Clinical Applications of Brain Imaging, Stimulation, and Modeling

Exercise 1

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1 Questions

1.1 Which are the major types of disorders of the nervous system? Is there any overlap between these types? (8 pts)

The three main types of disorders of the nervous system are as follows:

i. **Neurological Disorders:** These are caused by some physical condition, resulting in abnormalities or injuries to the nervous system. They include brain dysfunctions, neuropathy, and neurodegenerative disorders.

ii. **Neuropsychiatric or Mental Disorders:** These disorders are associated with altered mood and cognitive functions. Some examples include depression, mania, PTSD, schizophrenia, and phobias.

iii. **Neurodevelopmental Disorders:** These disorders usually appear in early childhood and consist of several intellectual, learning, and communication disabilities, motor disorders, ASD, ADHD, etc.

Since these disorders are largely caused by some abnormality in the brain, there exists some overlap between them. So, neurodegenerative and neurodevelopmental disorders can also affect mood and cognition, causing other mental health issues.

1.2 List some types of treatment approaches that exist for treating disorders of the nervous system (6 pts)

Five main types of treatment approaches are listed below:

i. **Surgery:** Involves the resection or physical repairing of brain issues. Mainly used in cases of neurological disorders with identifiable structure issues.

ii. **Therapy:** It is used to alter cognitive function via consultation or creative expression. It is commonly used for neuropsychiatric issues.

iii. **Medication:** Another commonly used treatment for neuropsychiatric issues, often in conjunction with therapy. It involves using medicine like antidepressants and mood stabilizers to alter the neurochemistry.

iv. **Electroconvulsive Therapy:** It is sometimes used in the case of severe psychotic disorders by using high-voltage electricity to induce seizure and "reset" the brain.

v. **Brain stimulation:** It uses electric or magnetic stimulation to stimulate specific brain regions. It is often used for treating neurological and neuropsychiatric disorders.

1.3 Are the effects of physical and psychological interventions fully separable? (4 pts)

The simple answer is, no, the effects of physical and psychological interventions may intertwine as one can affect the other. For example, it is largely believed that simply talking to a therapist may lead to some physical changes in the brain, that affect the way a person thinks or behaves. Similarly, physical stimulation, medicine, and surgeries can permanently affect a person's mood and cognition.

1.4 Which are the most common animal models in clinical neuroscience, and why? (6 pts)

The following are commonly used in clinical neuroscience:

i **Rodents:** Mice and rats are the most common subjects of experiments in clinical neuroscience. They are ideal for many tests due to their intelligence, small size, and short lifespan.

ii **Cats:** Using cats for research in clinical neuroscience was common until the mid-80s due to their sturdiness and large size apt for lab instruments. However, now their usage is uncommon due to the development of smaller equipment and public opinion of its ethics.

iii **Monkeys:** Some experiments of certain monkeys like Macaque and Marmoset are done, albeit, rarely. Although the use of great apes like Orangutans is prohibited in most countries.

1.5 Give some reasons why animal models are used in clinical neuroscience. (6 pts)

Although many ethical arguments can be made against the use of animals in clinical neuroscience research, some reasons as to why animal models are preferred are as follows:

i It is much easier to get official approvals to operate on animals in clinical tests.

ii Animals can be bred specifically for the purpose of clinical studies for certain experiments. These are known as the transgenic models.

iii Despite the differences in cognition and behavior from humans, many animals, mainly mammals, have similar nervous systems to humans.

1.6 Name one neurological condition in which surgery on the human brain sometimes becomes necessary. (2 pts)

One neurological condition in which surgery on the brain can be necessary is Epilepsy. It is categorized by recurrent seizures due to uncontrolled electrical discharge in the neurons. One of the common treatments for epilepsy is cutting connections or parts of the cortex through surgery.

1.7 Which are the main components of neurons? (3 pts)

The three main components of the neuron as as follows:

i **Soma:** It is the so-called "Cell Body" of the neuron. It processes the information received from other neurons.

ii **Axon:** It is the projection along which an electrical signal is transmitted from Soma to other neurons or muscles. It is protected by a myelin sheath.

iii **Dendrites:** There are many Dendrites connected to Soma which receive incoming signals from other neurons.

1.8 What is the function of afferent and efferent nerves? (5 pts)

i **Afferent Nerves:** These fibers connect the sensory neurons to brain, allowing for the brain to perceive different sensations.

ii **Efferent Nerves:** These fibers connect the brain to different muscles and glands, enabling various motor functions.

1.9 Which are the 'classical' four lobes of the cortex? Which regions are sometimes regarded as separate lobes? (6 pts)

The classical four lobes of the cortex and their common functions are given below:

i **Frontal Lobe:** Mainly responsible for motor functions, problem-solving, and speech production.

ii **Parietal Lobe:** Common functions include touch perception, body orientation, and sensory discrimination.

iii **Temporal Lobe:** Responsible for auditory processing, language comprehension, and information retrieval.

iv **Occipital Lobe:** Mainly used in sight, visual reception, and visual interpretation.

Sometimes, the insula and limbic cortex are considered as separate lobes, giving the six-lobe model of the cortex. The insular lobe in the lateral sulcus is involved in consciousness, emotion, and homeostasis, whereas the limbic lobe in the cingulate gyrus and hippocampus is responsible for emotion, motivation, and memory.

1.10 Which are 3 common approaches to identify clinical relevance of brain regions? Which of these is the oldest? (4 pts)

Following are the 3 common approaches to identifying the clinical relevance of the brain regions:

i **Lesion Study:** Lesion study is the oldest approach to identify the clinical relevance of brain regions. It involves studying the effects of brain injuries and abnormalities on a person's functioning and cognition.

ii **Brain Imaging:** Brain imaging involves techniques like MRI or PET scans to visualize and study brain structures.

iii **Electrophysiology (EEG):** EEG is used to measure brain activity over time with the help of electrodes. Neurological disorders like epilepsy can be diagnosed with EEG.

2 Python Exercises

2.1 Load the csv files 'patient_data.csv' and 'controls_data.csv' into numpy arrays. These arrays give you the mean brain activity for each parcel for each subject, during the experiment.

```
import pandas as pd
import numpy as np
import seaborn as sns
from scipy.stats import spearmanr, ttest_ind
import matplotlib.pyplot as plt
from collections import defaultdict

#Task 0:

patient_data = pd.read_csv('Patient_data.csv', delimiter=';', header=None)
patient_data = patient_data.to_numpy()

#print(patient_data)

control_data = pd.read_csv('Controls_data.csv', delimiter=';', header=None)
control_data = control_data.to_numpy()

#print(control_data)

print(patient_data.shape)
```

```
# Output
(100, 40)
```

2.2 Use independent-sample t-tests to compare the brain activity between patients and controls in each of the parcels. Save the test statistics and p-values to arrays. In how many parcels is there a significant difference ($p < 0.05$) between the two cohorts? In how many of these is the activity larger in patients? (7 pts)

```
#Task 1:

parcels = patient_data.shape[0]
#print(parcels)

t_stats = np.zeros(parcels)
p_vals = np.zeros(parcels)
```

```
for i in range(parcels):
    t_stat, p_val = ttest_ind(patient_data[i,:],control_data[i,:], equal_var=
    False)
    t_stats[i] = t_stat
    p_vals[i] = p_val

diff = p_vals < 0.05
diff_sum = np.sum(diff)
print(f'Significant difference in {diff_sum} parcels')

larger_act = (patient_data.mean(axis=1) > control_data.mean(axis=1)) & diff
larger_act = np.sum(larger_act)

print(f'Activity larger in patients in {larger_act} parcels')
```

```
# Output
Significant difference in 11 parcels
Activity larger in patients in 6 parcels
```

2.3 Load the 'parcel_names.txt file'. You will see from the parcel names that the parcels have been assigned to 7 different functional systems or 'networks'. Create for each network a list of indices with those parcels that belong to this network. How many parcels are in each network? (4 pts)

```
#Task 2:

with open('parcel_names.txt', 'r') as file:
    names_list = [line.strip() for line in file.readlines()]

parcel_network = defaultdict(list) #key = network name, value = list of
    indices of parcels

for i, parcel in enumerate(names_list):
    network_name = parcel.split('_')[2] #Format: 7
    Networks_LH_Cont_Cing_1__Left, Network name: Cont
    parcel_network[network_name].append(i)

#print(network)

counts = {network_key : len(indices) for network_key, indices in
    parcel_network.items()}

#print(counts)

for network_name, count in counts.items():
    print(f'Network: {network_name}, Number of parcels: {count}')
```

```
#Output
```

```
Network: Cont, Number of parcels: 13
Network: Default, Number of parcels: 24
Network: DorsAttn, Number of parcels: 15
Network: Limbic, Number of parcels: 5
Network: SalVentAttn, Number of parcels: 12
Network: SomMot, Number of parcels: 14
Network: Vis, Number of parcels: 17
```

2.4 Compute for each subject the mean brain activity in each network. Now compare for each network with t-tests the brain activity between patients and controls. In which networks is the brain activity significantly larger/smaller in patients? (7 pts)

```
#Task 3:
patient_dictionary = {}
control_dictionary = {}

for network in parcel_network:
    patient_dictionary[network] = np.zeros(patient_data.shape[1])

for network in parcel_network:
    control_dictionary[network] = np.zeros(control_data.shape[1])

for network, indices in parcel_network.items():
    patient_dictionary[network] = patient_data[indices, :].mean(axis=0)
    control_dictionary[network] = control_data[indices, :].mean(axis=0)

test_stat_net = {}
net_p = {}

for network in parcel_network:
    t_stat, p_val = ttest_ind(
        patient_dictionary[network],
        control_dictionary[network],
        equal_var=False
    )
    test_stat_net[network] = t_stat
    net_p[network] = p_val

sig_nets = {}
for network, p_val in net_p.items():
    if p_val < 0.05:
        sig_nets[network] = p_val

print("\nSignificant networks (p < 0.05):")
for network, p_val in sig_nets.items():
    mean_patient = patient_dictionary[network].mean()
    mean_control = control_dictionary[network].mean()
    if mean_patient > mean_control:
```

```
        print(f"Network: {network} - Brain activity is significantly larger in
     patients (p = {p_val:.4f}).")
    else:
        print(f"Network: {network} - Brain activity is significantly smaller
    in patients (p = {p_val:.4f}).")
```

```
# Output
Significant networks (p < 0.05):
Network: SomMot - Brain activity is significantly smaller in patients (p = 0.0373).
Network: Vis - Brain activity is significantly larger in patients (p = 0.0129).
```

2.5 On a single figure, plot the mean brain activity per network in each cohort in an informative way (6 pts). Show also the standard deviation for each network in the above plot. (2 bonus points). Plot the distribution of subjects' activity per network in violinplots. (3 bonus points)

```
#Task 4:

net_names = list(parcel_network.keys())
mean_patient_activity = []
std_patient_activity = []
mean_control_activity = []
std_control_activity = []

for network in net_names:
    mean_patient_activity.append(patient_dictionary[network].mean())
    std_patient_activity.append(patient_dictionary[network].std())
    mean_control_activity.append(control_dictionary[network].mean())
    std_control_activity.append(control_dictionary[network].std())

plt.figure(figsize=(10, 6))
x = np.arange(len(net_names))
width = 0.35

plt.bar(x - width/2, mean_patient_activity, width, yerr=std_patient_activity,
    capsize=5, label='Patients', alpha=0.7)
plt.bar(x + width/2, mean_control_activity, width, yerr=std_control_activity,
    capsize=5, label='Controls', alpha=0.7)
plt.xticks(x, net_names, rotation=45, ha='right')
plt.xlabel('Network')
plt.ylabel('Mean Brain Activity')
plt.title('Mean Brain Activity per Network in Each Cohort')
plt.legend()
plt.tight_layout()
plt.show()

network_list = []
brain_activity_list = []
cohort_list = []
```

```python
for network in net_names:
    for activity in patient_dictionary[network]:
        network_list.append(network)
        brain_activity_list.append(activity)
        cohort_list.append('Patients')

    for activity in control_dictionary[network]:
        network_list.append(network)
        brain_activity_list.append(activity)
        cohort_list.append('Controls')

violin_data = pd.DataFrame({
    'Network': network_list,
    'Brain Activity': brain_activity_list,
    'Cohort': cohort_list
})

plt.figure(figsize=(10, 6))
sns.violinplot(data=violin_data, x='Network', y='Brain Activity', hue='Cohort'
    , split=True, inner='quartile')
plt.xticks(rotation=45, ha='right')
plt.title('Distribution of Subjects\' per Network in Violinplots')
plt.xlabel('Network')
plt.ylabel('Brain Activity')
plt.tight_layout()
plt.show()
```

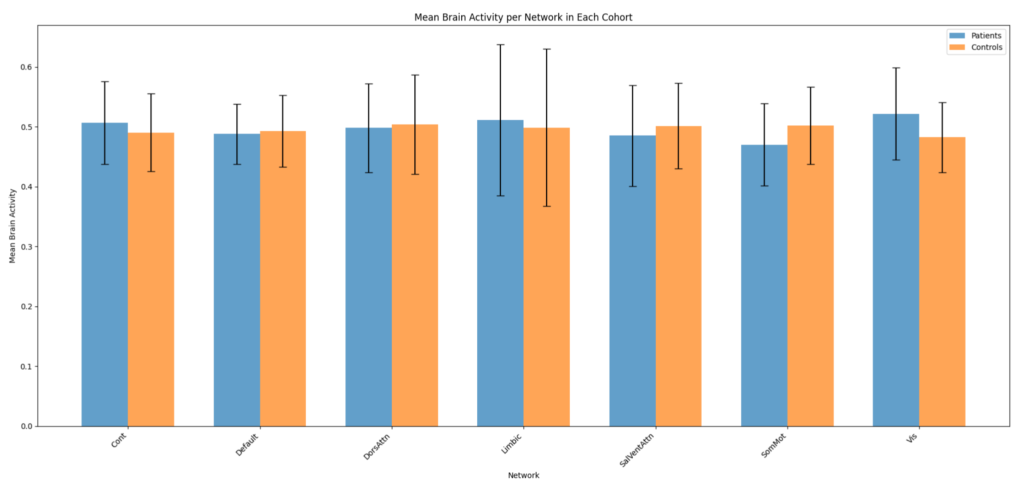

Figure 1: Mean Brain Activity per Network in Each Cohort

2.6 Load the patients' symptom scores from 'symptom_scores.txt' and plot them in a histogram with 20 bins. (4 pts)

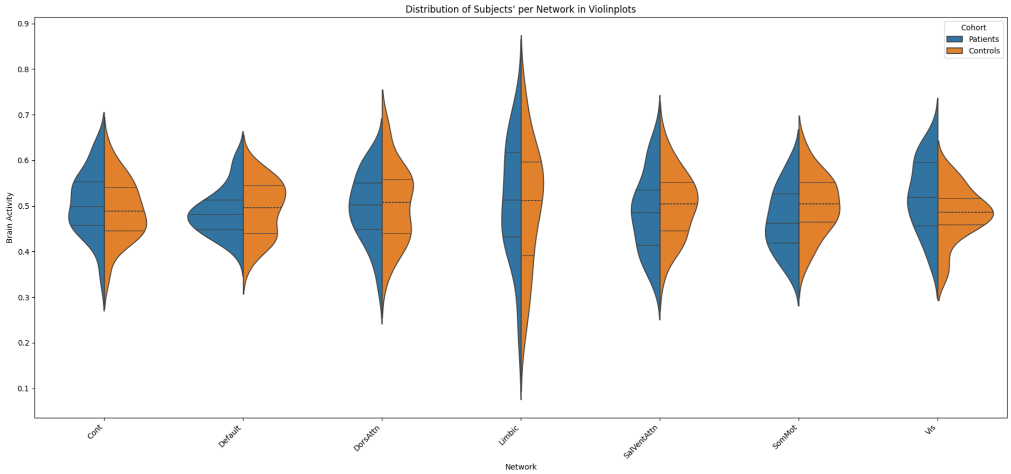

Figure 2: Distribution of Subjects per Network in Violinplots

```
#Task 5

symptom_scores = pd.read_csv('symptom_scores.txt', header=None, names=['Score'
    ])['Score'].to_numpy()

plt.figure(figsize=(10, 6))
plt.hist(symptom_scores, bins=20, edgecolor='black', alpha=0.7)
plt.title('Distribution of Patients\' Symptom Scores')
plt.xlabel('Symptom Score')
plt.ylabel('Frequency')
plt.grid(True, linestyle='--', alpha=0.7)
plt.tight_layout()
plt.show()
```

2.7 For each parcel, compute the Spearman correlation between symptom score and brain activity in the patient group. In how many parcels is the correlation significant? In which network are most significant correlations? (8 pts)

```
#Task 6

parcel_corr = np.zeros(parcels)
parcel_p = np.zeros(parcels)

for i in range(parcels):
    corr, p_val = spearmanr(symptom_scores, patient_data[i, :])
    parcel_corr[i] = corr
    parcel_p[i] = p_val

sig_parcels = []
```

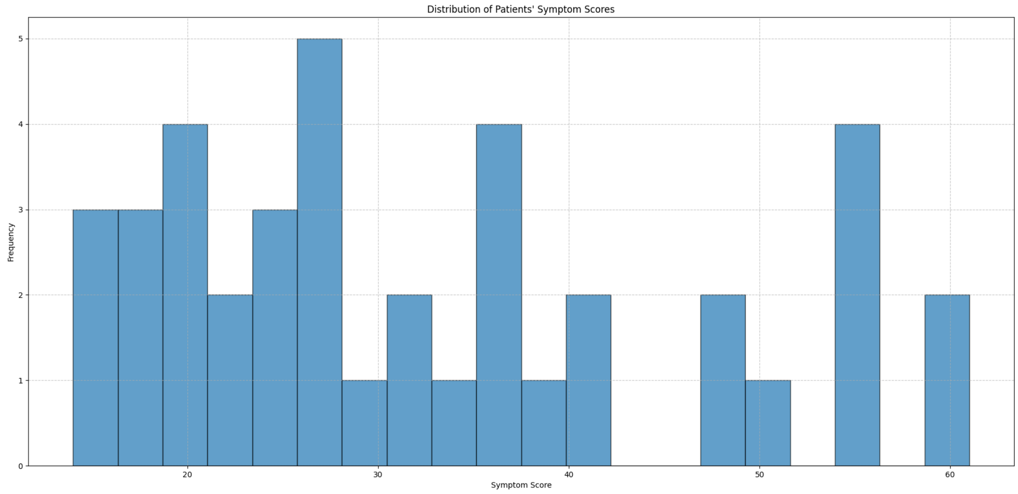

Figure 3: Distribution of Patients Symptom Scores

```
for index, p_val in enumerate(parcel_p):
    if p_val <0.05:
        sig_parcels.append(index)

print(f"Number of parcels with significant correlations: {len(sig_parcels)}")

no_sig_nets = defaultdict(int)
for idx in sig_parcels:
    for network, indices in parcel_network.items():
        if idx in indices:
            no_sig_nets[network] += 1

most_significant_network = max(no_sig_nets, key=no_sig_nets.get)
print(f"Network with most significant correlations: {most_significant_network} ({no_sig_nets[most_significant_network]} significant parcels)")
```

```
#Output
Number of parcels with significant correlations: 4
Network with most significant correlations: Vis (2 significant parcels)
```

2.8 Compute the correlation with scores at the network level (network mean with score). For which networks is the correlation significant? (6 pts)

```
#Task 7

net_corr = {}
net_p = {}


for network, indices in parcel_network.items():
```

```
    network_mean_activity = np.mean(patient_data[indices, :], axis=0)
    corr, p_val = spearmanr(symptom_scores, network_mean_activity)
    net_corr[network] = corr
    net_p[network] = p_val

print("Correlations for all networks:")
for network in net_corr:
    print(f"Network: {network}, Correlation: {net_corr[network]}, p-value: {
    net_p[network]}")

sig_net_corr = {}

for network in net_corr:
    if net_p[network] < 0.05:
        sig_net_corr[network] = (net_corr[network], net_p[network])

print("\nSignificant correlations at the network level:")
for network, (corr, p_val) in sig_net_corr.items():
    print(f"Network: {network}, Correlation: {corr}, p-value: {p_val}")
```

```
#Output
Correlations for all networks:
Network: Cont, Correlation: -0.008826709769444876, p-value: 0.9568907118658024
Network: Default, Correlation: -0.003380442039361868, p-value: 0.9834834739623961
Network: DorsAttn, Correlation: 0.32583705212738007, p-value: 0.04018923978041639
Network: Limbic, Correlation: 0.13981883879471724, p-value: 0.3895194456142549
Network: SalVentAttn, Correlation: 0.06516741042547601, p-value: 0.6895170025716175
Network: SomMot, Correlation: -0.06103575904403374, p-value: 0.708305838296523
Network: Vis, Correlation: 0.4693180364647393, p-value: 0.0022504147474182523

Significant correlations at the network level:
Network: DorsAttn, Correlation: 0.32583705212738007, p-value: 0.04018923978041639
Network: Vis, Correlation: 0.4693180364647393, p-value: 0.0022504147474182523
```

2.9 For each of the significantly correlated networks, plot symptom scores and the network's mean brain activity in a scatterplot and label both axes. (8 pts). Add a linear fit to each of the scatterplots. (3 bonus points)

```
#Task 8

for network in sig_net_corr:
    network_mean_activity = patient_data[parcel_network[network], :].mean(axis
    =0)

    plt.figure(figsize=(10, 6))

    plt.scatter(symptom_scores, network_mean_activity, label="Data Points",
    color='blue', alpha=0.6)
```

```
    plt.title(f'Relationship Between Symptom Scores and {network} Mean
    Activity')
    plt.xlabel('Symptom Scores')
    plt.ylabel(f'{network} Mean Brain Activity')

    regression_plot = sns.regplot(
        x=symptom_scores,
        y=network_mean_activity,
        scatter=False,
        color='red',
        line_kws={"linestyle": "--"}
    )

    plt.legend()
    plt.grid(visible=True, linestyle='--', linewidth=0.5)
    plt.tight_layout()
    plt.show()
```

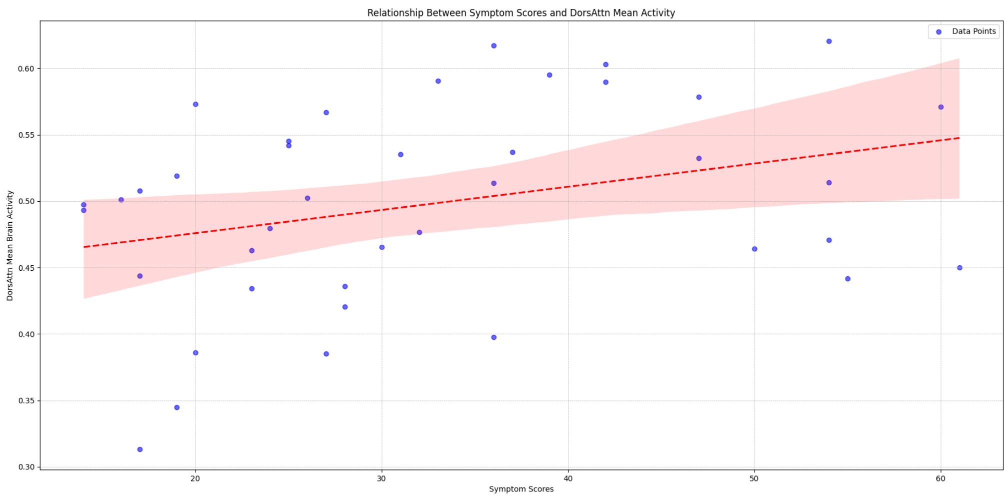

Figure 4: Relationship Between Symptom Scores and DorsAttn Mean Activity

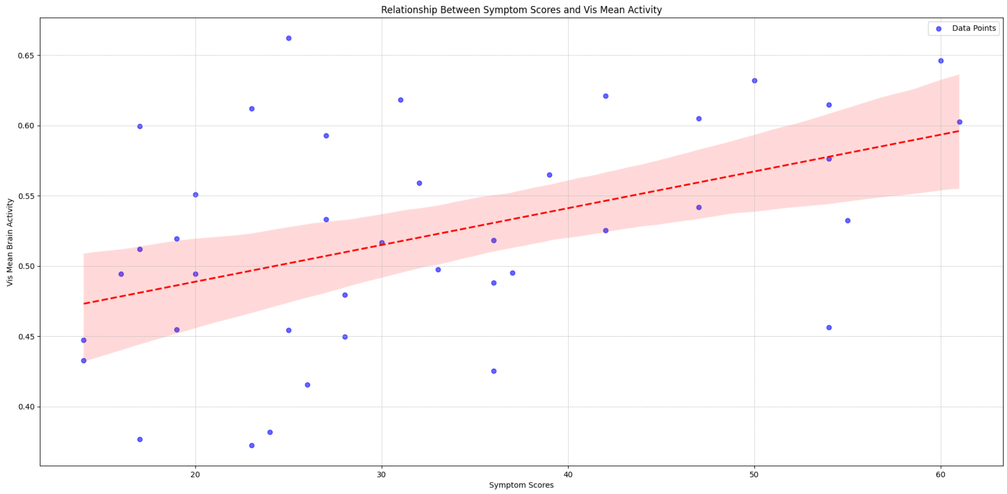

Figure 5: Relationship Between Symptom Scores and Vis Mean Activity