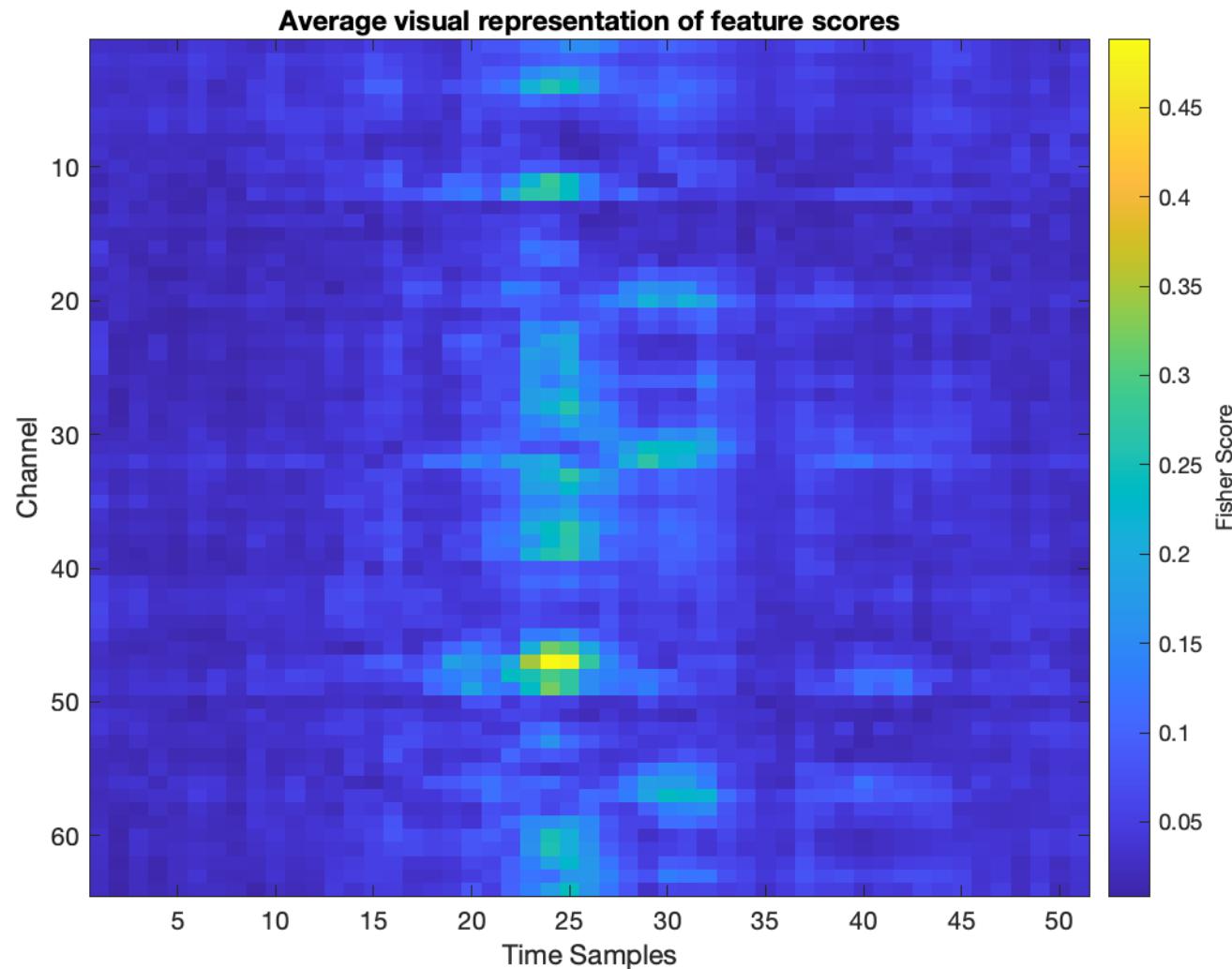
Average Error Activation at t=332ms



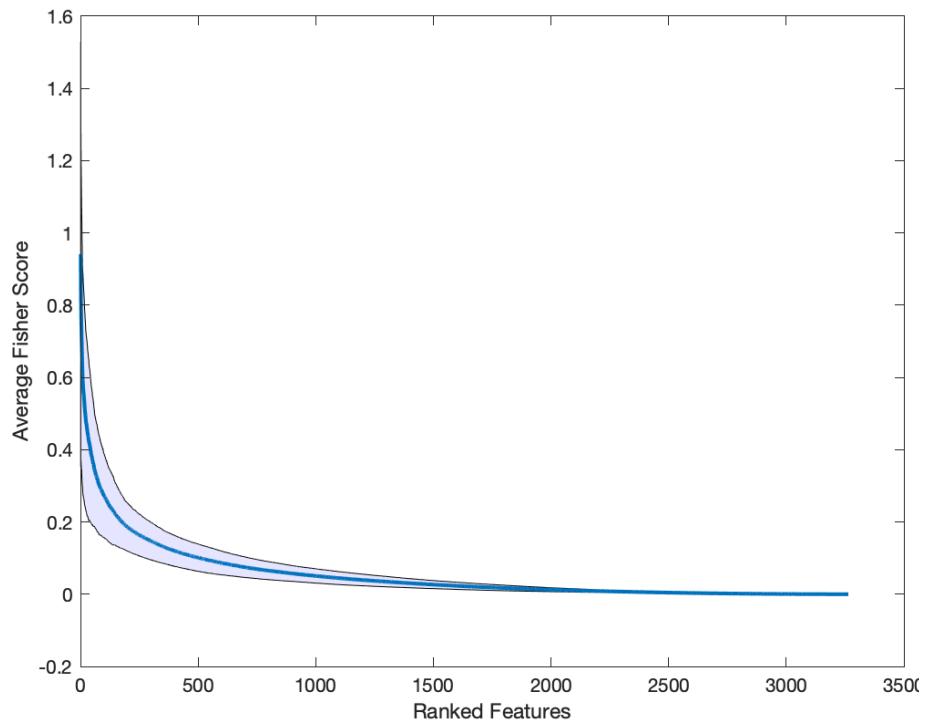
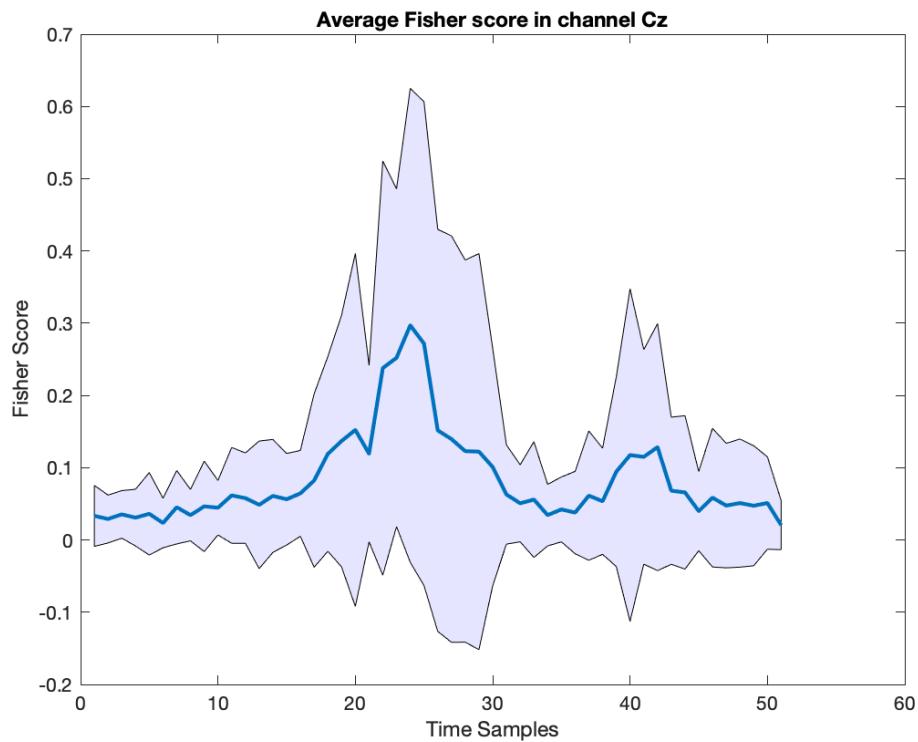
Average Activation Difference at t=332ms



Ehrlich 2018 – Average Feature Results

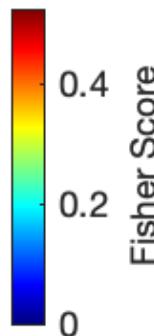
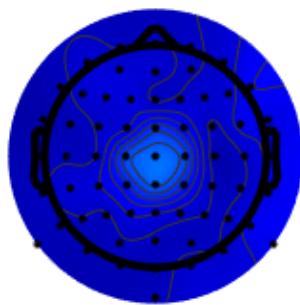


Ehrlich 2018 – Average Feature Results

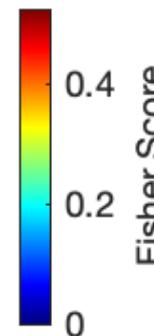
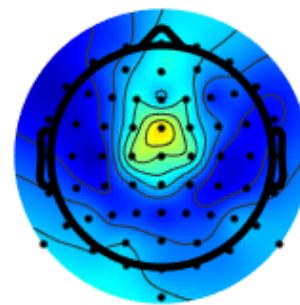


Ehrlich 2018 – Average Feature Results

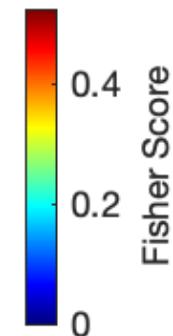
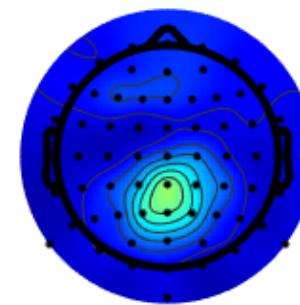
N200 (t=243ms)



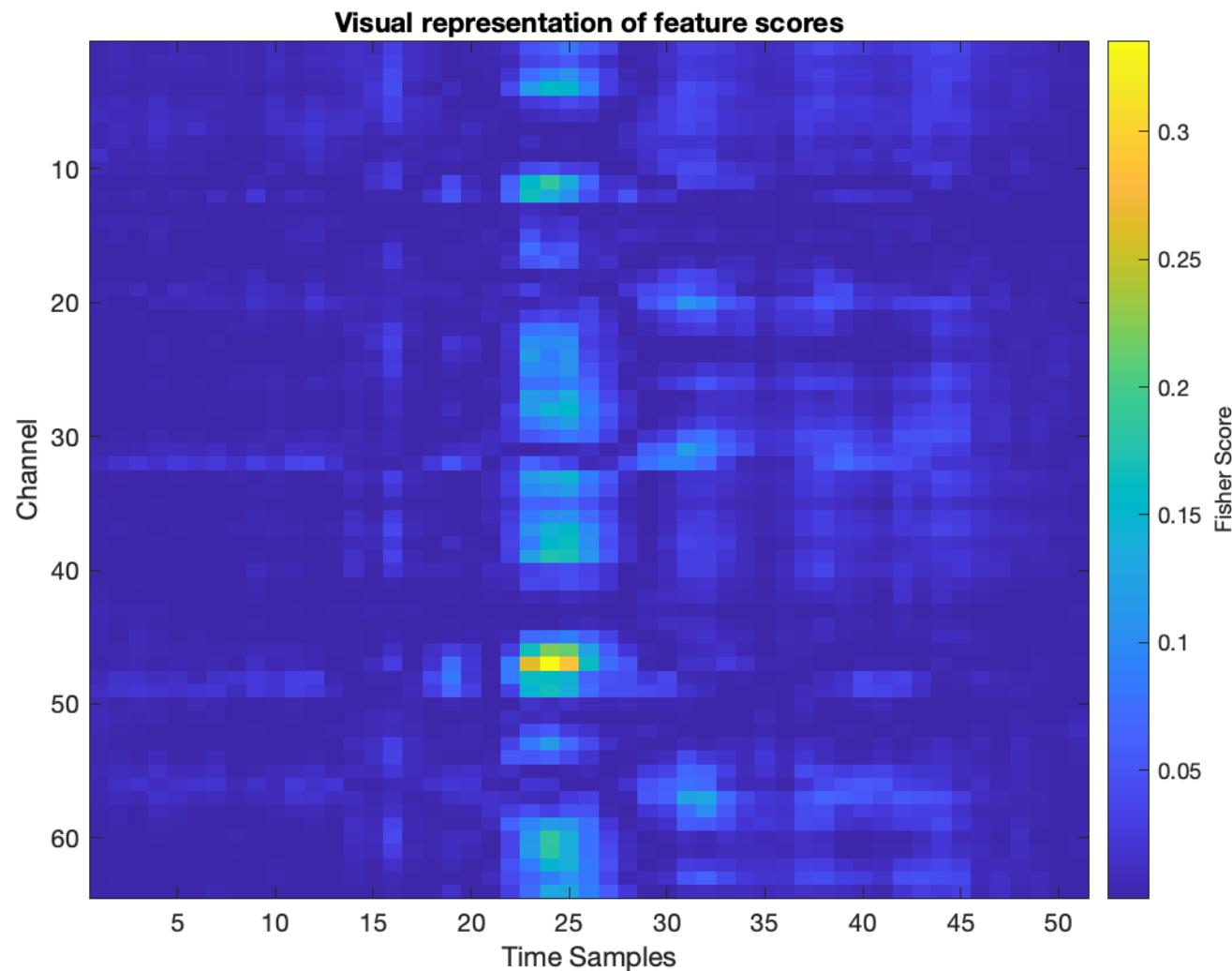
P300 (t=280ms)



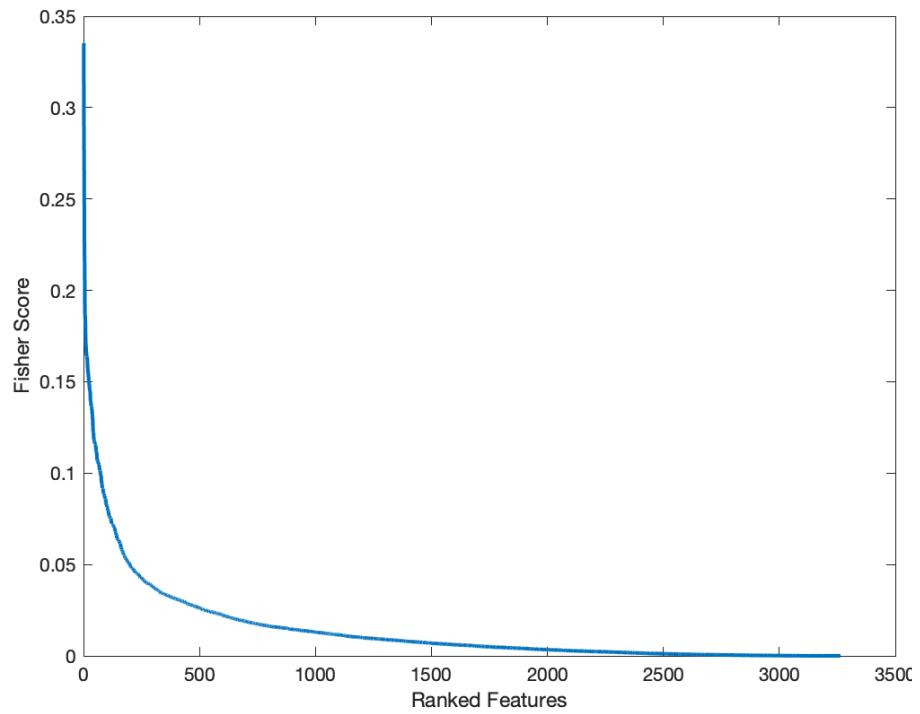
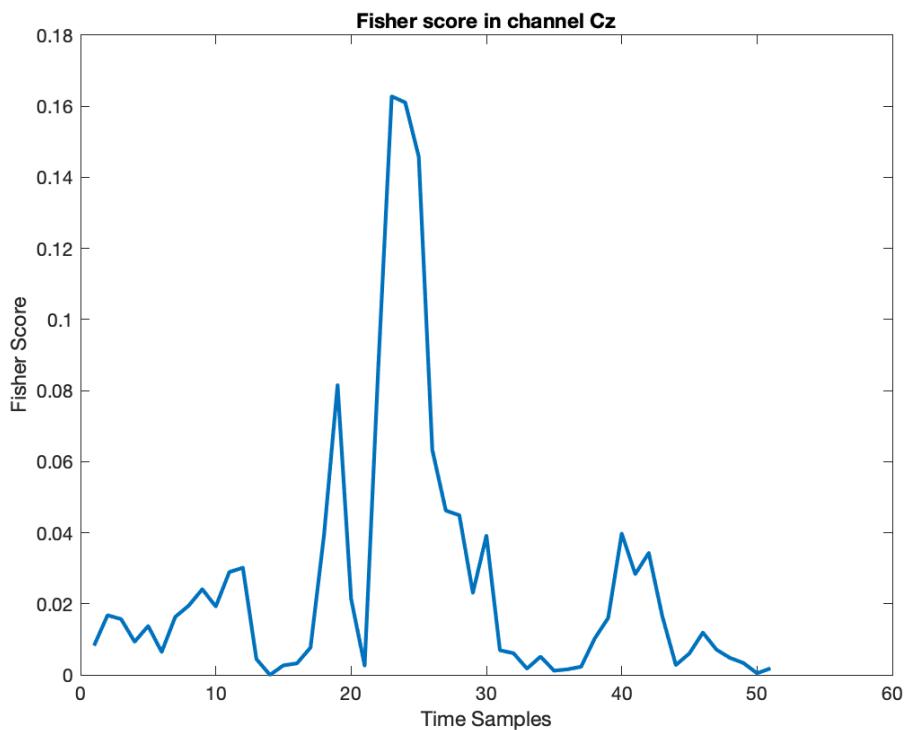
N400 (t=332ms)



Ehrlich 2018 – All Together Feature Results

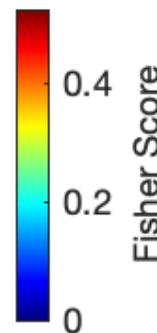
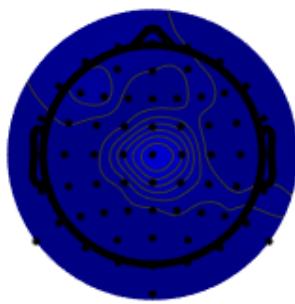


Ehrlich 2018 – All Together Feature Results

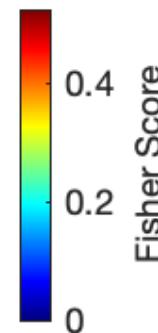
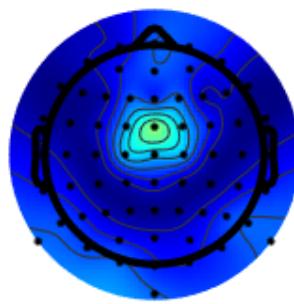


Ehrlich 2018 – All Together Feature Results

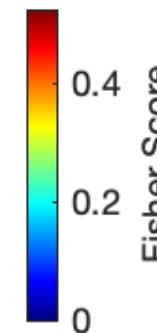
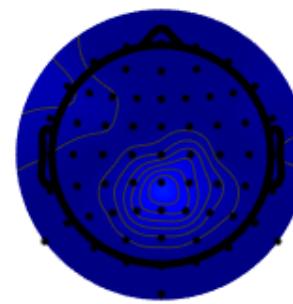
N200 (t=243ms)



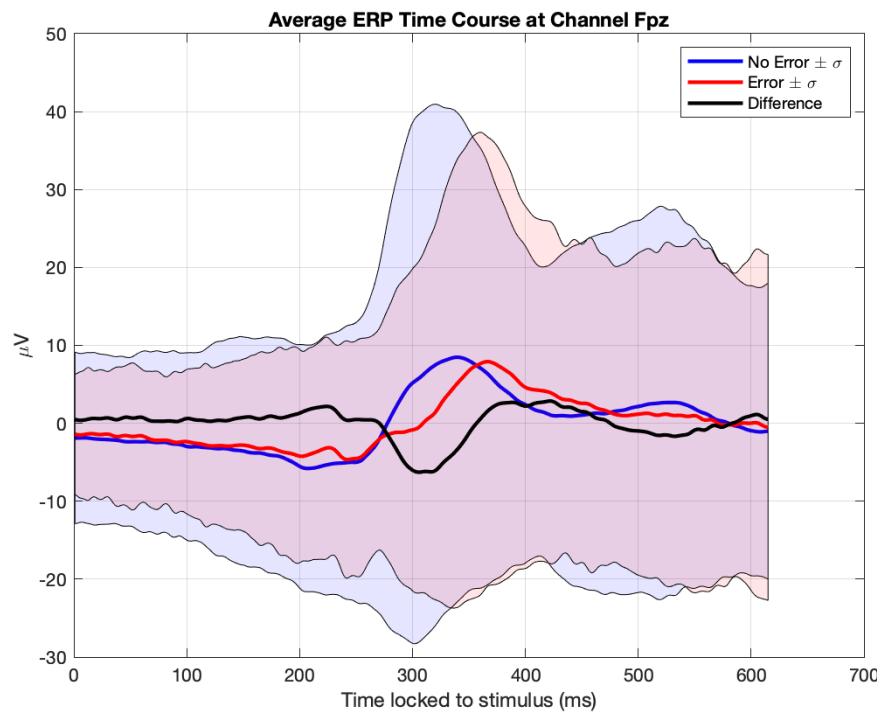
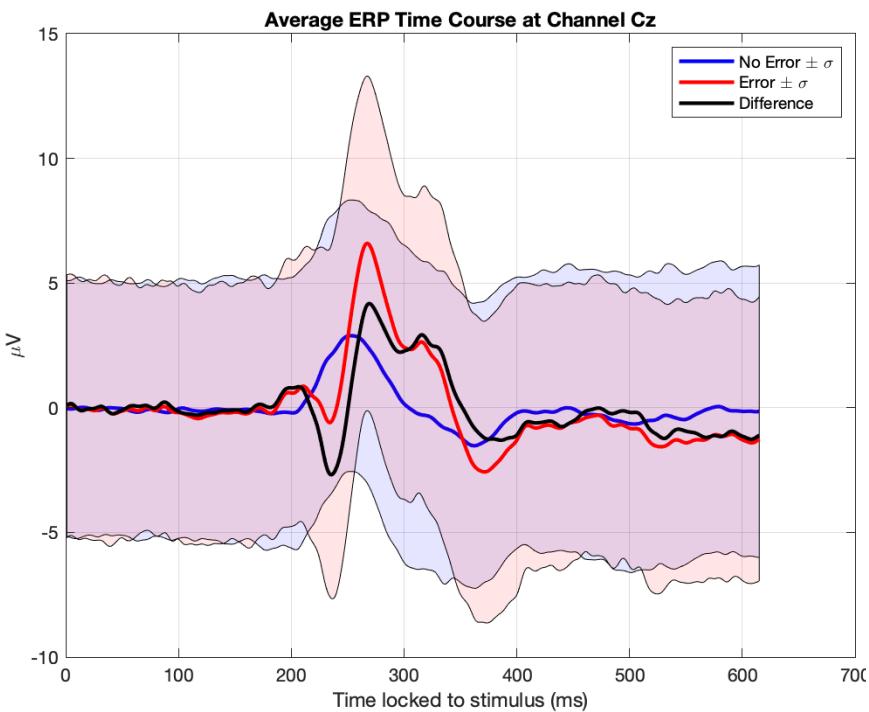
P300 (t=280ms)



N400 (t=332ms)

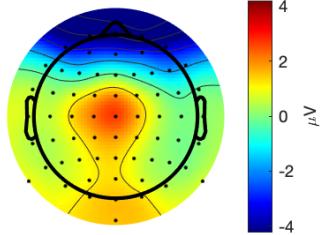


Chavarriaga 2015 – ERP

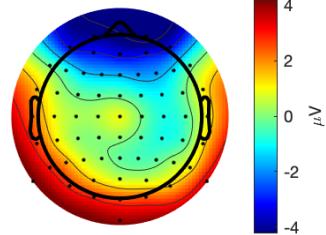


Chavarriaga 2015 – ERP

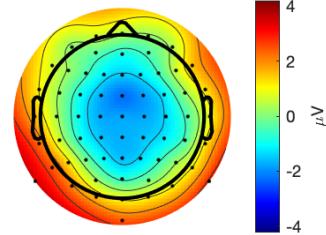
Average No Error Activation at t=244ms



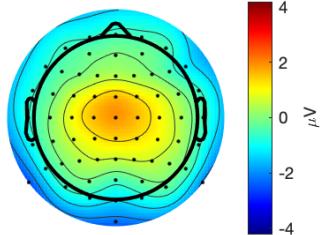
Average Error Activation at t=244ms



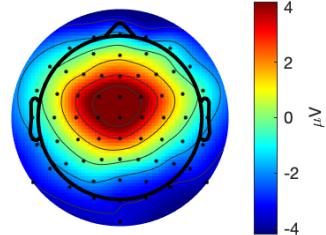
Average Activation Difference at t=244ms



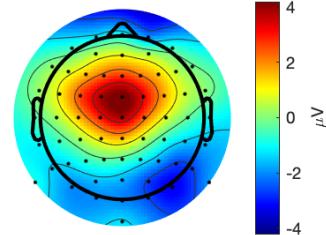
Average No Error Activation at t=276ms



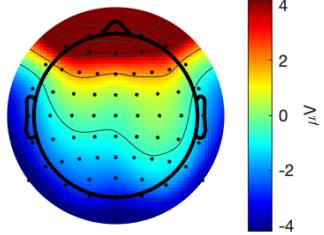
Average Error Activation at t=276ms



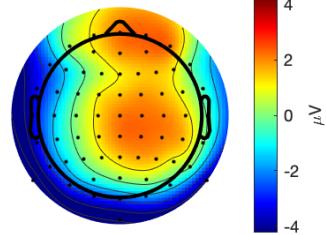
Average Activation Difference at t=276ms



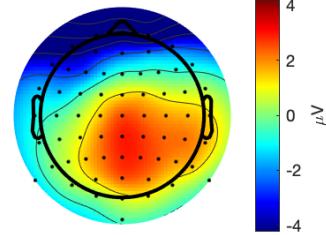
Average No Error Activation at t=324ms



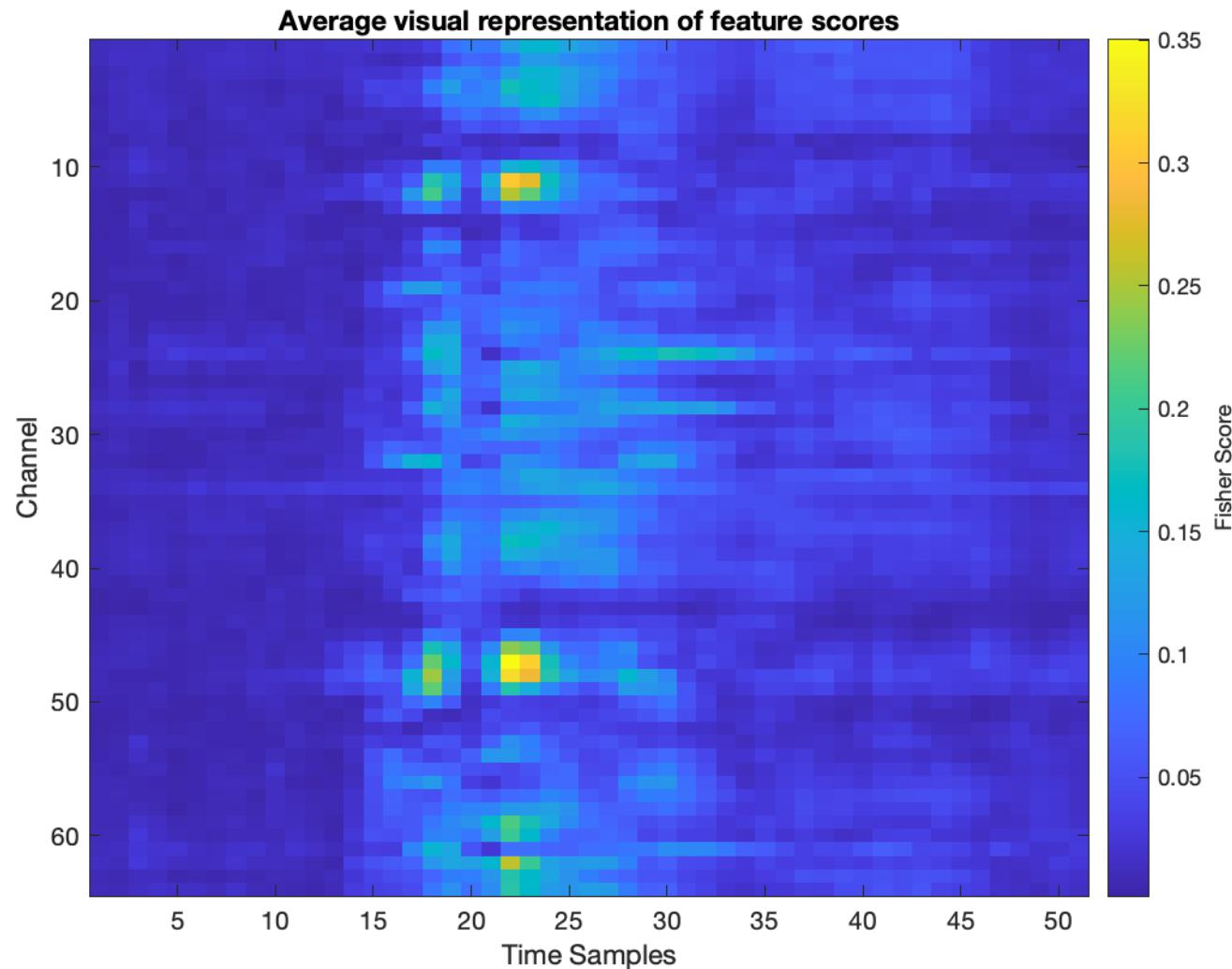
Average Error Activation at t=324ms



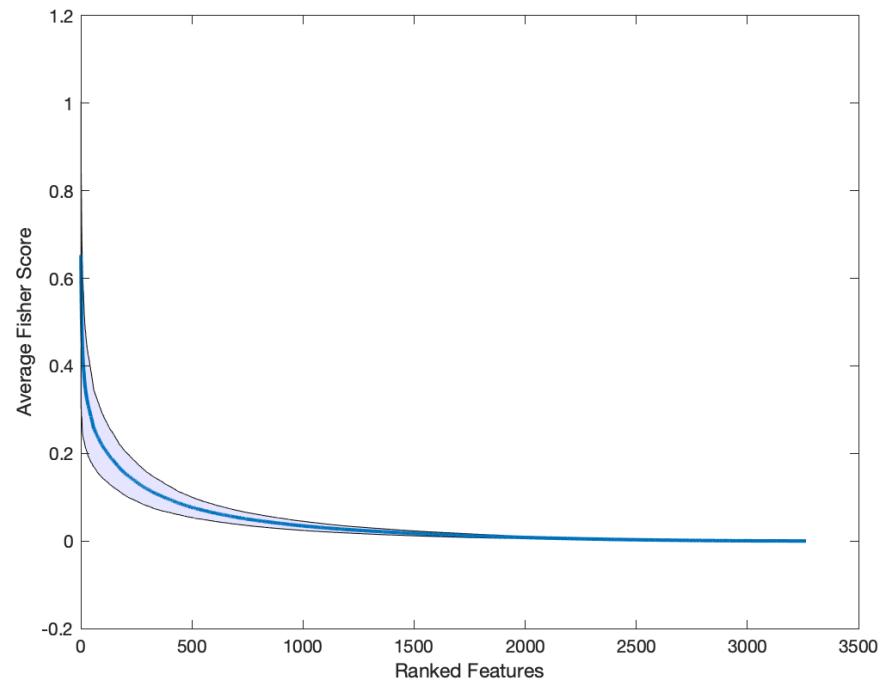
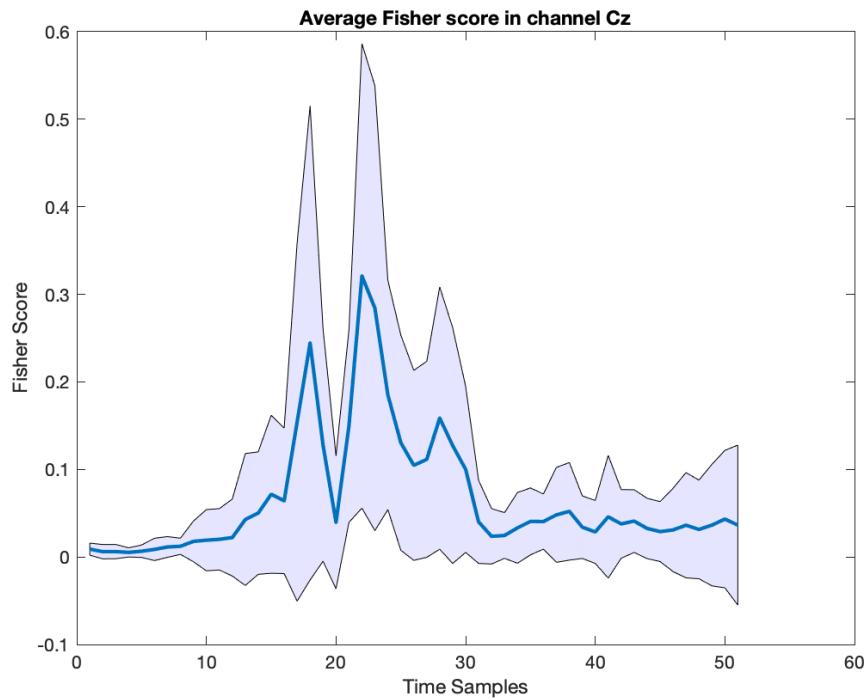
Average Activation Difference at t=324ms



Chavarriaga 2015 – Average Feature Results

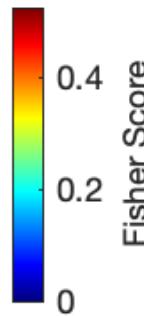
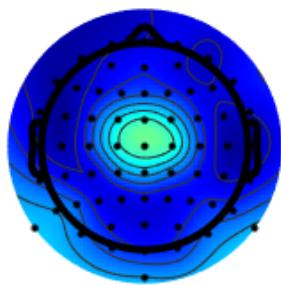


Chavarriaga 2015 – Average Feature Results

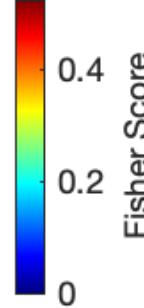
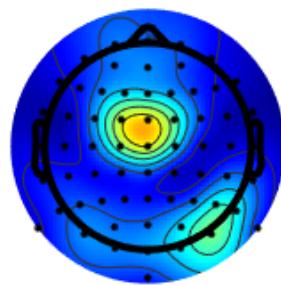


Chavarriaga 2015 – Average Feature Results

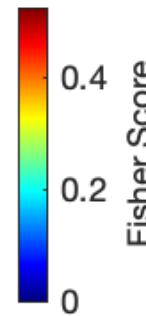
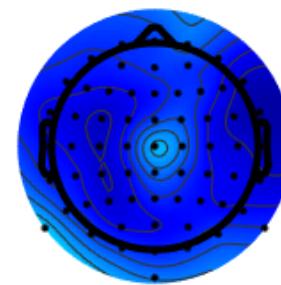
N200 (t=244ms)



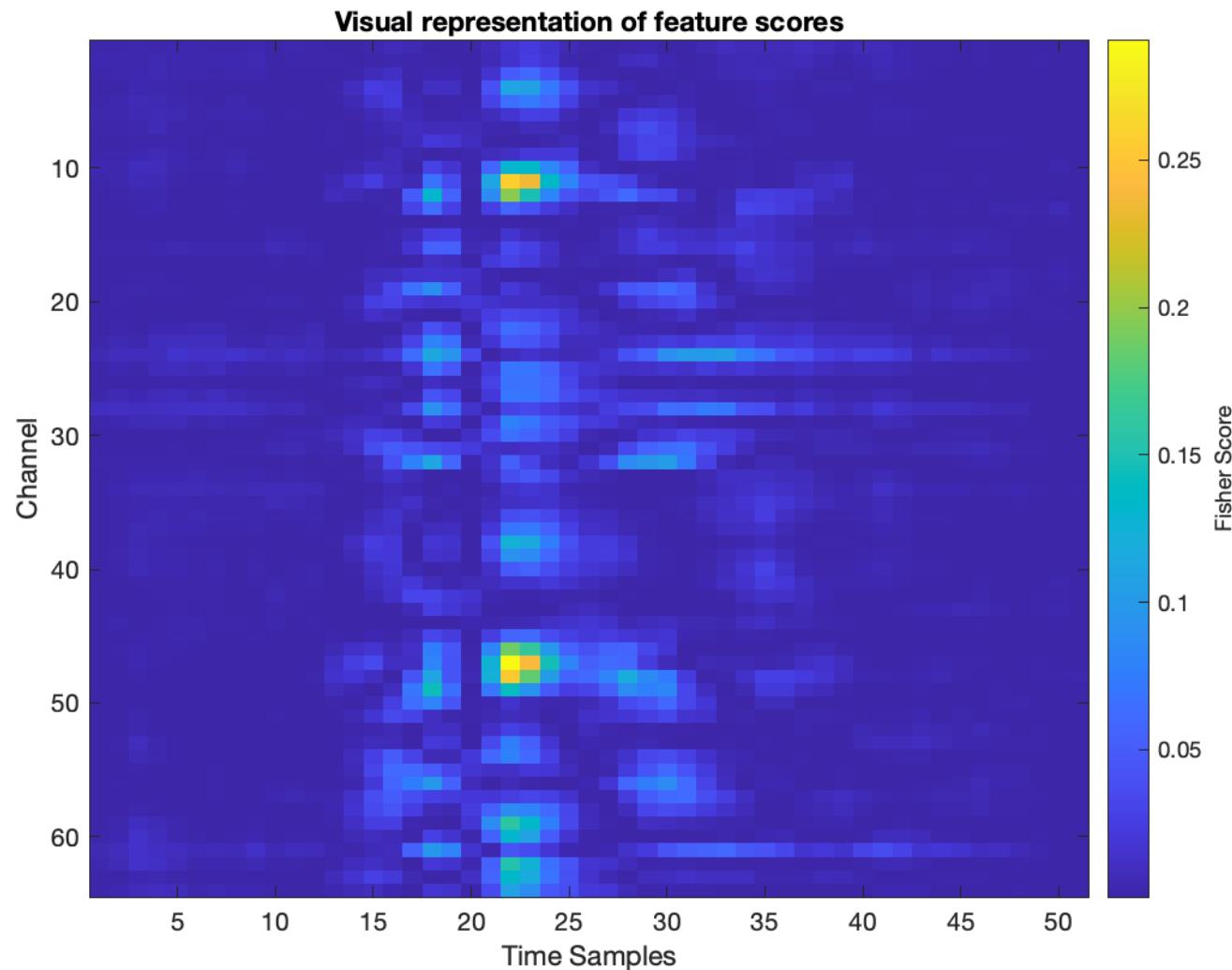
P300 (t=276ms)



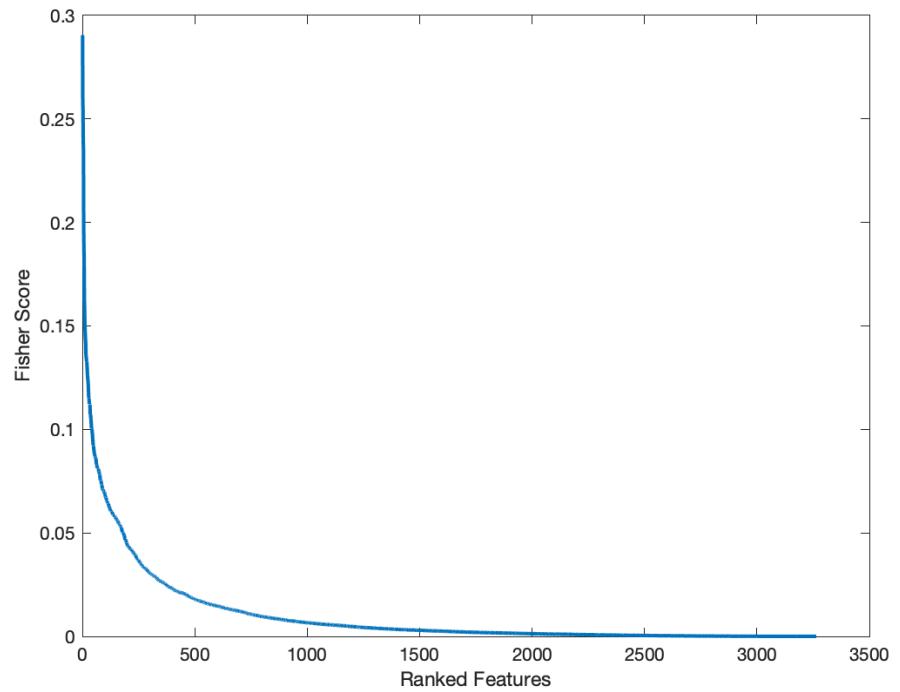
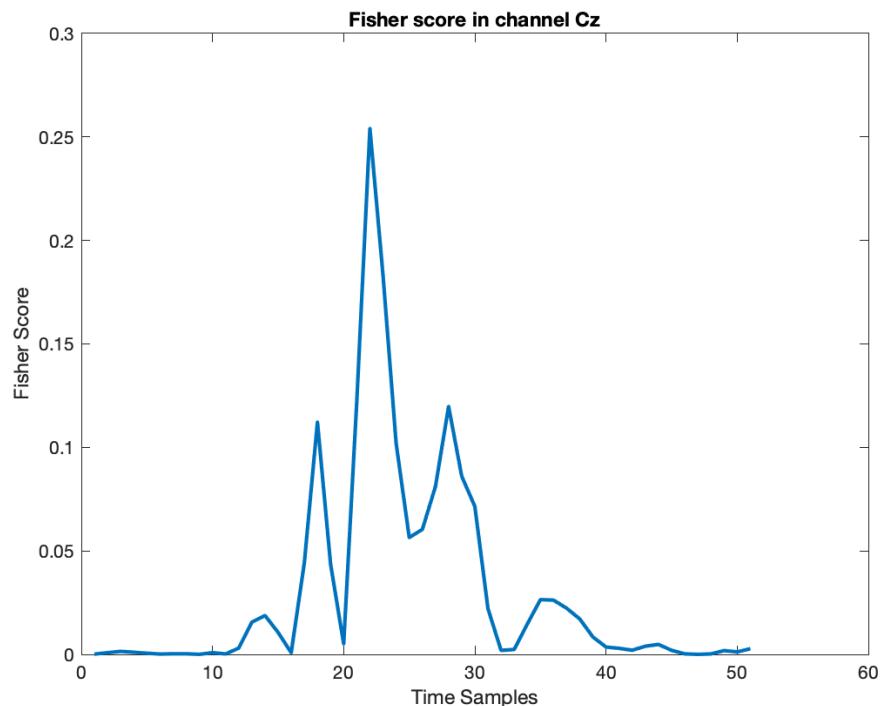
N400 (t=324ms)



Chavarriaga 2015 – All Together Feature Results

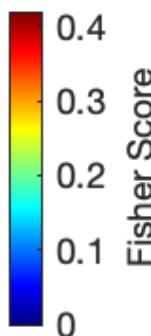
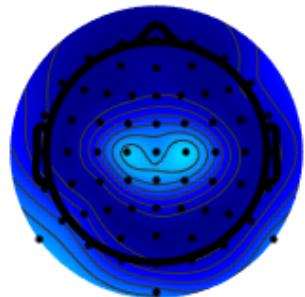


Chavarriaga 2015 – All Together Feature Results

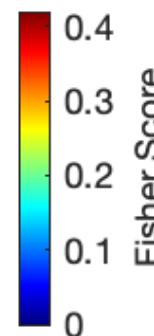
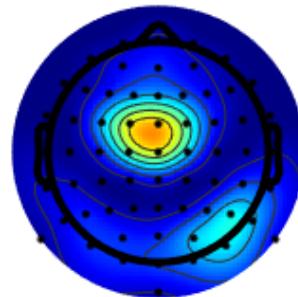


Chavarriaga 2015 – All Together Feature Results

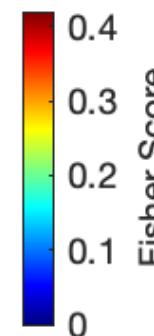
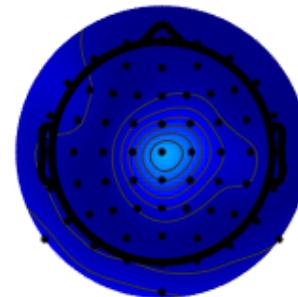
N200 (t=244ms)



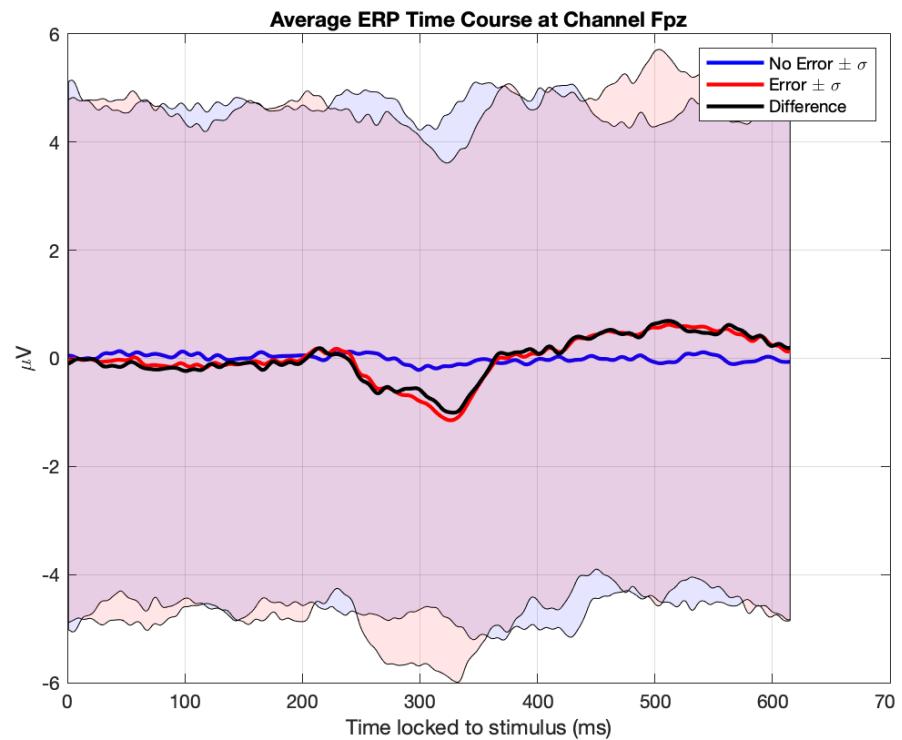
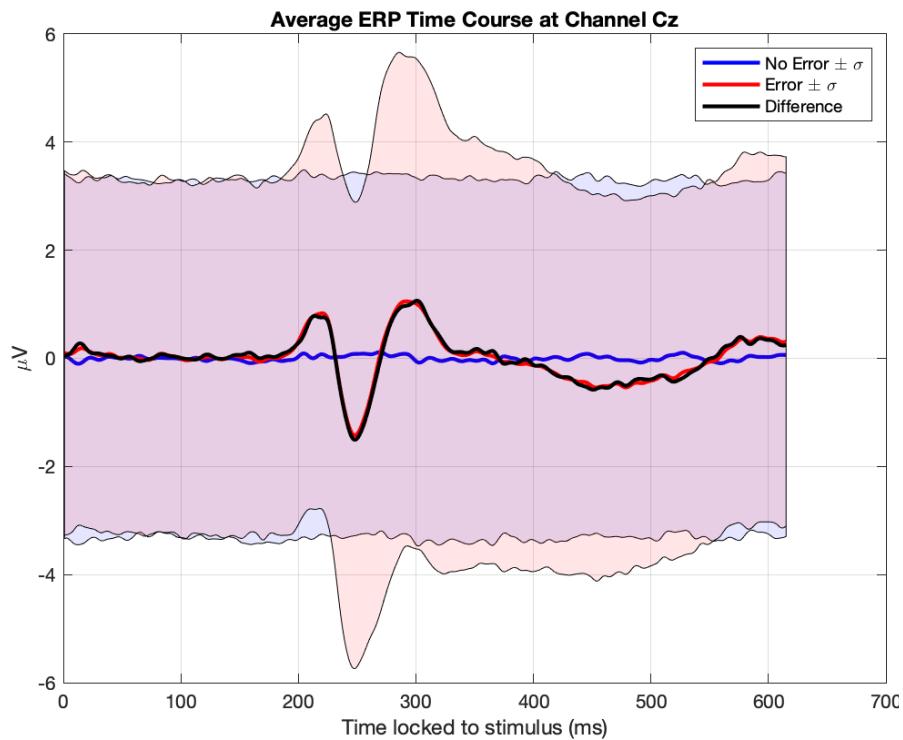
P300 (t=276ms)



N400 (t=324ms)

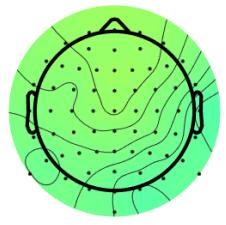


Spueler 2015 – ERP

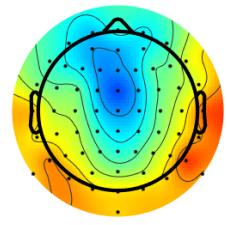


Spueler 2015 – ERP

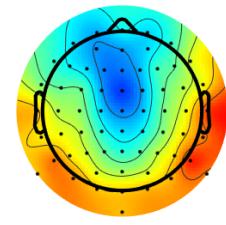
Average No Error Activation at t=258ms



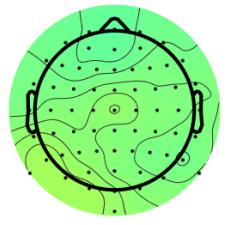
Average Error Activation at t=258ms



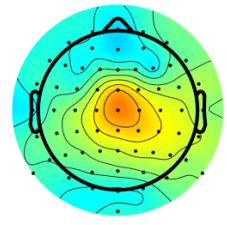
Average Activation Difference at t=258ms



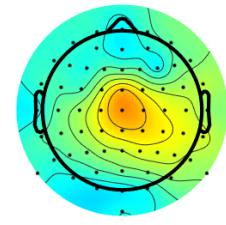
Average No Error Activation at t=292ms



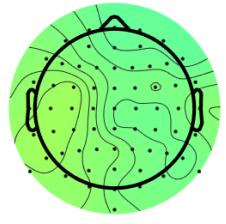
Average Error Activation at t=292ms



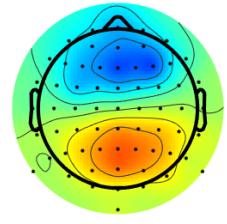
Average Activation Difference at t=292ms



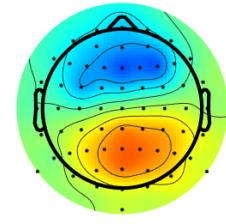
Average No Error Activation at t=340ms



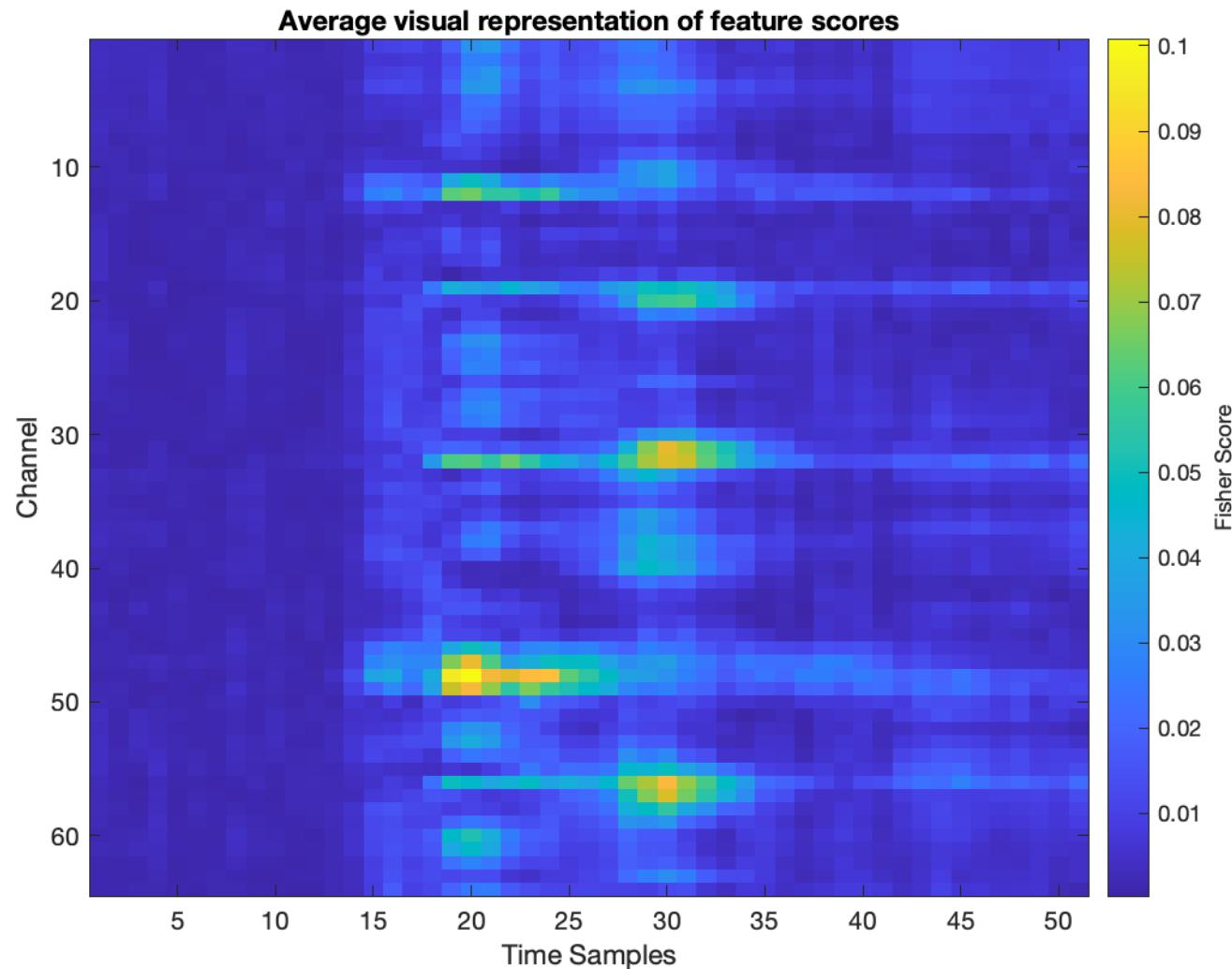
Average Error Activation at t=340ms



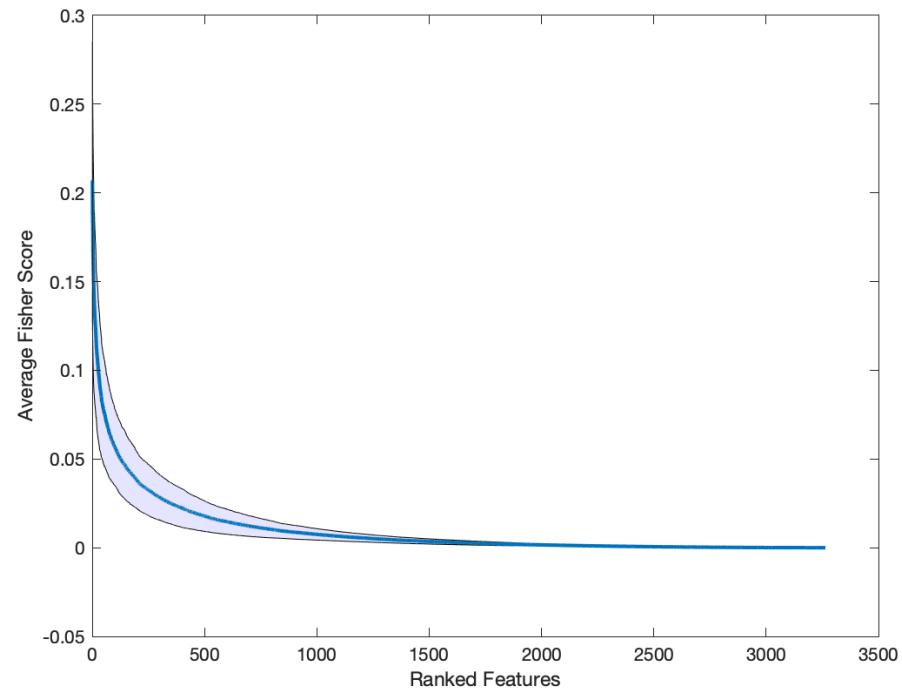
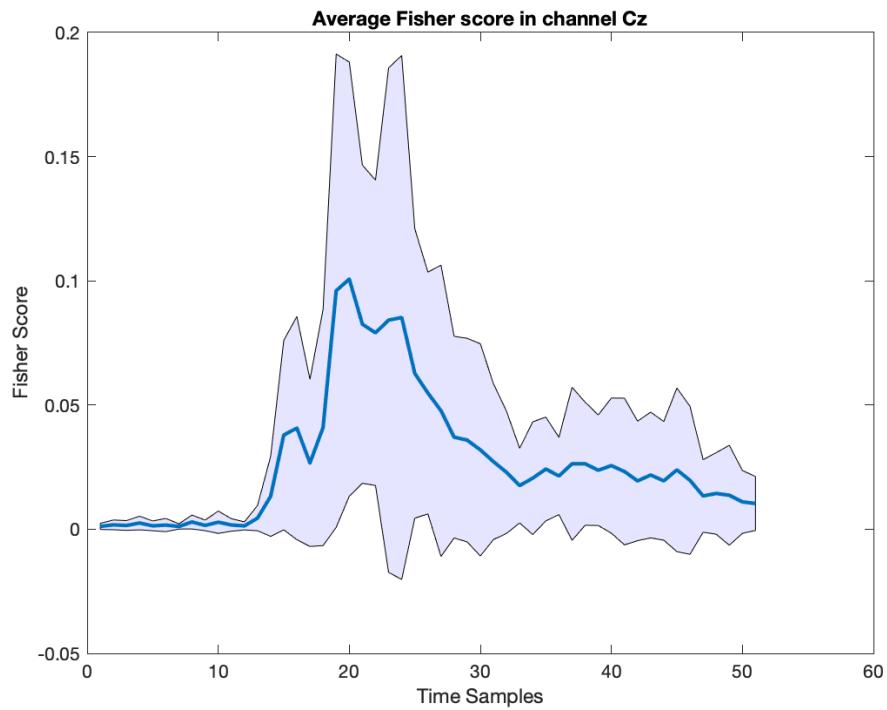
Average Activation Difference at t=340ms



Spueler 2015 – Average Feature Results

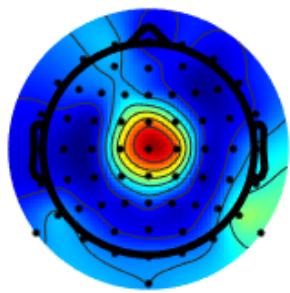


Spueler 2015 – Average Feature Results

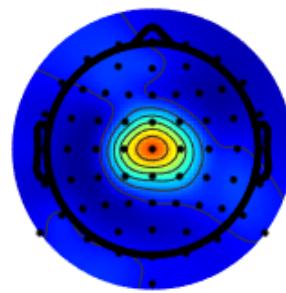


Spueler 2015 – Average Feature Results

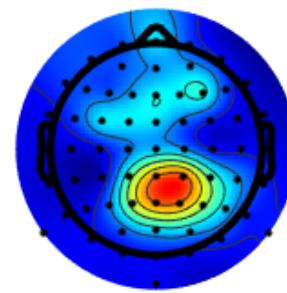
N200 (t=258ms)



P300 (t=292ms)

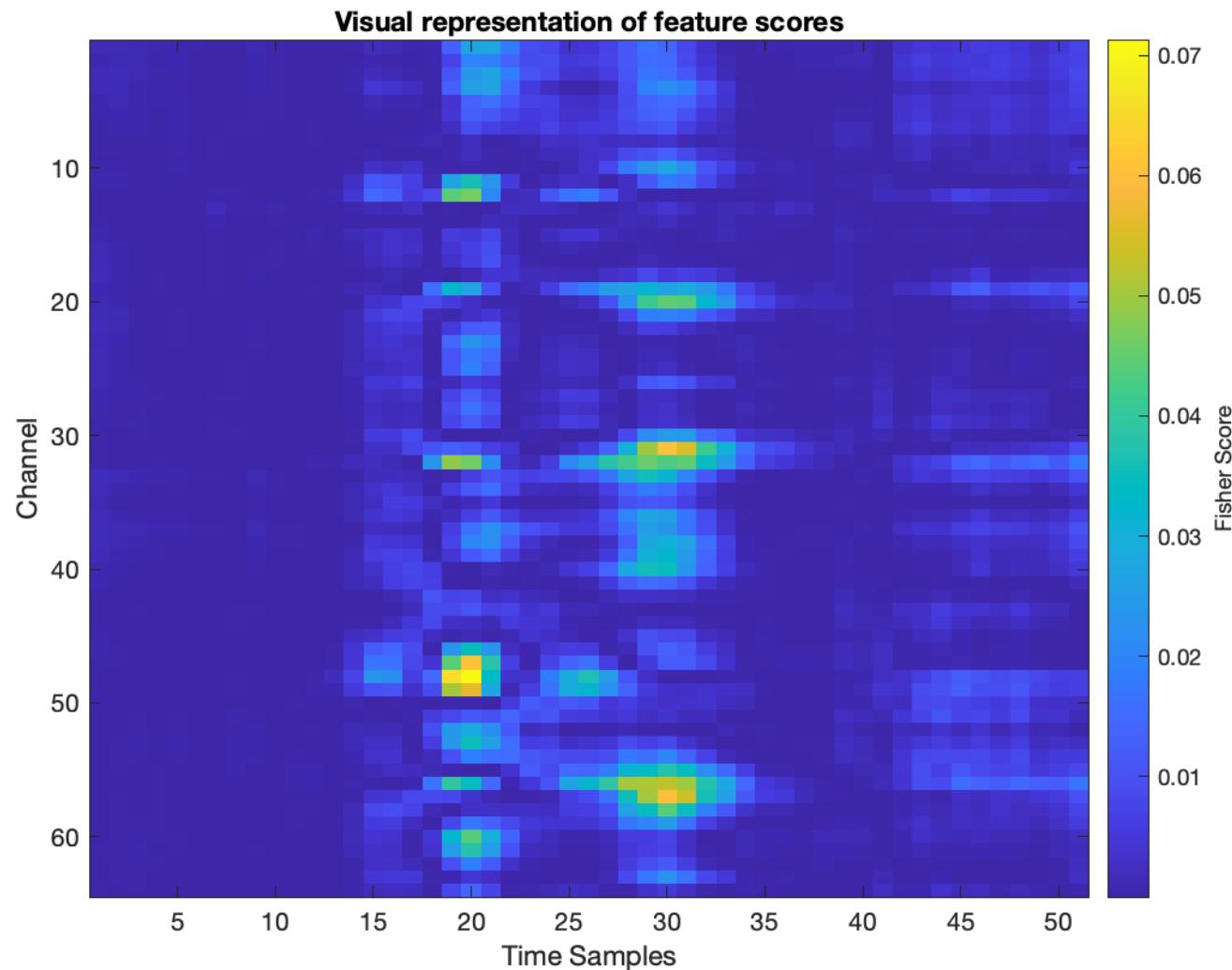


N400 (t=340ms)

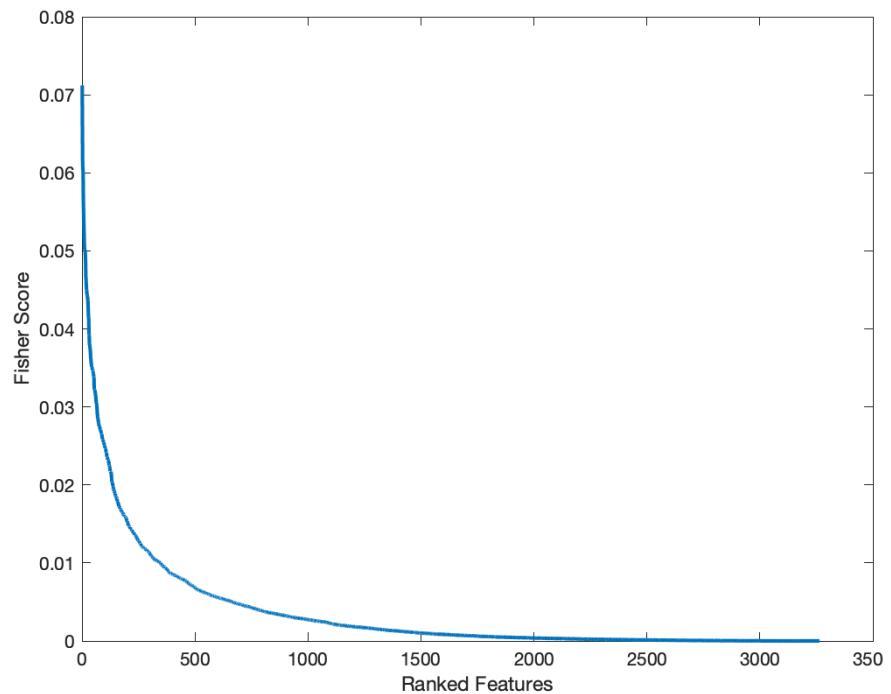
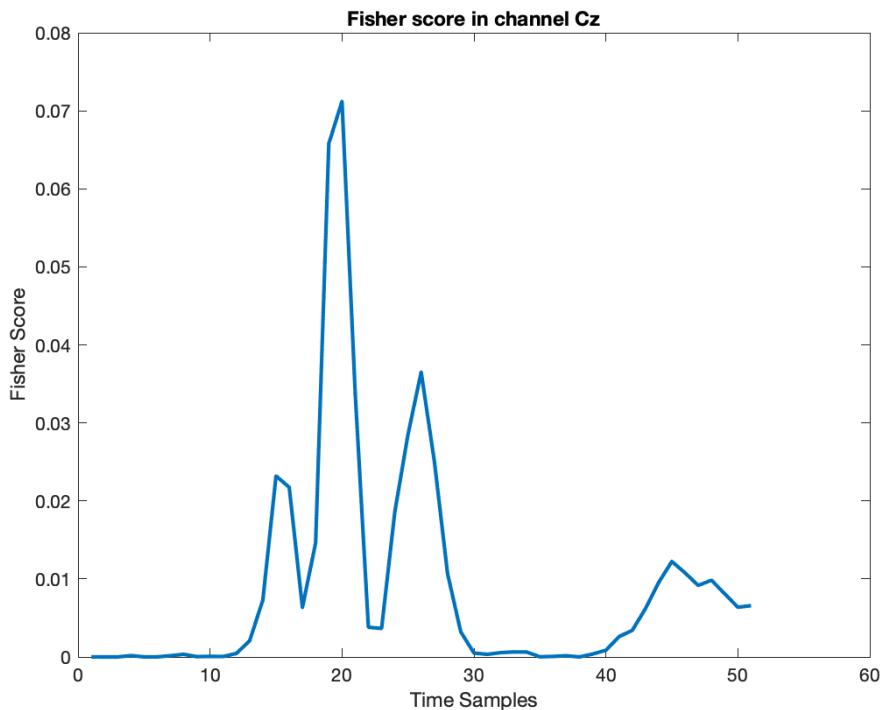


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Spueler 2015 – All Together Feature Results

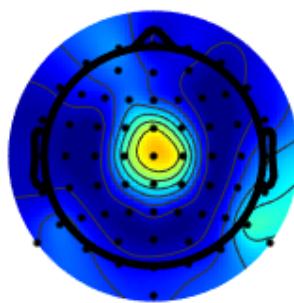


Spueler 2015 – All Together Feature Results

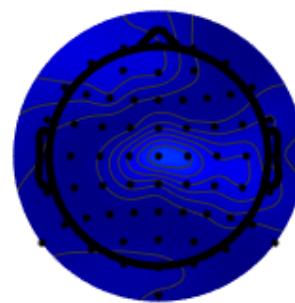


Spueler 2015 – All Together Feature Results

N200 (t=258ms)



P300 (t=292ms)



N400 (t=340ms)

