ReTune Early Career Methods Workshop:

Basic introduction to invasive neurophysiology

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Requirements:

Software:
Matlab, if you have access, please install Matlab 2020b
Python/Anaconda including Jupyter

GitHub code repositories:
https://github.com/retune-commons/InvasiveElectrophysiologyWorkshop_I
https://github.com/neuromodulation/wjn_toolbox/
https://github.com/spm/spm12
https://github.com/fieldtrip/fieldtrip.git

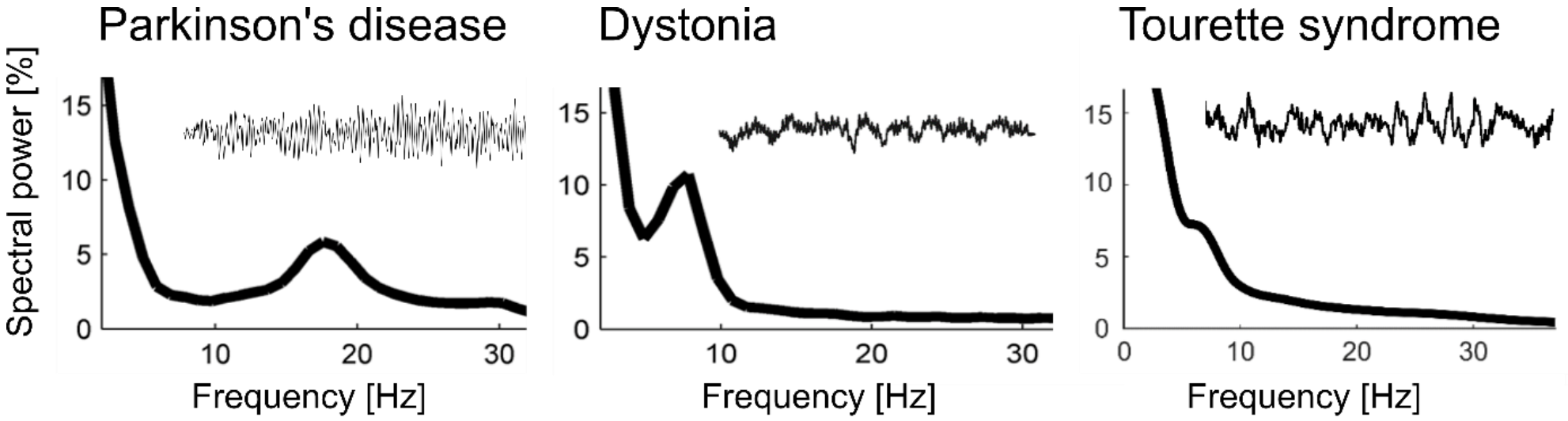
Please have a computer ready with Matlab and Anaconda installed.

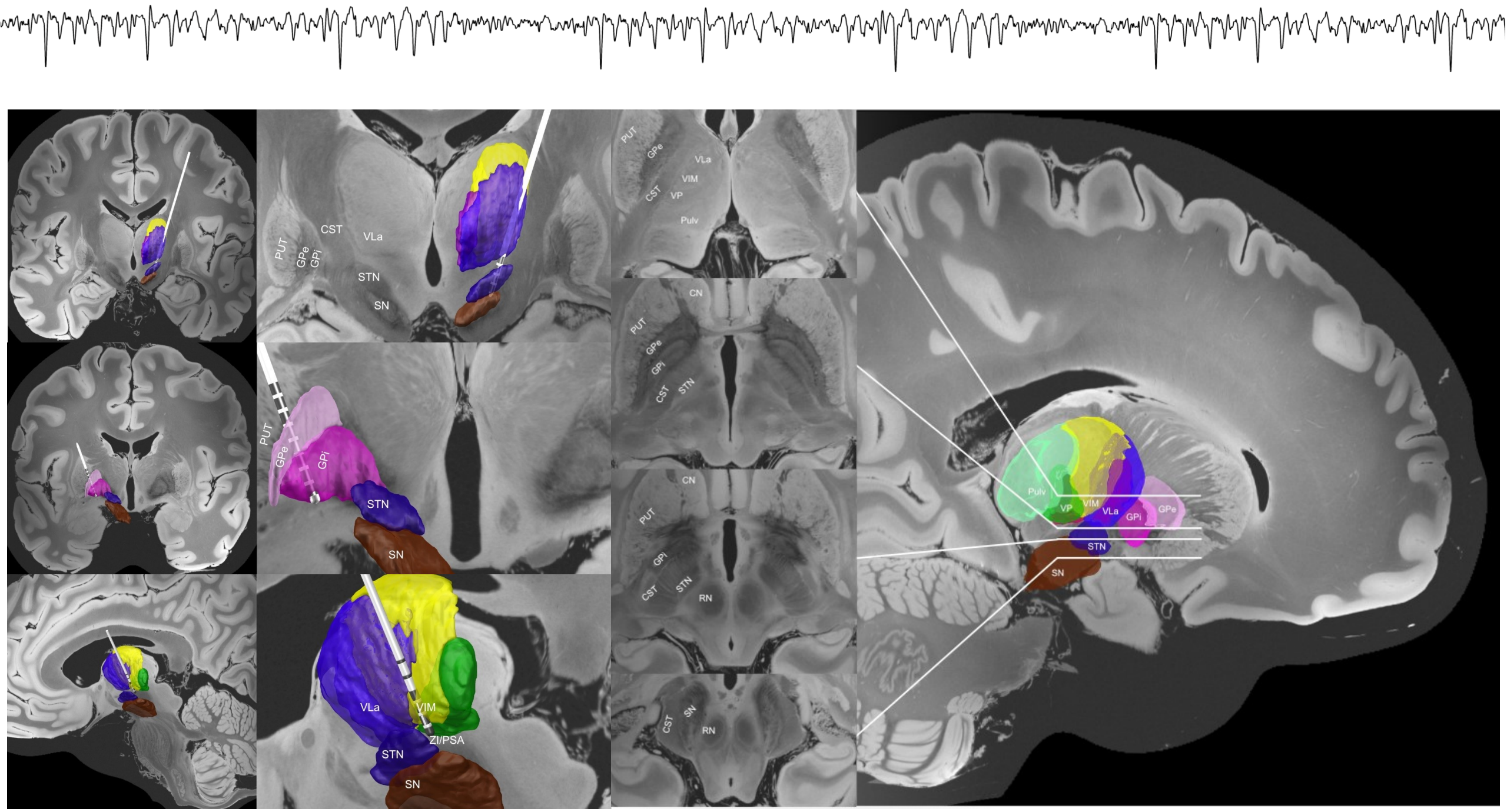
Clone the identified repositories and create a working directory.

Python packages:
MNE toolbox, can be installed using the following command in a Jupiter notebook:

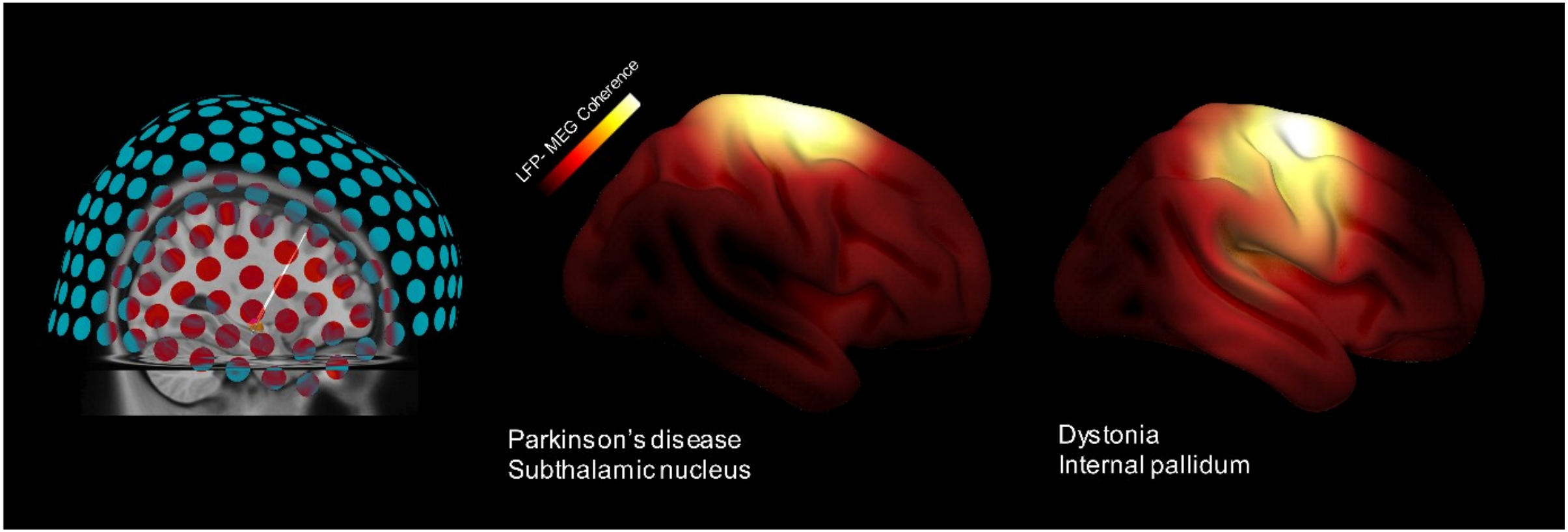
```
import sys
!{sys.executable} -m pip install mne
```

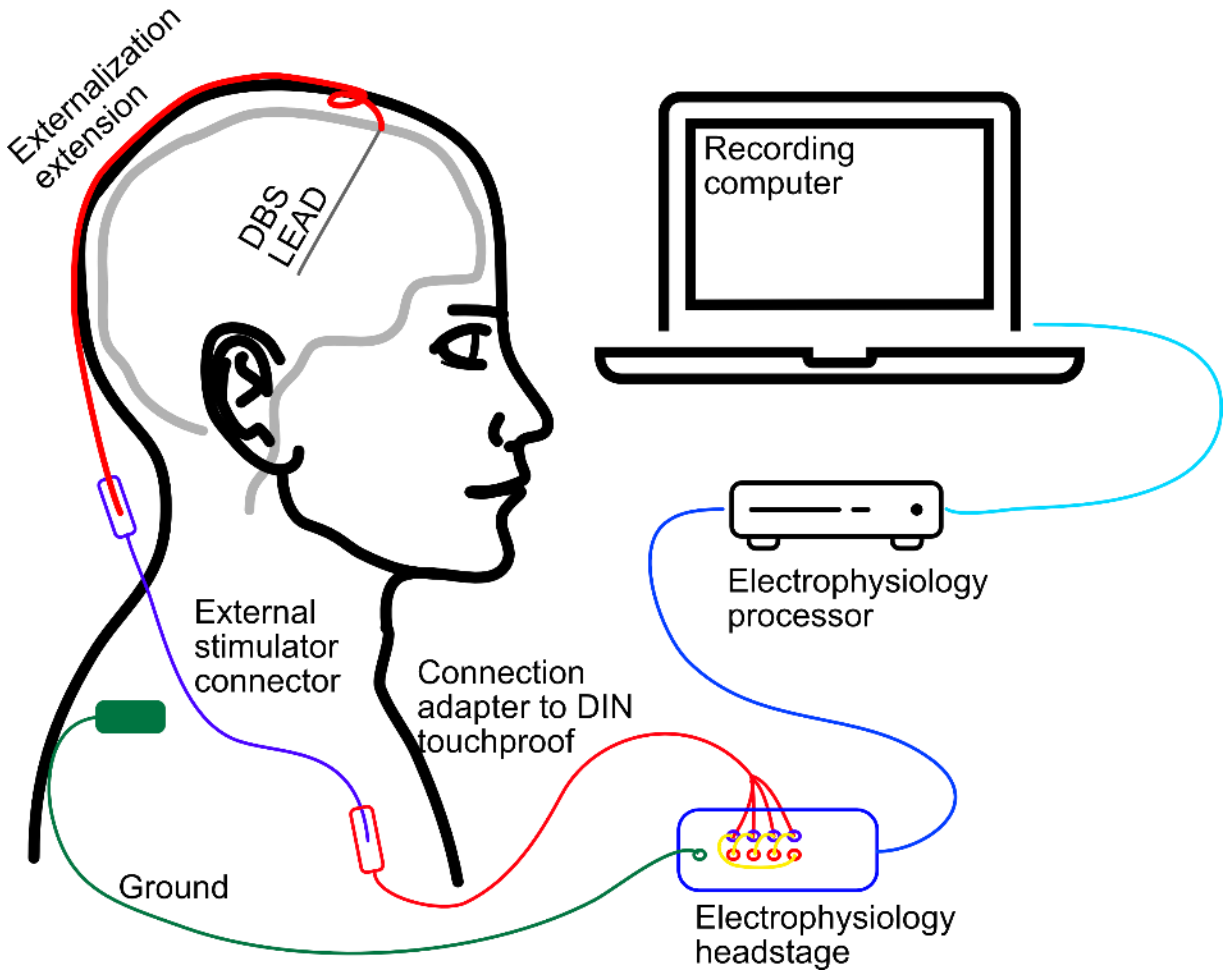
Invasive neurophysiology research in DBS patients

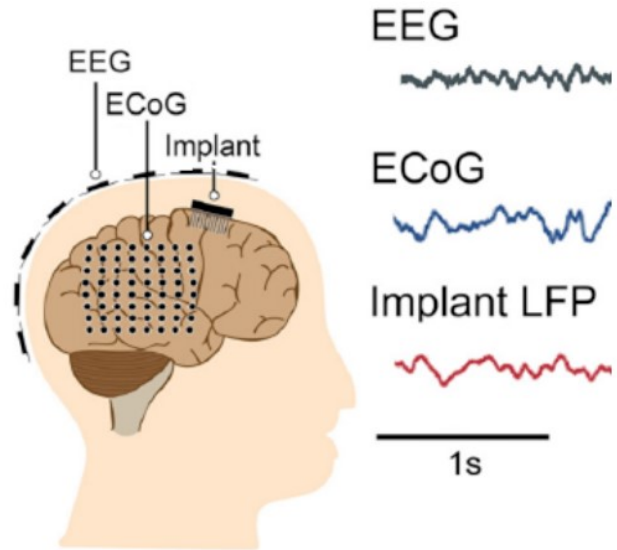


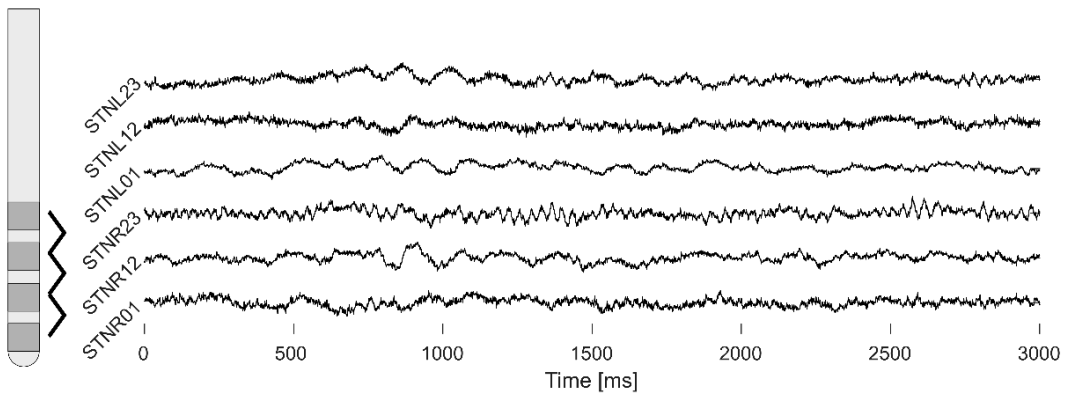

PUT
GPe
GPi
CST
VLa
STN
SN
PUT
GPe
VLa
VIM
CST
VP
Pulv
CN
PUT
GPe
GPi
CST
STN
CN
PUT
GPi
CST
STN
RN
CST
SN
RN
PUT
GPe
GPi
STN
SN
VLa
VIM
ZI/PSA
STN
SN
Pulv
VP
VIM
VLa
GPi
GPe
STN
SN

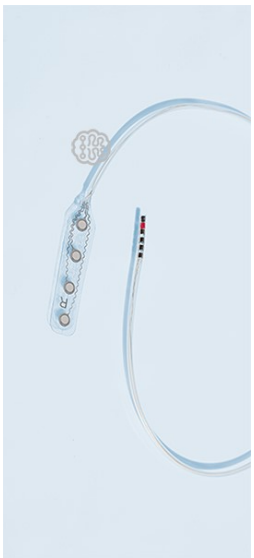
Combined LFP and whole-head recordings

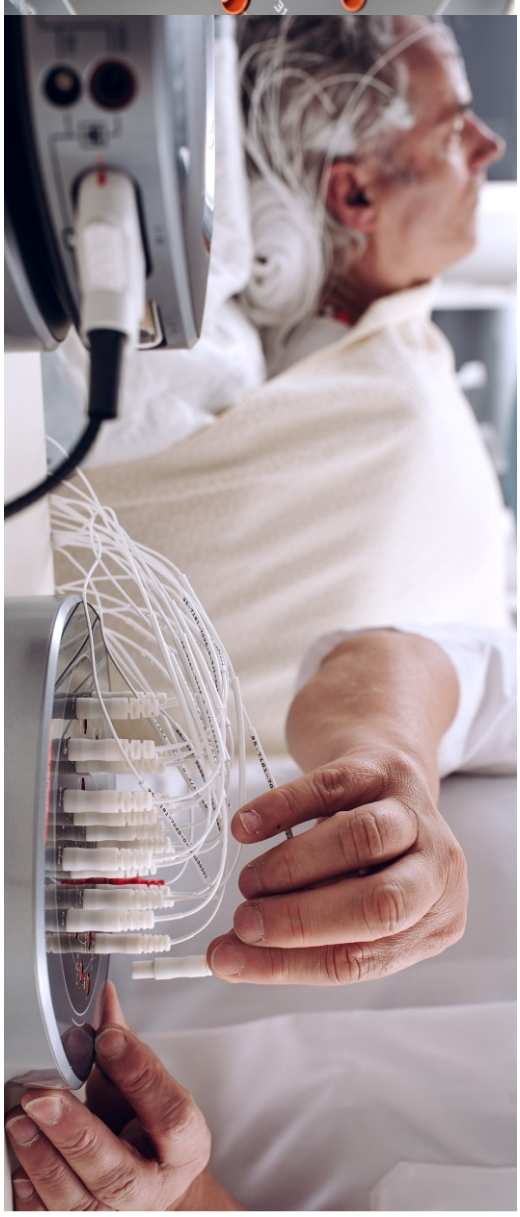


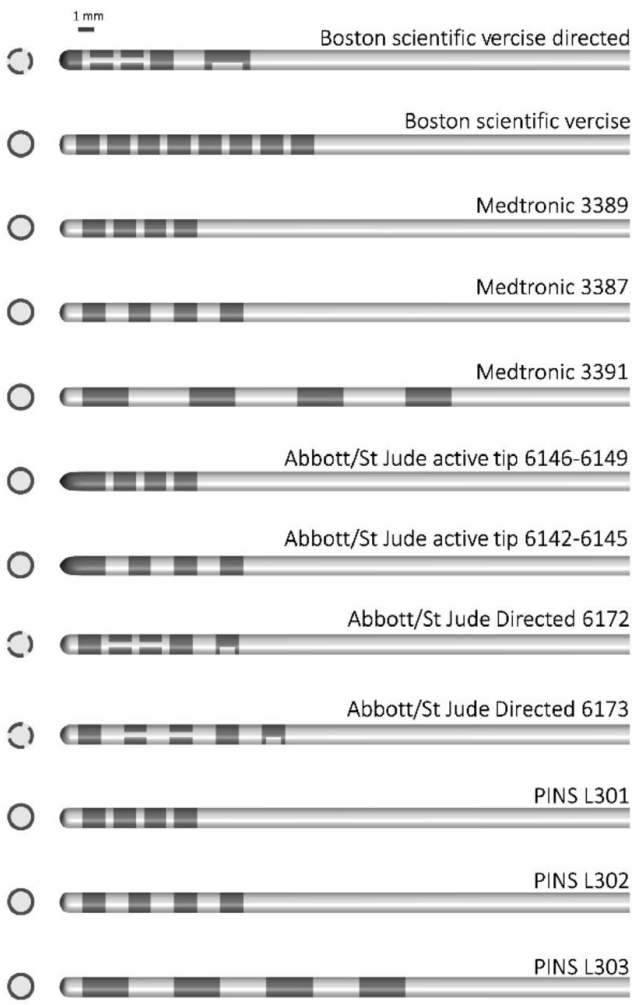

Externalization extension
DBS LEAD
Recording computer
Electrophysiology processor
External stimulator connector
Connection adapter to DIN touchproof
Ground
Electrophysiology headstage

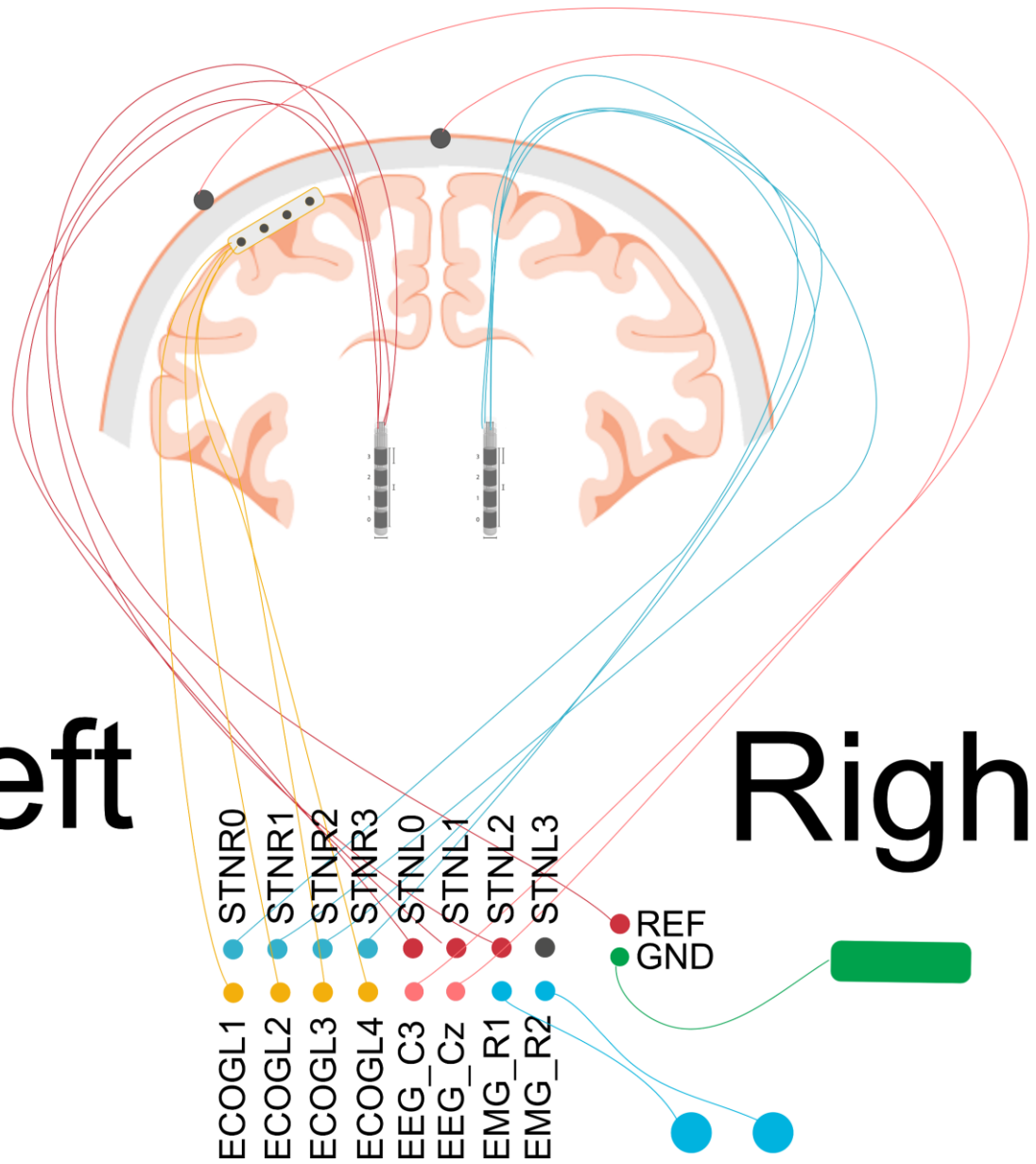

EEG
ECoG
Implant
EEG
ECoG
Implant LFP
1s


STNL23
STNL12
STNL01
STNR23
STNR12
STNR01
0
500
1000
1500
2000
2500
3000
Time [ms]






1 mm
Boston scientific vercise directed
Boston scientific vercise
Medtronic 3389
Medtronic 3387
Medtronic 3391
Abbott/St Jude active tip 6146-6149
Abbott/St Jude active tip 6142-6145
Abbott/St Jude Directed 6172
Abbott/St Jude Directed 6173
PINS L301
PINS L302
PINS L303



1. STNR0 - REF STNL3
2. STNR1 - REF STNL3
3. STNR2 - REF STNL3
4. STNR3 - REF STNL3
5. STNL0 - REF STNL3
6. STNL1 - REF STNL3
7. STNL2 - REF STNL3
8. Empty (STNL3-STNL3=0)
9. ECOGL1 - REF STNL3
10. ECOGL2 - REF STNL3
11. ECOGL3 - REF STNL3
12. ECOGL4 - REF STNL3
13. EEG_C3 - REF STNL3
14. EEG_Cz - REF STNL3
15. EMG_R1 - REF STNL3
16. EMG_R2 - REF STNL3

Practical rules of thumb

- Connectors and adapters can be a source of bad signal quality. Check and replace regularly.
- Turn of any unrequired electric device to reduce 50 Hz noise.
- Ground and reference need to be good, otherwise all signals are bad.
- Smaller contacts have higher impedance and therefore smaller signals.

Let’s open Matlab now.

Setting the path: change the folders in your version of the code

Tutorial_I_Import_and_rereference.m

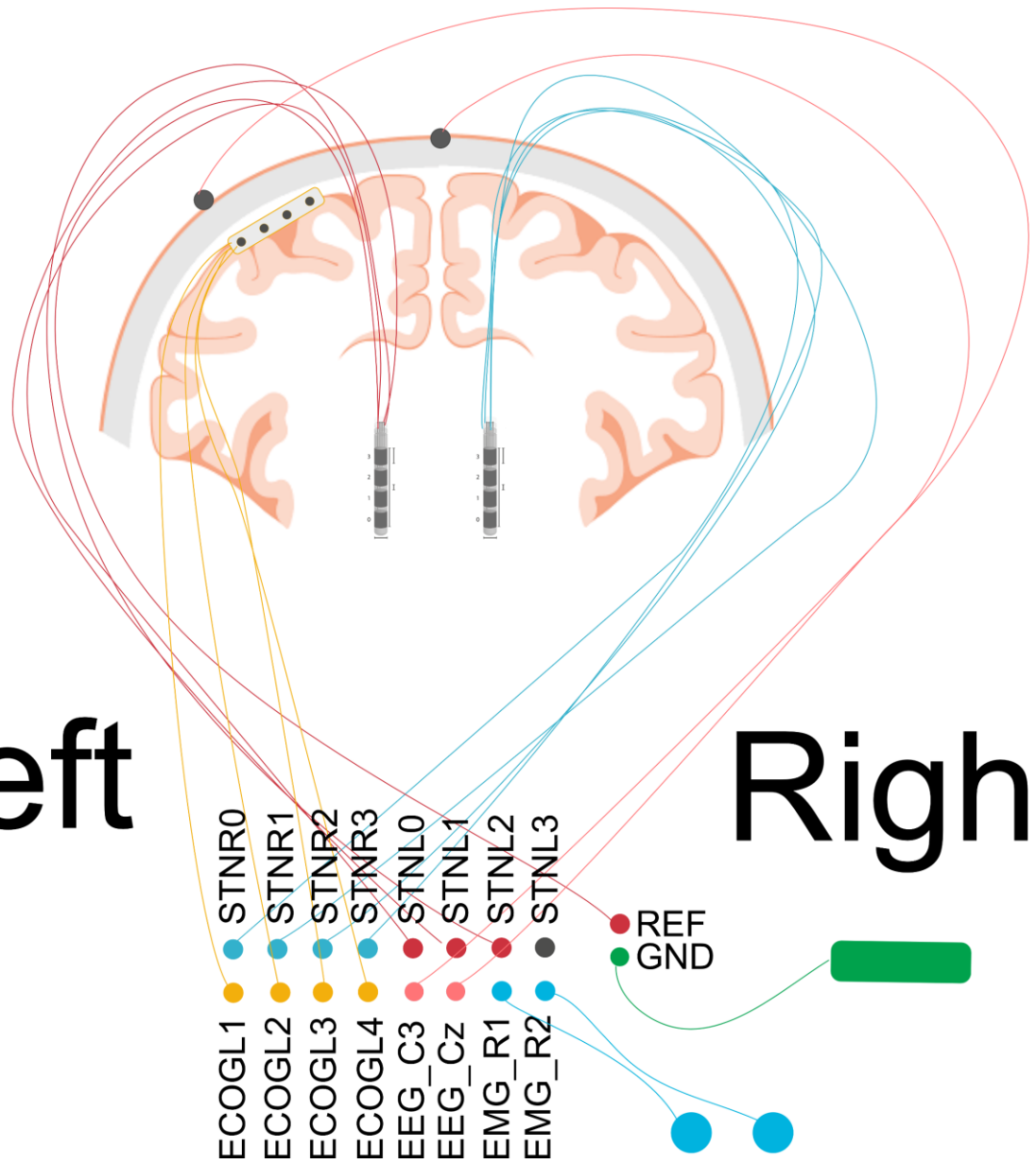
```
%% CLEAR ALL CLOSE ALL CLC
clear all, close all, clc
%% SET FOLDERS AND PATH
% this is where you are going to work, choose any folder of your liking, we
% will create some files here:
root = 'G:\EphysTutorial'; % This needs to be adapted!
% let's create the directory you specified as root and move there
if ~exist(root,'dir')
    mkdir(root)
end

cd(root)

% Now add the required code to your path this is where your code
% repositories for wjn_toolbox and SPM are.
addpath('G:\EphysTutorial\code\wjn_toolbox') % This needs to be adapted
addpath('G:\EphysTutorial\code\spm12') % This needs to be adapted
% SPM needs to be initialized to include FieldTrip folders in path:
% Do not initialize FieldTrip yet, as MatLab will get confused!
spm('defaults','eeg')
```

Simulate Time-Series Data

Var1	Var2	Var3	Var4	Var5	Var6	Var7	Var8	Var9	Var10	Var11	Var12	Var13	Var14	Var15	Var16
17.44536	-13.0001	15.6813	-6.94418	-21.5084	4.4889	-21.0278	0.982859	30.08133	5.326157	-2.30612	14.27718	-8.85583	-10.6297	16.42631	17.79824
51.90393	5.37778	1.317042	-1.12494	-43.3604	-0.67658	23.41852	0.832861	-52.5087	-28.1725	35.33451	-42.6062	-19.7562	-22.4933	-42.8699	-25.43
-91.8978	15.15133	5.867663	61.01972	-30.3506	8.426437	-22.1146	0.182351	-2.9379	-63.9388	15.90375	-52.8492	-39.3723	-22.7746	-7.98778	30.09908
-72.5365	16.09462	-42.3924	113.7275	-22.8124	-30.2174	34.59551	0.646033	7.429764	-55.0718	12.63944	57.0005	-12.9305	-40.2934	4.812994	-35.0529
75.17835	24.12775	27.68883	11.61614	-48.8152	-25.7187	7.830364	0.617373	-38.5238	-55.1546	64.09477	-72.5609	-43.7526	-56.3797	-36.2747	-75.1297
34.79199	23.4456	-17.2983	-50.9208	-24.4215	-19.6319	0.456993	0.761195	-29.1957	10.01181	58.05339	80.79337	-19.5403	-42.051	20.66676	-24.8653
-61.5551	39.47957	-17.6771	1.255369	-23.351	-33.9789	8.167683	0.727523	-57.8605	-47.2746	55.85162	-18.696	35.6154	-23.869	26.14276	-107.437
36.0438	28.37469	-44.2112	-36.7413	15.07316	-62.6933	-16.9531	0.387199	32.78063	2.312314	53.90074	85.34775	27.66106	-21.0495	57.85951	-99.1668
153.7921	26.23782	-31.976	22.39836	5.253314	-45.7416	43.54859	0.716847	59.36172	-38.3371	44.30501	22.4196	-7.0191	-1.34378	13.65297	-7.73064
17.45117	17.52548	-36.5379	3.767606	29.81859	-4.33784	16.50035	0.701032	37.55614	30.81724	-7.06581	-22.0732	17.88272	12.15191	34.22113	8.48559
29.76182	-0.98175	-26.8312	-108.415	2.687854	9.125535	-3.62467	0.45435	30.2548	46.84432	-16.3401	49.57781	9.337698	8.759205	33.58927	1.965049
-6.36476	-17.8688	33.09917	-83.038	-0.16815	-11.2906	36.24333	0.732844	-11.9892	-10.1684	-14.6021	20.77275	-1.72423	43.9281	-37.5261	19.72874
7.487063	-35.6332	47.51357	-49.752	-14.8916	41.15798	15.10401	0.646537	-6.58481	42.15858	-7.95156	-55.1885	-35.78	45.34515	10.27148	26.80412
20.01179	-45.0391	35.36561	-64.4856	-15.8741	36.38661	37.80298	0.270532	-47.3709	40.72408	-43.7877	18.30379	4.639576	43.8289	20.67567	12.47853
-11.3748	-46.2684	52.73747	-2.63776	-35.9673	32.14233	4.932565	0.285897	29.37526	86.87274	24.138	-44.3159	9.068216	61.2276	-19.7672	78.83935
-11.8261	-38.5289	46.05513	0.082233	-12.1433	9.245147	5.641308	0.193862	3.184588	4.109796	-15.7396	22.47213	-31.9581	51.45656	-39.2911	103.1842
-34.0922	-16.9374	-4.38926	-11.3297	-12.9588	20.53083	-1.48429	0.40899	29.85839	56.89172	-1.28392	68.28397	22.84973	17.935	-34.1983	22.07202
37.68356	0.533614	12.73025	29.75901	-5.43509	0.264179	-9.76934	0.193403	43.05617	11.03539	-6.05721	67.43886	34.16503	18.04861	-34.4119	35.78535
-31.9657	22.22055	-15.3088	80.28134	6.574914	20.06449	34.20739	0.215159	59.11546	-3.12321	-1.56831	42.39405	18.15485	1.089486	4.731444	-38.3134
-31.0677	30.33194	-49.8891	-24.8434	8.838566	24.49235	32.73998	0.812468	-83.0213	-25.5399	-17.8273	43.18268	1.679539	-37.4333	-15.8355	-48.1168
27.6425	39.85008	-35.1994	93.84351	5.73753	36.34956	49.86088	0.459907	-21.1995	-74.3763	4.549324	2.55071	-6.11439	-29.1226	28.73343	-10.4274
29.88149	33.21375	-29.0897	-18.3224	5.604261	9.167906	-54.2746	0.899439	28.82499	-40.3767	-9.48072	-51.0134	-15.2109	-35.9024	-40.3472	-25.5436
-66.0893	19.42211	-29.9614	5.943495	-3.4123	20.29811	-100.501	0.015098	54.04399	-58.8302	38.27845	-34.4326	-35.8176	-45.3434	-47.5275	-86.9544
-11.3684	-3.65518	48.82773	-3.40188	-0.37275	-1.78601	-66.729	0.744351	12.25692	-38.1102	56.71299	-82.0972	-37.4819	-28.0853	-2.67428	-48.3667
-34.2167	-5.40506	11.85179	69.87623	-21.7087	-32.905	-29.2424	0.754856	-61.7641	-34.6055	55.46386	-78.5531	-24.555	-28.6499	-24.3321	-66.2543
16.43898	-13.2297	1.10015	-138.952	10.09671	-33.2883	-36.5844	0.343331	-3.47171	-2.076	40.24761	-4.57457	22.43007	-23.1425	-38.1281	39.54056
16.07016	-12.4444	-11.7876	-36.5838	-6.56562	-54.9113	-58.2282	0.543056	-18.0979	-32.4063	22.7851	-58.8418	43.45751	-6.85928	-22.2435	12.13253
-55.0326	-8.14906	15.86381	-58.6922	38.21364	-73.7752	21.46917	0.577012	18.74397	6.340346	-11.6219	115.9483	24.42737	-27.7732	36.31003	-25.0824
66.38997	-2.86262	-10.8249	-124.56	24.55427	-35.2635	-22.4949	0.172231	-48.1145	6.815774	-19.8621	98.0166	48.77447	-7.21047	42.71241	-70.4991
8.853215	7.288987	-37.6876	-47.8082	37.78739	-19.3908	-8.49496	0.6478	-32.8787	24.49967	-24.2829	62.77574	23.88836	3.014698	36.01303	-70.4949
-5.04604	-1.97609	-14.7075	-34.665	10.60594	6.808931	-20.2666	0.190622	62.53931	34.28518	-24.7601	34.50995	38.38434	31.19845	72.30648	45.11849
-57.1958	-7.18087	-0.28	-90.9189	15.53834	62.28071	-11.3165	0.083458	69.63988	66.23926	-11.333	30.68545	1.492255	42.5674	51.49889	35.54219
-63.515	-6.18045	0.685492	-13.2673	-23.1377	52.12532	5.868337	0.42064	112.3798	14.70433	4.167601	-6.08189	-19.3545	62.19946	-46.8215	42.74239
-62.6236	-7.8435	20.2987	-89.2496	-38.6299	42.16783	-40.0786	0.788193	33.44399	9.740401	-10.6829	-27.6077	-7.57753	69.26978	49.74078	74.45663
25.9154	-8.36571	2.240641	7.874467	-46.2067	31.5143	-43.803	0.041129	59.02993	-18.8199	37.23523	-37.8786	-14.8558	60.89416	-23.077	93.80872

CSV file with 16 time-series columns in forgotten_trashy_dataset.csv

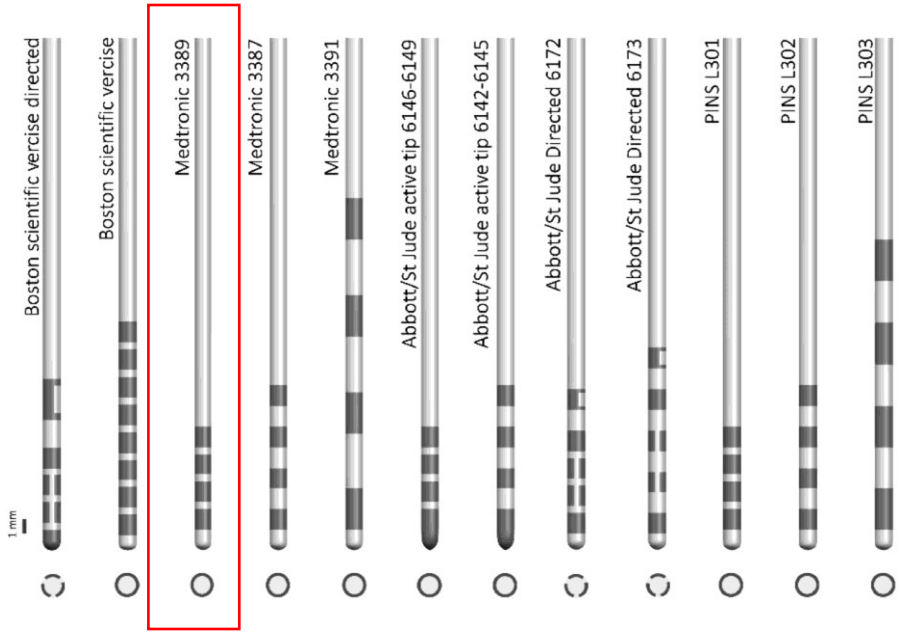
Additional info in trashy_info.txt

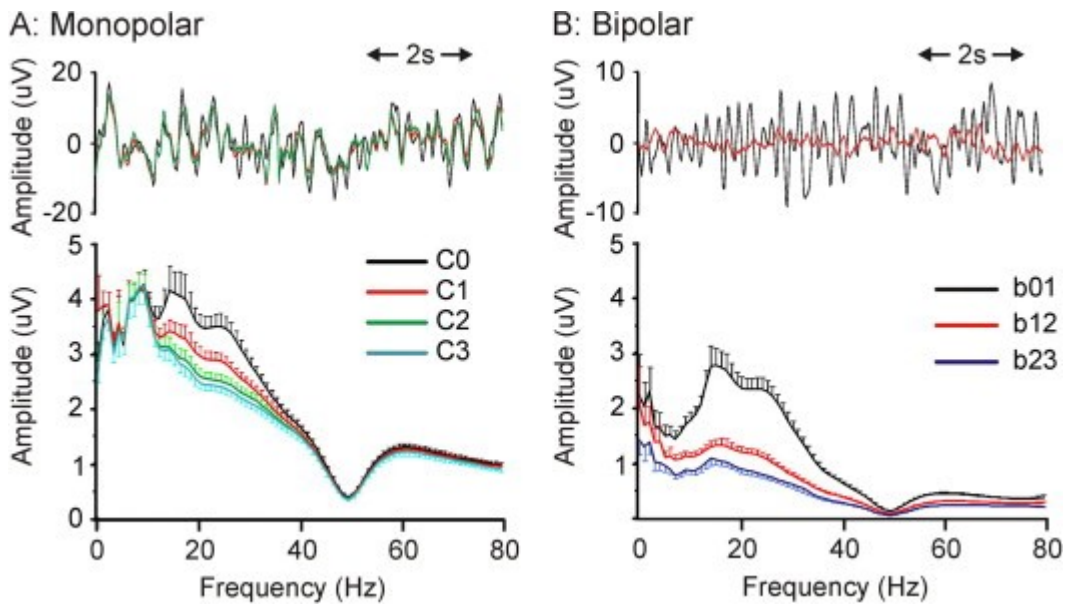


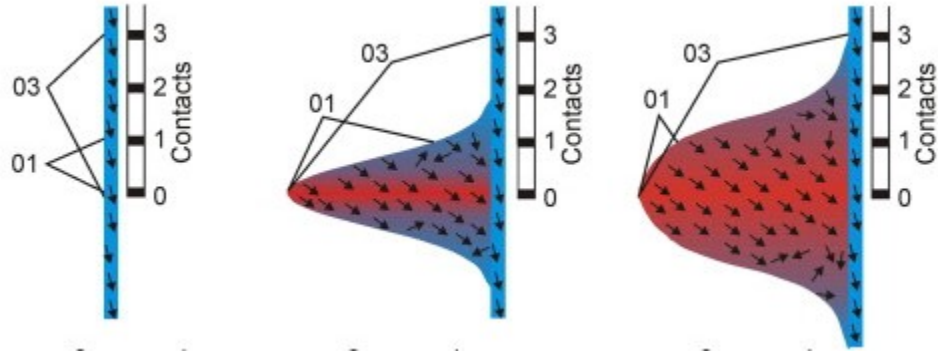
1. STNR0 - REF STNL3
2. STNR1 - REF STNL3
3. STNR2 - REF STNL3
4. STNR3 - REF STNL3
5. STNL0 - REF STNL3
6. STNL1 - REF STNL3
7. STNL2 - REF STNL3
8. Empty (STNL3-STNL3=0)
9. ECOGL1 - REF STNL3
10. ECOGL2 - REF STNL3
11. ECOGL3 - REF STNL3
12. ECOGL4 - REF STNL3
13. EEG_C3 - REF STNL3
14. EEG_Cz - REF STNL3
15. EMG_R1 - REF STNL3
16. EMG_R2 - REF STNL3

Rereferencing LFP

Bipolar rereferencing serves a more focal analysis.







Rereferencing should always be done as the first step of any further processing!

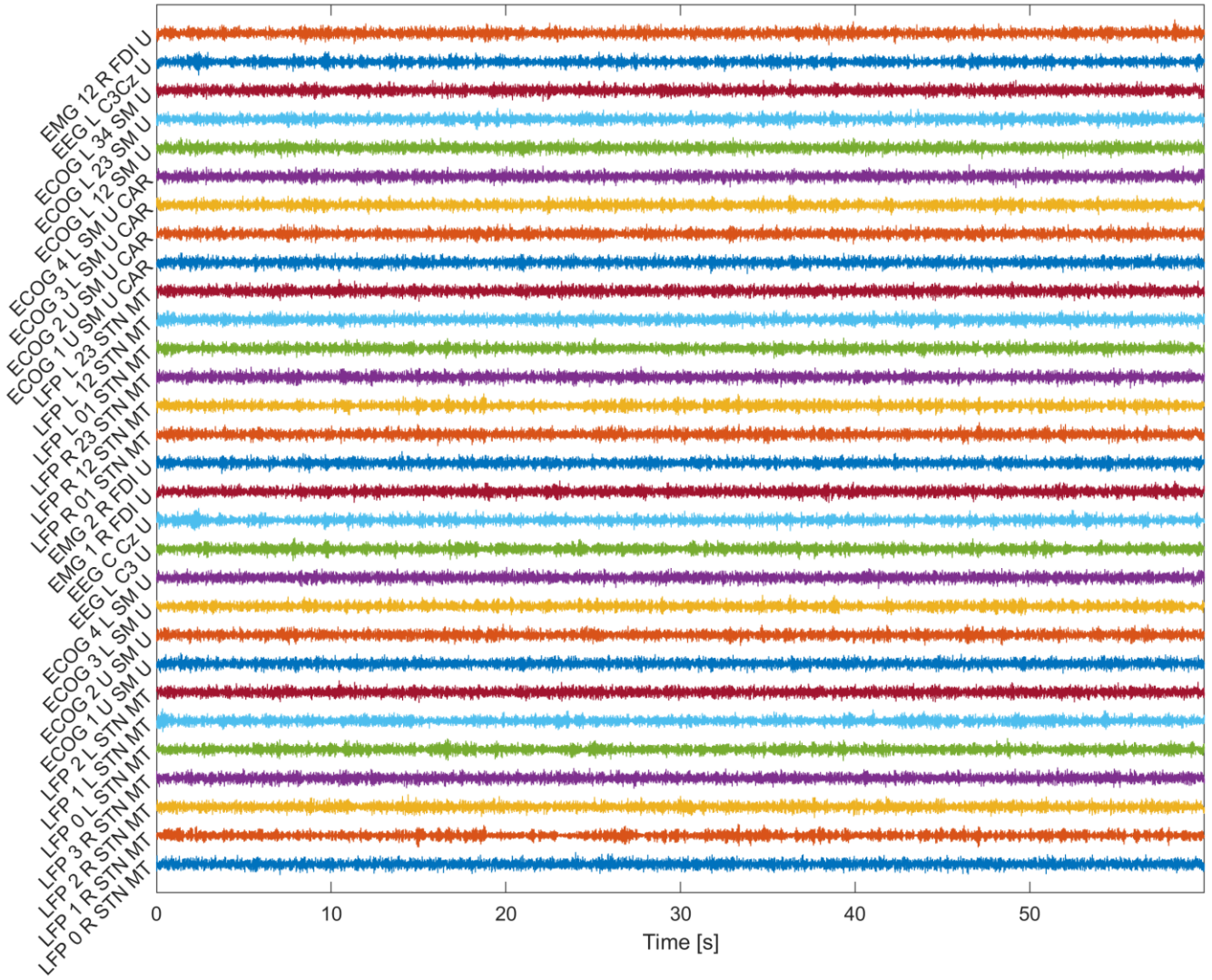
For bipolar rereferencing subtract adjacent recordings.

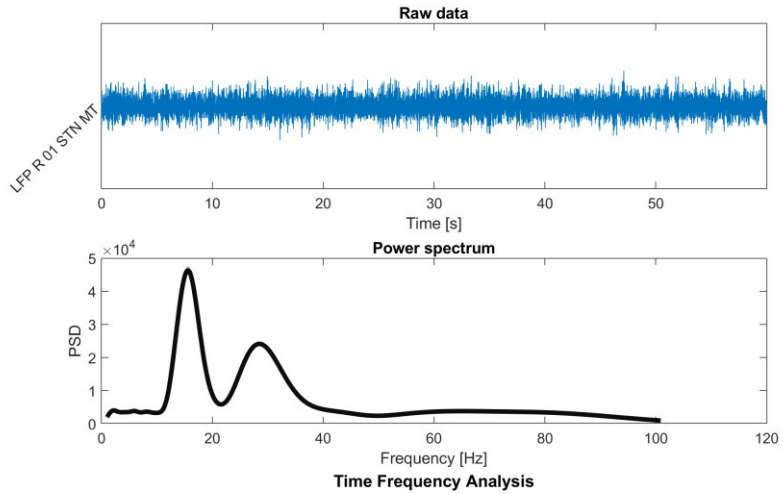
1. STNR0 - REF STNL3
2. STNR1 - REF STNL3
3. STNR2 - REF STNL3
4. STNR3 - REF STNL3
5. STNL0 - REF STNL3
6. STNL1 - REF STNL3
7. STNL2 - REF STNL3

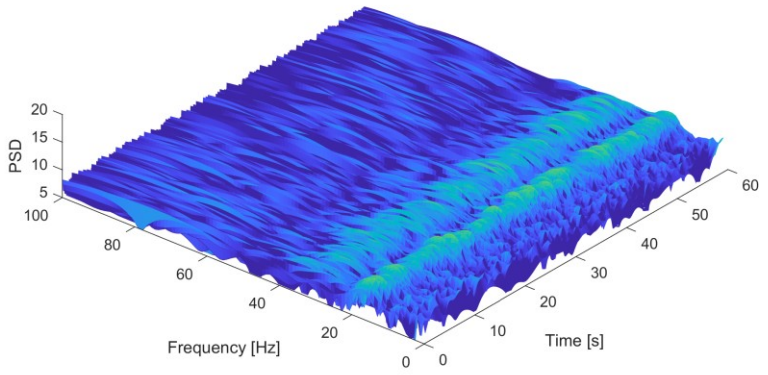
> Channel 1-2 = STNR01
> Channel 2-3 = STNR12
> Channel 3-4 = STNR23
> Channel 5-6 = STNL01
> Channel 6-7 = STNL12
= Channel 7 = STNL23

Note that Channel 7 is already hardware bipolar.

Dataset milestone: Rereferenced and clean.







www.nature.com/scientificdata

SCIENTIFIC DATA

OPEN

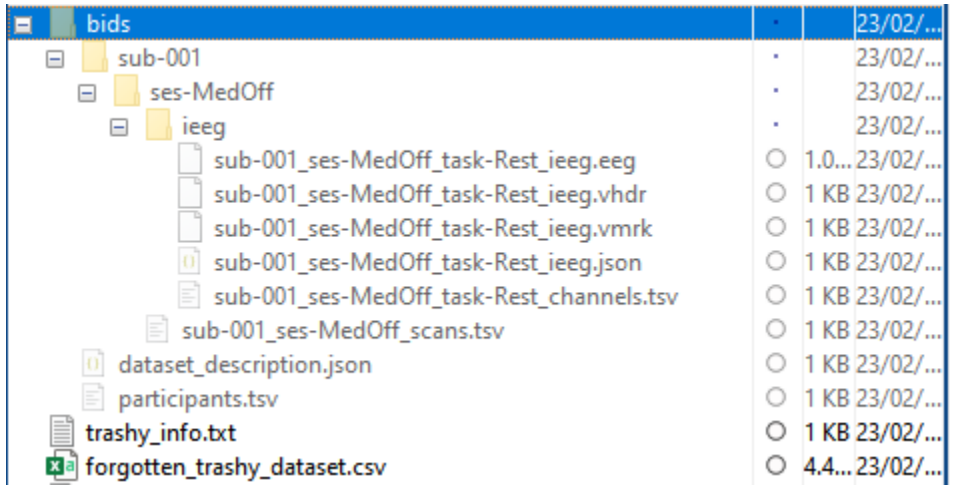
COMMENT

iEEG-BIDS, extending the Brain Imaging Data Structure specification to human intracranial electrophysiology

Received: 29 January 2019
Accepted: 24 May 2019
Published online: 25 June 2019

Christopher Holdgraf[1,16], Stefan Appelhoff[2], Stephan Bickel[3], Kristofer Bouchard[4], Sasha D'Ambrosio[5], Olivier David[6], Orrin Devinsky[7], Benjamin Dichter[8], Adeen Flinker[7], Brett L. Foster[9], Krzysztof J. Gorgolewski[8], Iris Groen[10], David Groppe[11], Aysegul Gunduz[12], Liberty Hamilton[13], Christopher J. Honey[14], Mainak Jas[15], Robert Knight[16], Jean-Philippe Lachaux[17], Jonathan C. Lau[18], Christopher Lee-Messer[8], Brian N. Lundstrom[19], Kai J. Miller[20], Jeffrey G. Ojemann[21], Robert Oostenveld[22], Natalia Petridou[23], Gio Piantoni[24], Andrea Pigorini[5], Nader Pouratian[25], Nick F. Ramsey[24], Arjen Stolk[16], Nicole C. Swann[26], François Tadel[6,27], Bradley Voytek[28], Brian A. Wandell[8], Jonathan Winawer[10], Kirstie Whitaker[29,32], Lyuba Zehl[30] & Dora Hermes[8,24,31]

The Brain Imaging Data Structure (BIDS) is a community-driven specification for organizing neuroscience data and metadata with the aim to make datasets more transparent, reusable, and reproducible. Intracranial electroencephalography (iEEG) data offer a unique combination of high spatial and temporal resolution measurements of the living human brain. To improve internal (re)use and external sharing of these unique data, we present a specification for storing and sharing iEEG data: iEEG-BIDS.



https://www.nature.com/articles/s41597-019-0105-7.pdf

Let‘s move to Python now