



# SAN Final Assignment

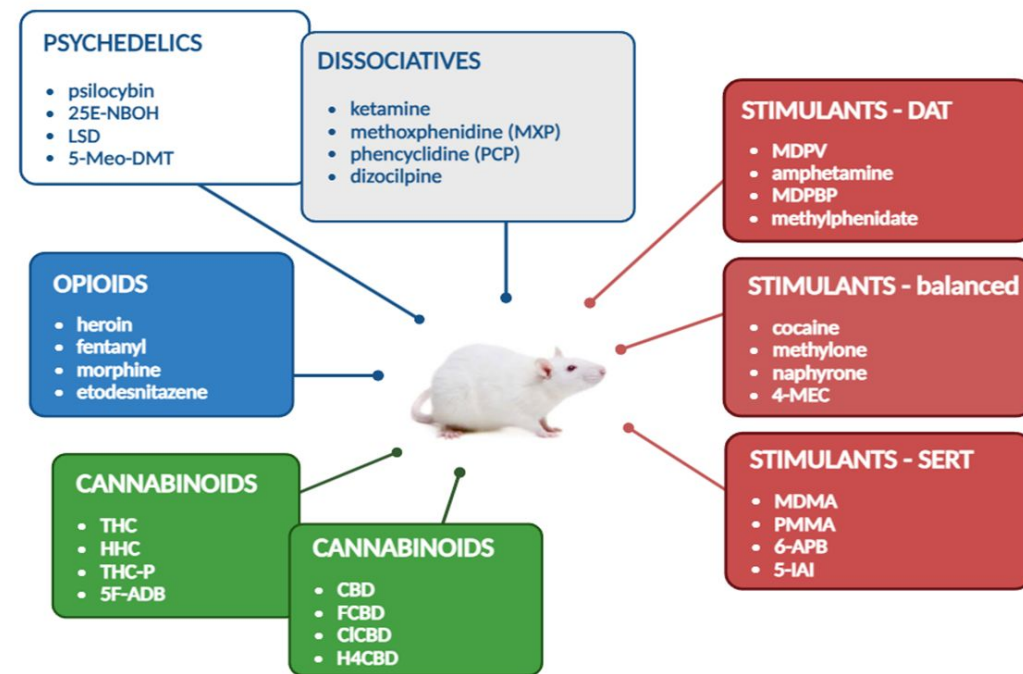
## Fingerprinting drug classes via EEG

Timur Abragimovič,  
Jakub Benetin,  
Čestmír Vejmla

7.1.2025

# Study design

- Data z projektu VK01010212
- Drugs divided into 8 groups
- 4 runs of experiment
- $\pm 18$  rats in each run
- Each rat received each treatment just once in randomized order



	RUN 1			RUN 2			RUN 3 a 4		
GROUP	TREATMENT	dose mg/kg	file name	GROUP	dose mg/kg	file name	TREATMENT	dose mg/kg	file name
VEH	SAL+deionized	x	x	SAL+deionized	x	x	SAL+deionized	x	x
VEHET	SAL+eth+Tween	x	x	SAL+eth+Tween	x	x	SAL+eth+Tween	x	x
psychedelics	psilocybin	5	psilocybin_H	25E-NBOH	5	25E_H	psilocybin	0,5/2	psilocybin_L/psilocybin_M
SERT	MDMA	5	MDMA_M	PMMA	20	PMMA_M	MDMA	2,5/10	MDMA_L/MDMA_H
BALANCED	cocaine	20	cocaine_H	MDMC	10	MDMC_M	cocaine	5/10	cocaine_L/cocaine_M
DAT	MDPV	2	MDPV_M	amphetamine	5	AMP_M	MDPV	1/4	MDPV_L/MDPV_H
dissociatives	MXP	20	MXP_M	ketamine	30	ketamine_M	MXP	10/40	MXP_L/MXP_H
opiods	heroin	0,25	heroin_M	fentanyl	20ug	fentanyl_M	heroin	0,05/2	heroin_L/heroin_H
CBR modulators	CBD	10	CBD_H	FCBD	10 H	FCBD_H	CBD	1/5	CBD_L/CBD_M
CBR agonists	HHC	10	HHC_H	THC	10 H	THC_H	HHC	1/5	HHC_L/HHC_M



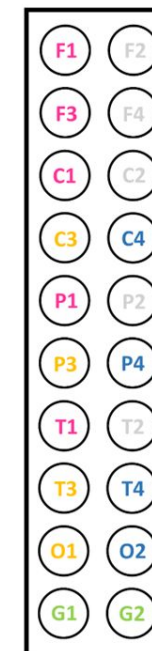
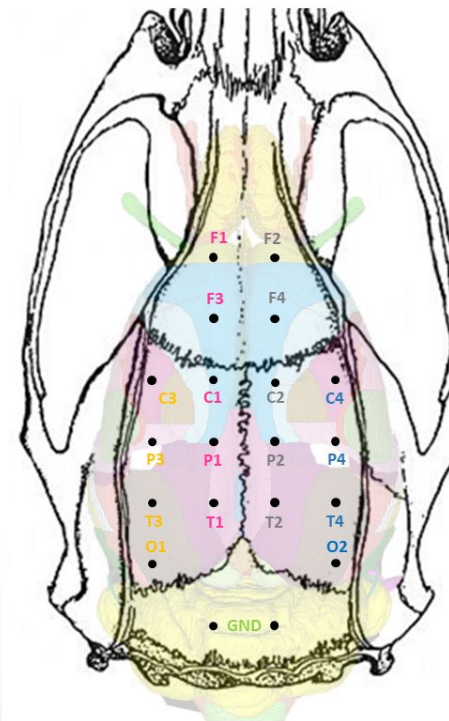
# Reviewer's questions

- example of rat randomization within the 1st run of experiment

RUN 1 by week	WEEK									
ID	1	2	3	4	5	6	7	8	9	10
1	MDMA	psilo	CBD	HHC	heroin	MXP	cocaine	VEH	MDPV	VEHET
2	VEH	MXP	MDMA	MDPV	HHC	VEHET	CBD	psilo	cocaine	heroin
3	VEH	MDMA	psilo	MXP	heroin	cocaine	VEHET	HHC	MDPV	CBD
5	VEH	MXP	MDPV	HHC	VEHET	psilo	MDMA	heroin	cocaine	CBD
19	heroin	CBD	cocaine	HHC	MDPV	VEH	psilo	MXP	VEHET	MDMA
7	cocaine	VEHET	HHC	heroin	MDMA	CBD	MDPV	VEH	psilo	MXP
8	HHC	VEHET	CBD	cocaine	heroin	VEH	psilo	MXP	MDPV	MDMA
9	VEHET	VEH	heroin	MDPV	cocaine	HHC	CBD	MDMA	psilo	MXP
10	MDPV	HHC	MDMA	MXP	VEH	heroin	psilo	VEHET	cocaine	CBD
11	psilo	VEHET	CBD	HHC	VEH	MDPV	heroin	cocaine	MXP	MDMA
12	heroin	MDPV	CBD	VEH	HHC	VEHET	cocaine	MDMA	MXP	psilo
13	MDPV	VEH	VEHET	heroin	CBD	cocaine	MDMA	HHC	psilo	MXP
14	MXP	cocaine	psilo	VEHET	VEH	MDPV	heroin	HHC	CBD	MDMA
15	HHC	CBD	MDPV	VEHET	heroin	MDMA	cocaine	MXP	psilo	VEH
16	cocaine	CBD	VEHET	heroin	HHC	psilo	MDPV	MDMA	VEH	MXP
17	VEHET	MXP	VEH	cocaine	heroin	MDMA	CBD	MDPV	HHC	psilo
18	MDPV	HHC	MDMA	heroin	MXP	VEH	cocaine	psilo	CBD	VEHET

# Data collection

- 20 equidistantly-placed electrodes
- Freely moving rat in OFT arena
- → 15 min baseline → sc. application → 90 min test
- EEG preprocessing:
  - → baseline + 6 segments of 15 min
  - → no artifacts or SWS
- Average power ( $\mu V^2$ ) per band and 15-minute segment
- Data structure
- Numpy matrices 7x5x18 (time segment x band x electrode)
- ID16\_psilocybin\_H\_week7\_ar2



1	F1	frontal association cortex
11	F2	
2	F3	secondary motor cortex
12	F4	
3	C1	primary motor cortex
13	C2	
4	C3	primary somatosensory cortex, forelimb area
14	C4	
5	P1	medial parietal association cortex
15	P2	
6	P3	primary somatosensory cortex, trunk area
16	P4	
7	T1	secondary visual cortex, mediomedial area
17	T2	
8	T3	primary visual cortex, binocular area
18	T4	
9	O1	primary visual cortex, binocular area
19	O2	
10	GND	
20		



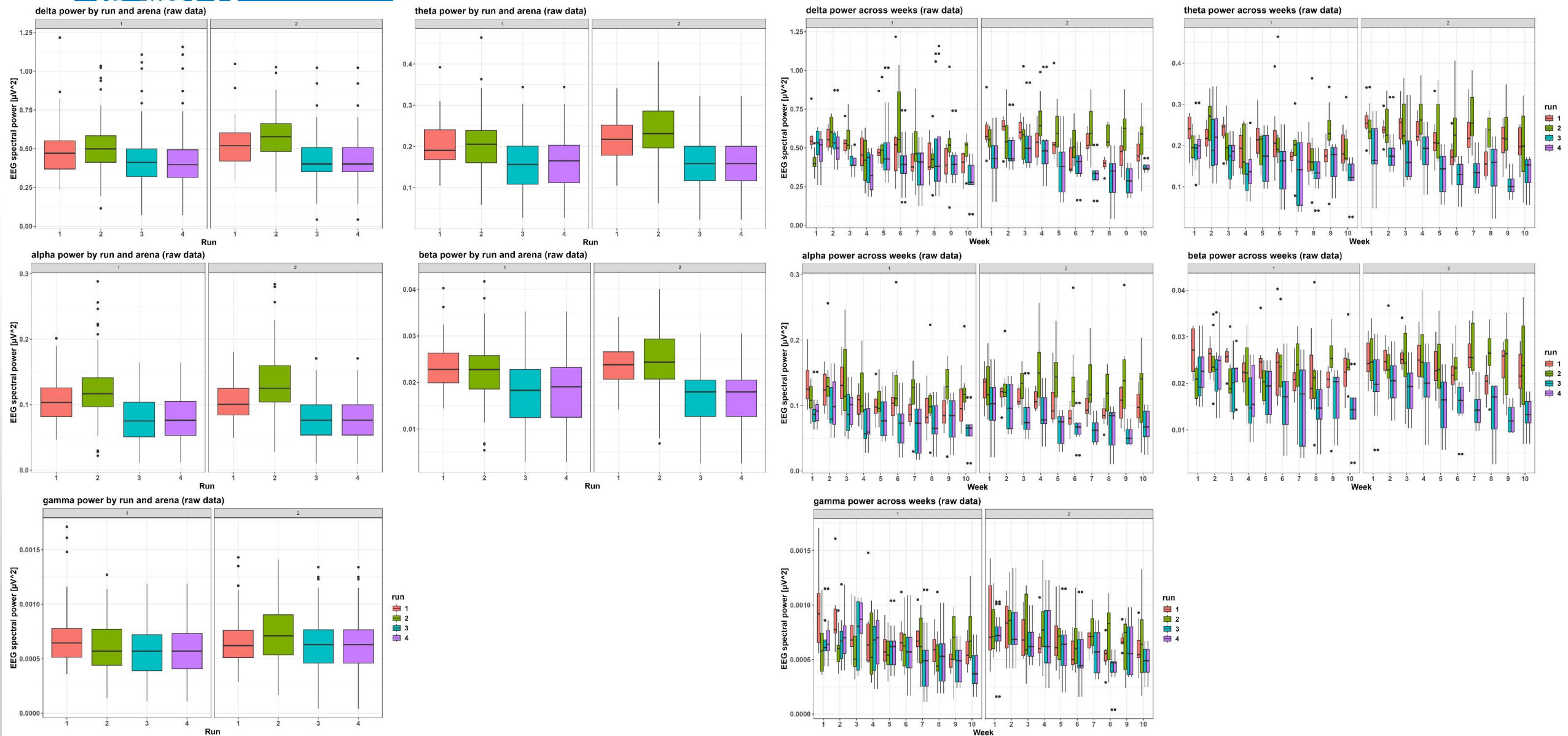
# Validation of cross-over design

- Validating the cross-over design by checking baseline EEG's of all rats – sensitivity to arena, time, and run
- Hypothesis: negligible arena differences, minimal run effects, and stable EEG over ten weeks
- Testing separately for each band: delta, theta, alpha, beta, gamma
- Factors in data: rat\_id, arena (categorical – ar1/ar2), run (categorical – run 1/2/3/4), week (numeric 1-10), mean spectral power values
- Used linear mixed-effects models (LMM), with arena, run, week as fixed effects and a random intercept for each rat
- Employed post-hoc Tukey comparisons to pinpoint differences
- $\text{Power}_{ijkl} = \beta_0 + \beta_{\text{arena}} \times \text{Arena}_i + \beta_{\text{run}} \times \text{Run}_j + \beta_{\text{week}} \times \text{Week}_k + (1 | \text{rat\_id})$





# Boxplots of baseline EEG spectral power



# Validation of cross-over design

- **Arena:** Minimal influence overall; Arena 2 yields slightly higher power in gamma (borderline for theta).
- **Time Dependence:** Baselines decline from Week 1 to Week 10, indicating instability over extended periods.
- **Rat Adaptation vs. Implant Aging:** The broadband decrease suggests implant/hardware issues (e.g., glial scar) rather than simple behavioral adaptation.
- **Run Effects:** Runs 3 and 4 show systematically lower power than Runs 1 and 2, revealing potential technical or environmental variability.
- **Normalization with baseline:** Vital to correct for these time, run, and hardware-related biases in a cross-over design.



# Modeling EEG Power as a Function of Time for Different Substances

- Using ALL available recordings
- Disregard effect of week when recording occurred
- Disregard effect of arena
- Each dose modeled separately (LMM)
- Some substances and dosages have more recordings,  $n = [11; 35]$







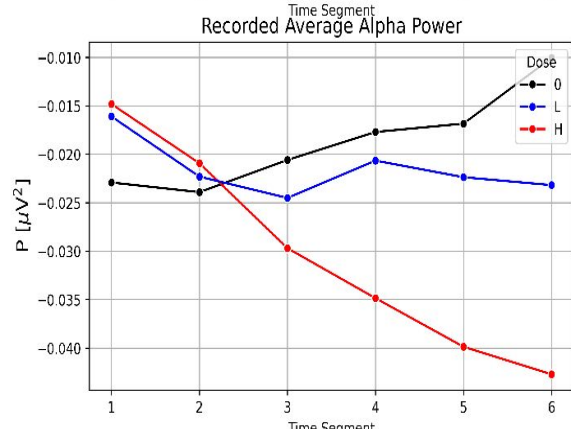
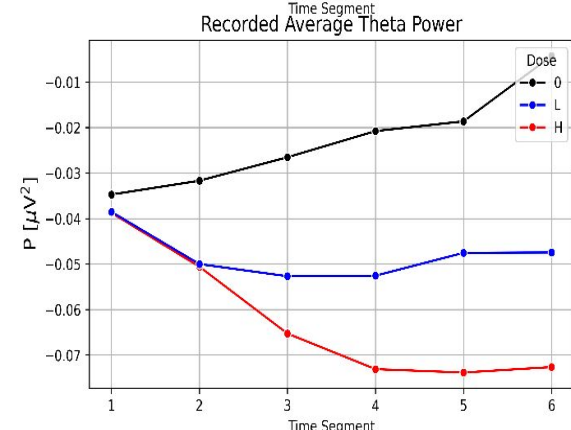
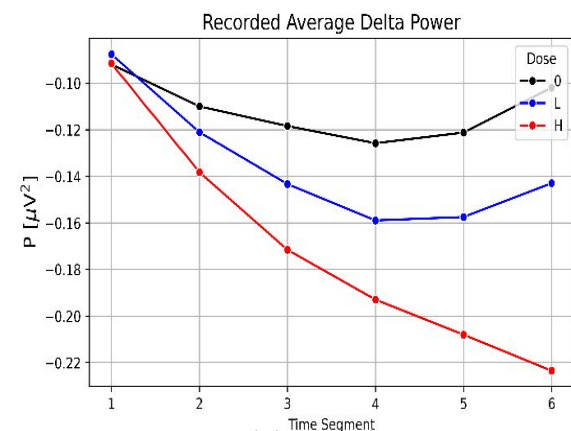
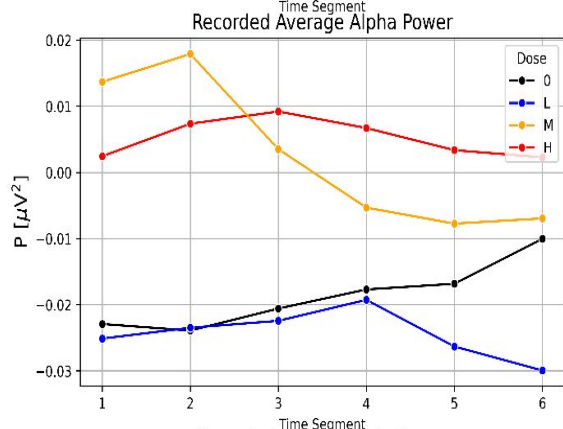
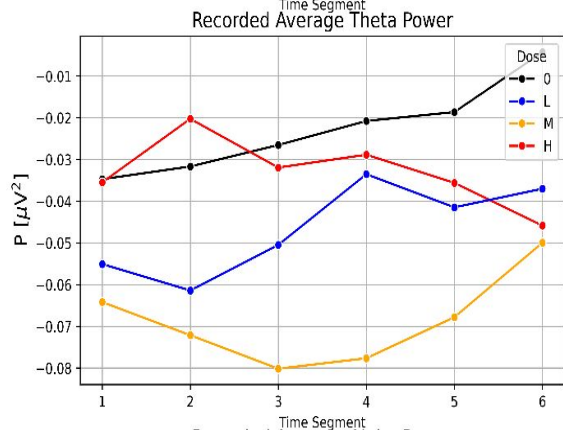
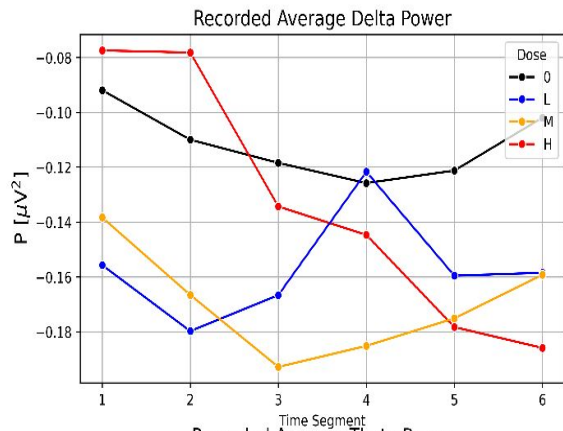




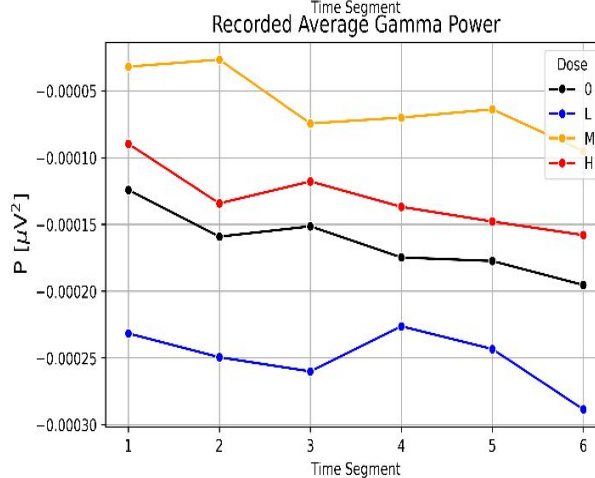
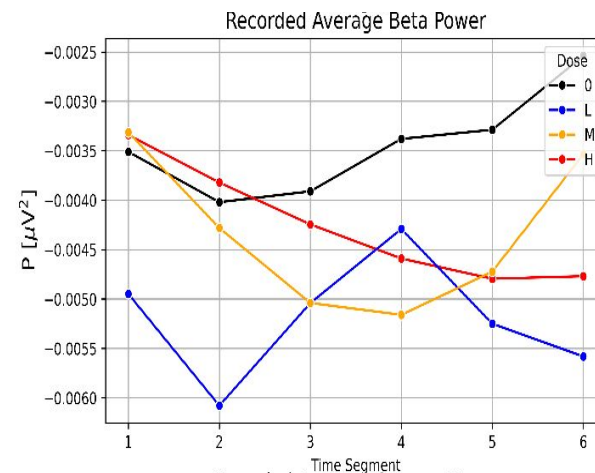
$$\begin{array}{ccccccc}
 1 & & 1 & & 1 & & 1 \\
 & \nearrow & & \nearrow & & \nearrow & \\
 & 1 & & 1 & & 1 & \\
 & & \searrow & & \searrow & & \searrow \\
 & & 1 & & 1 & & 1
 \end{array}$$

$$\begin{array}{ccccccc}
 1 & & 1 & & 1 & & 1 \\
 & \nearrow & & \nearrow & & \nearrow & \\
 & 1 & & 1 & & 1 & \\
 & & \searrow & & \searrow & & \searrow \\
 & & 1 & & 1 & & 1
 \end{array}$$

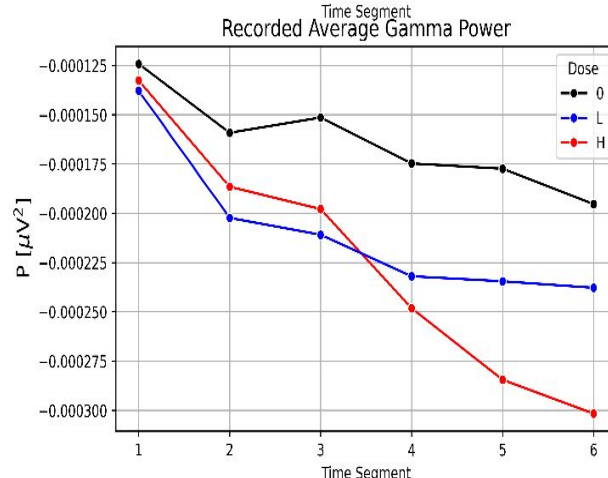
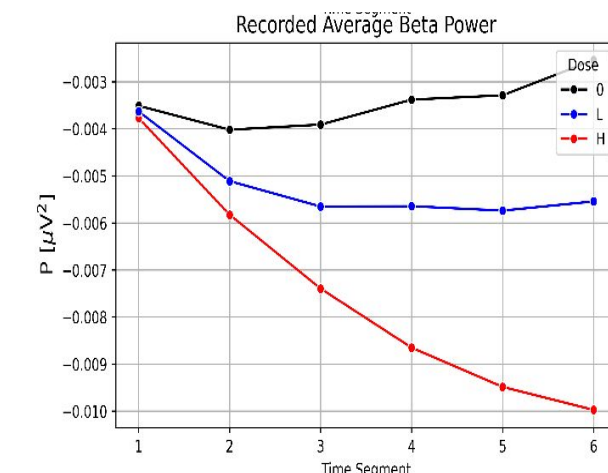
# Heroin



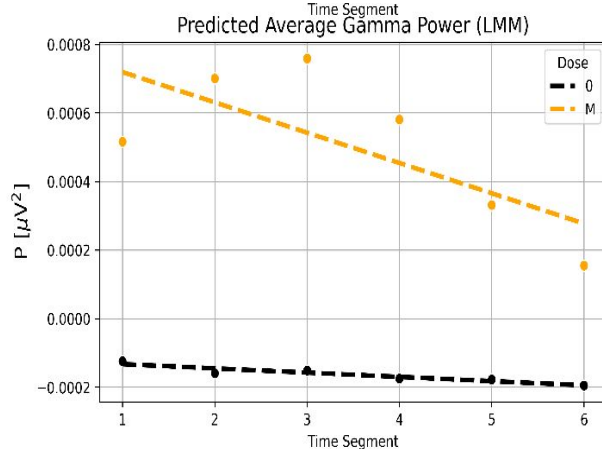
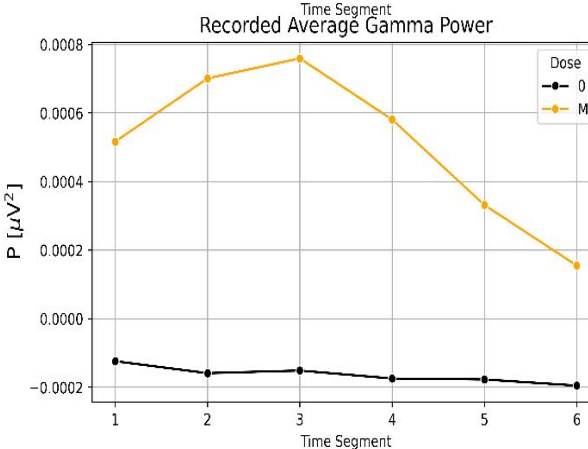
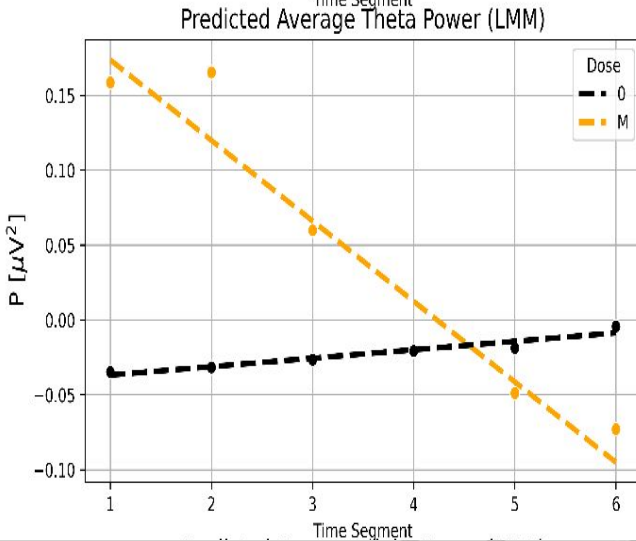
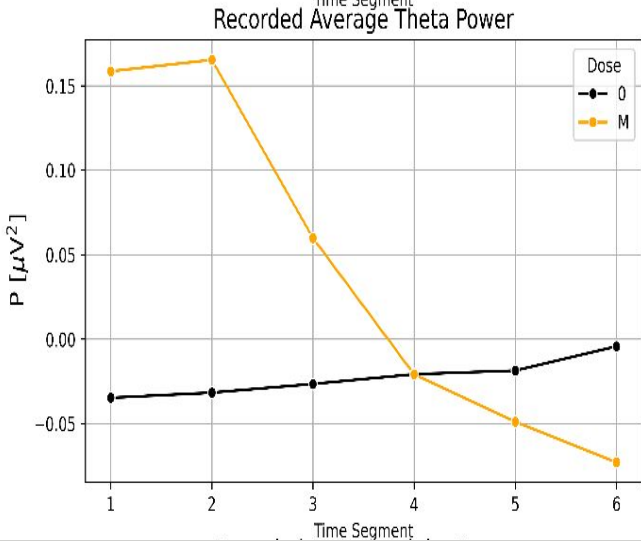
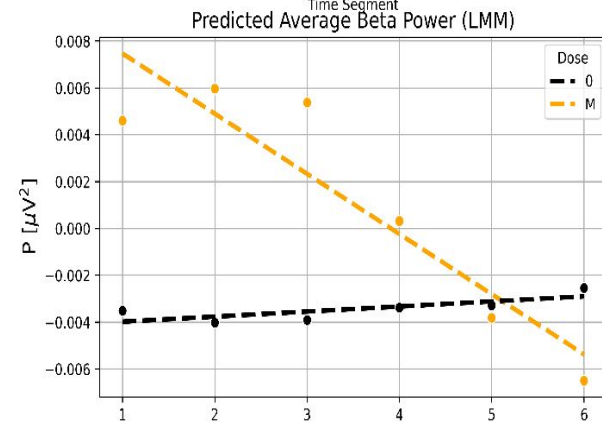
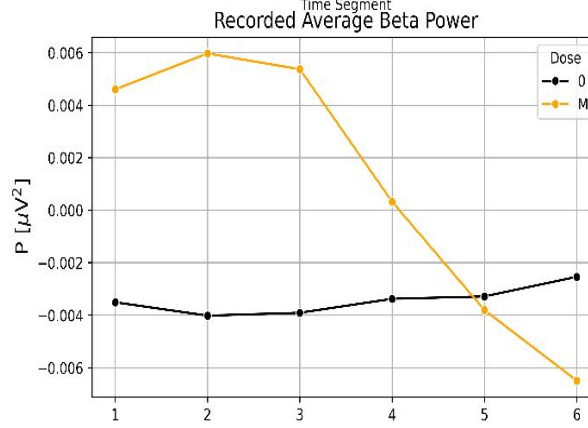
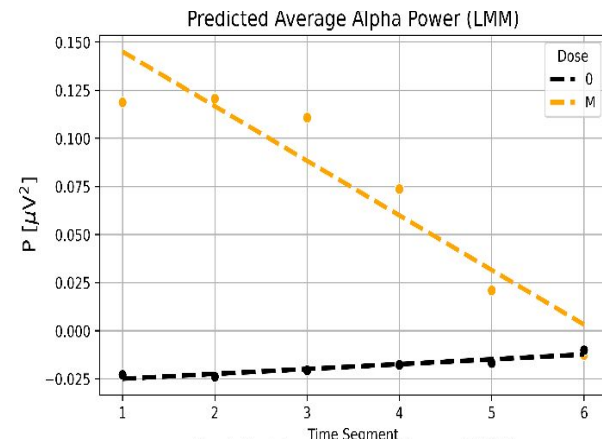
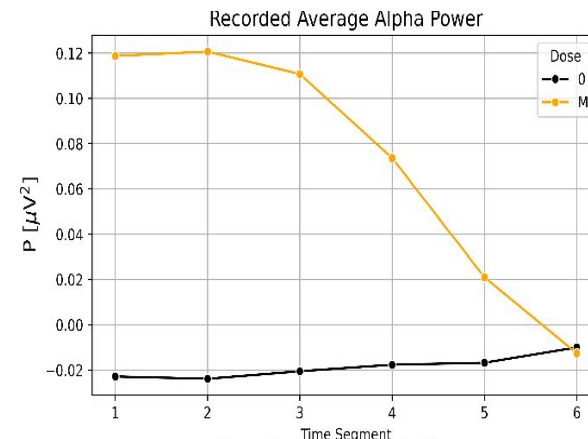
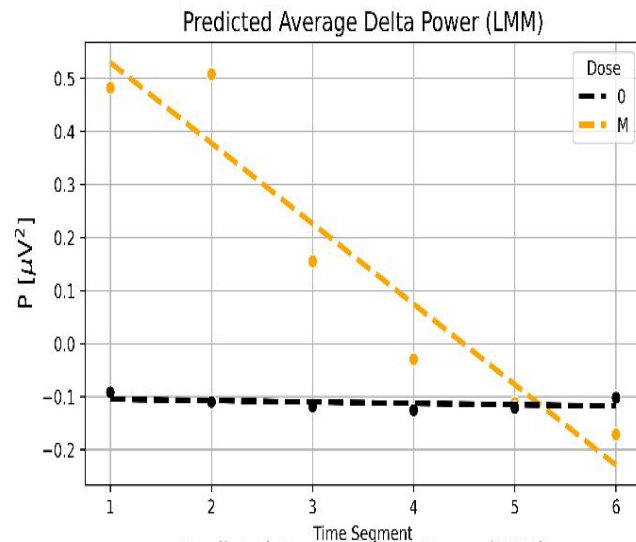
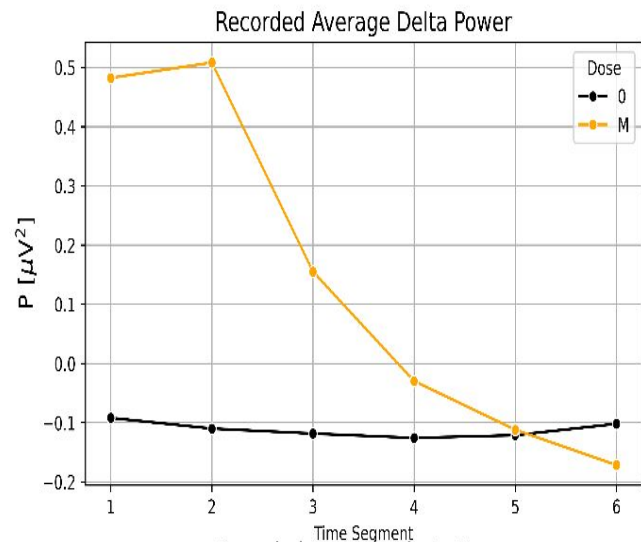
# Heroin



# HHC

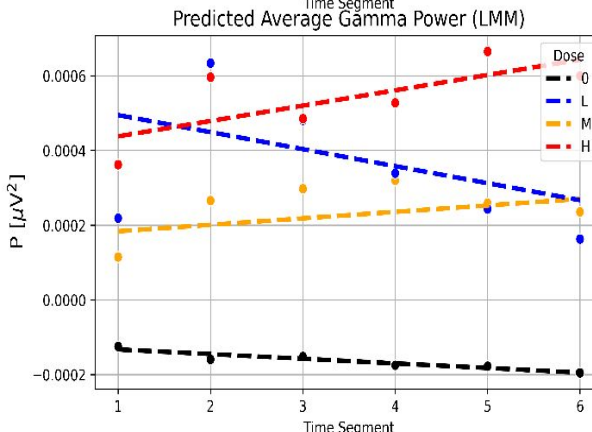
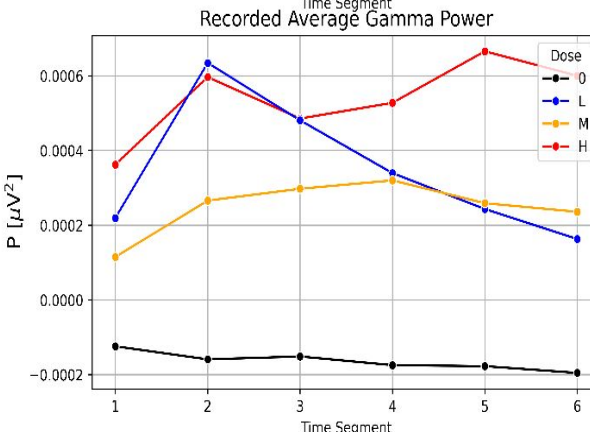
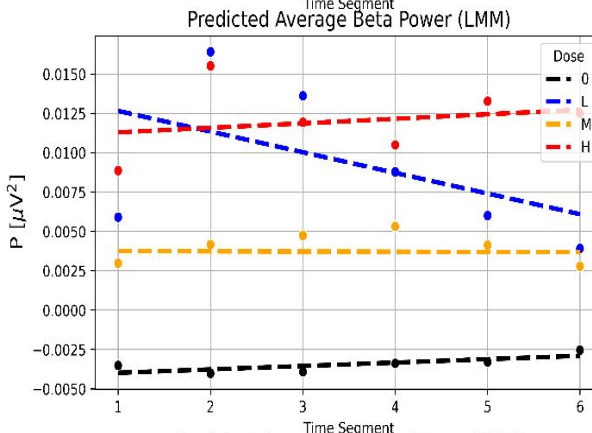
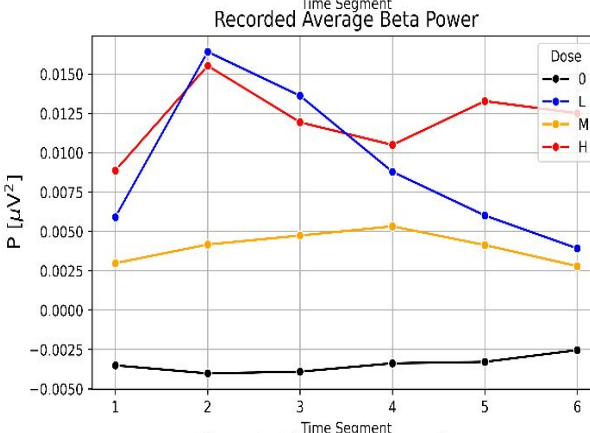
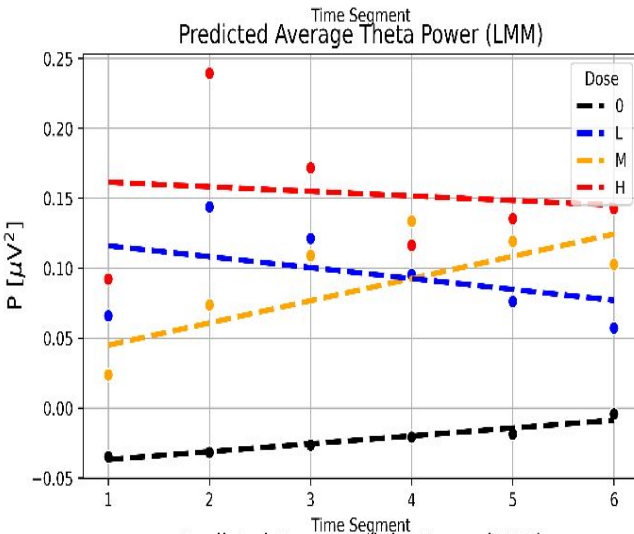
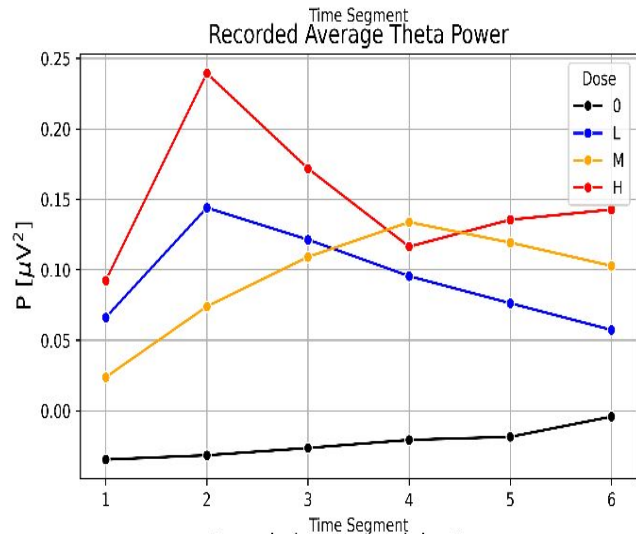
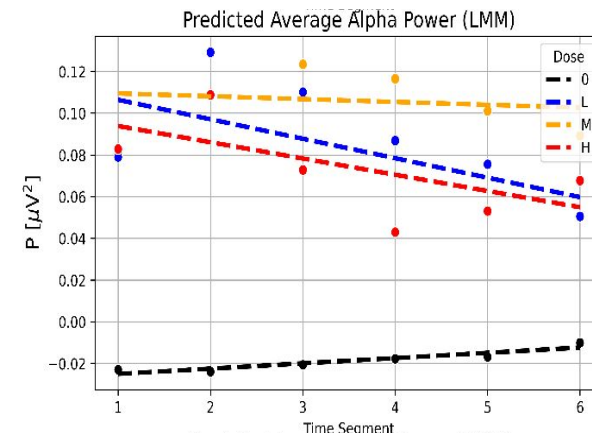
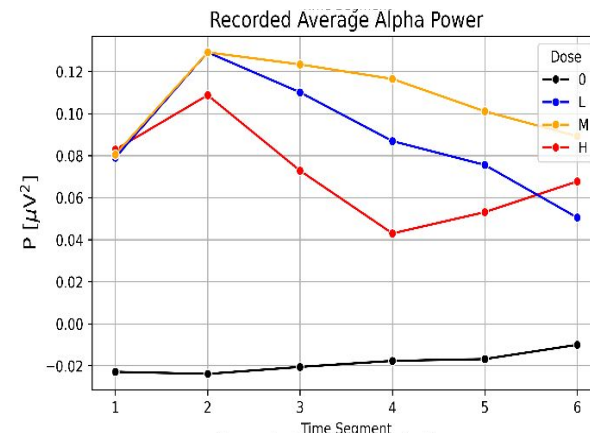
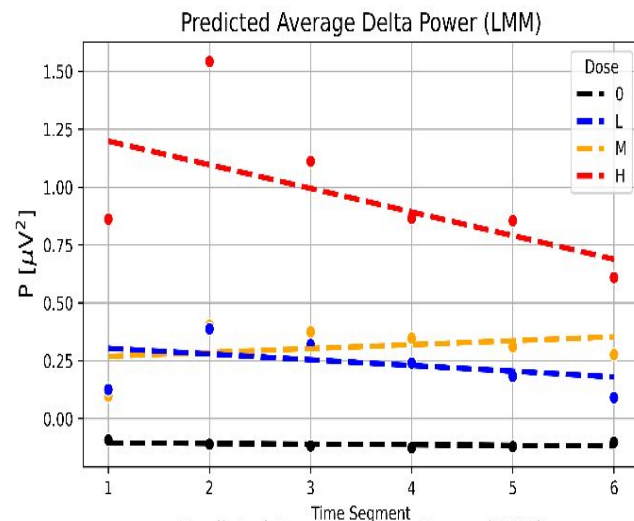
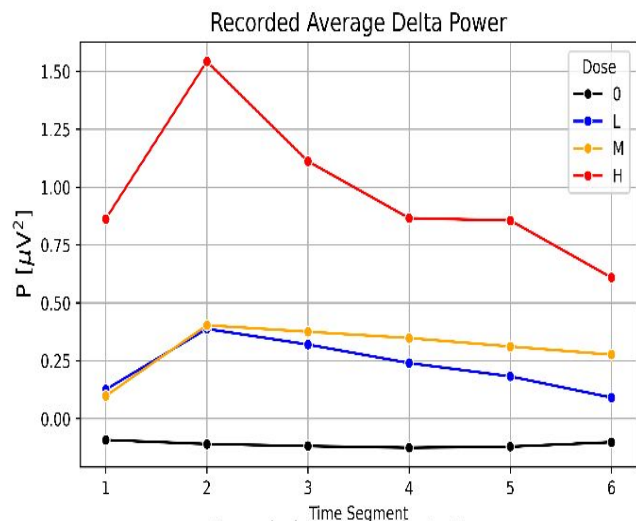


# Ketamine

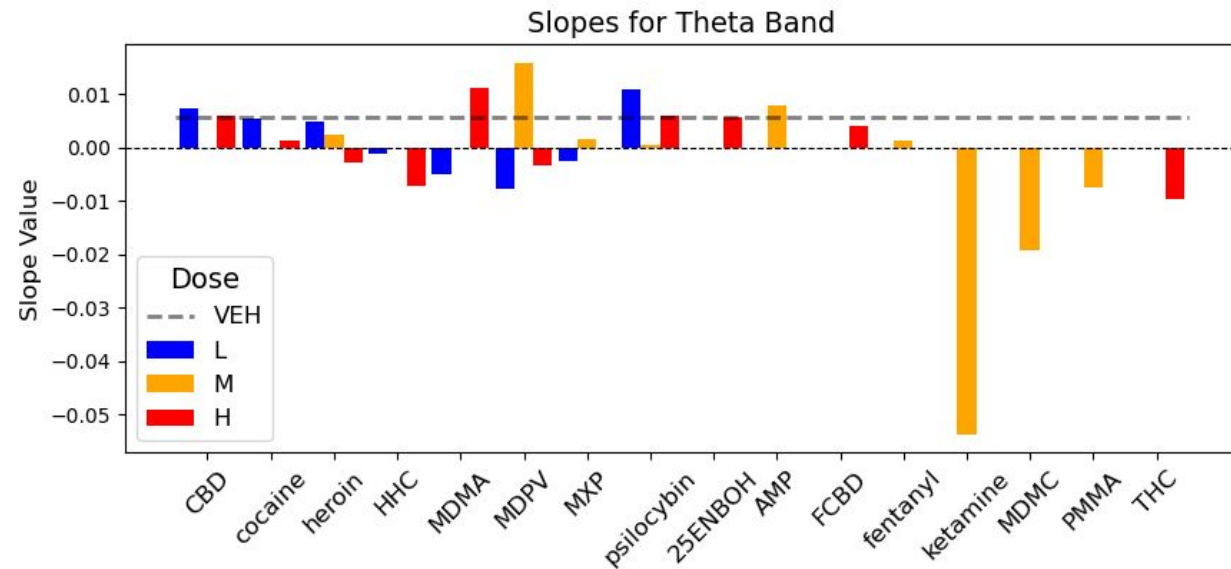
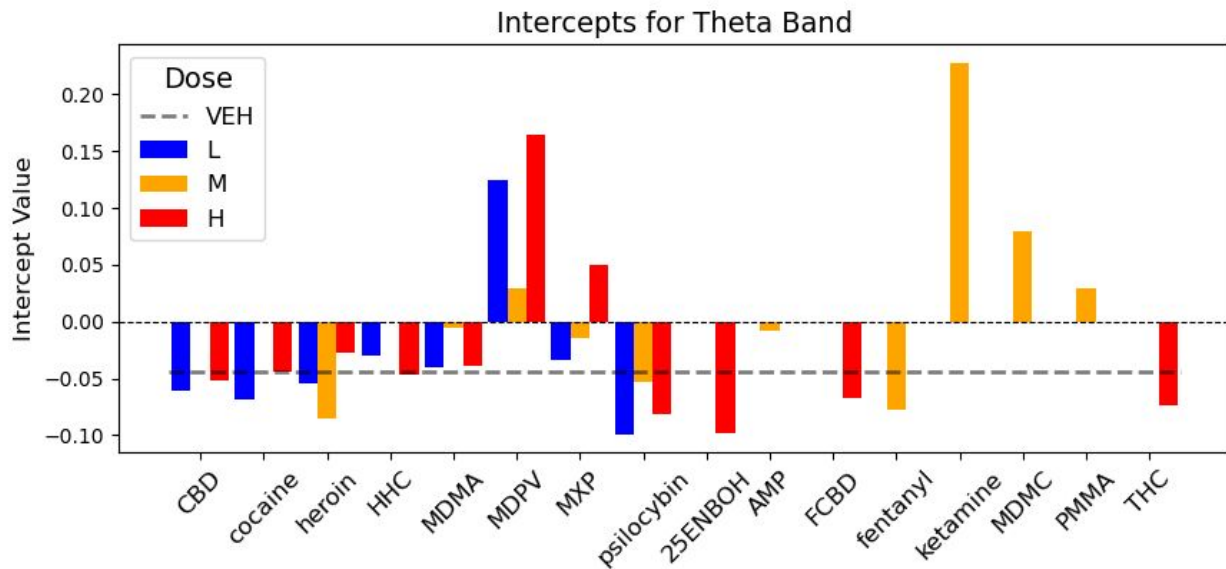
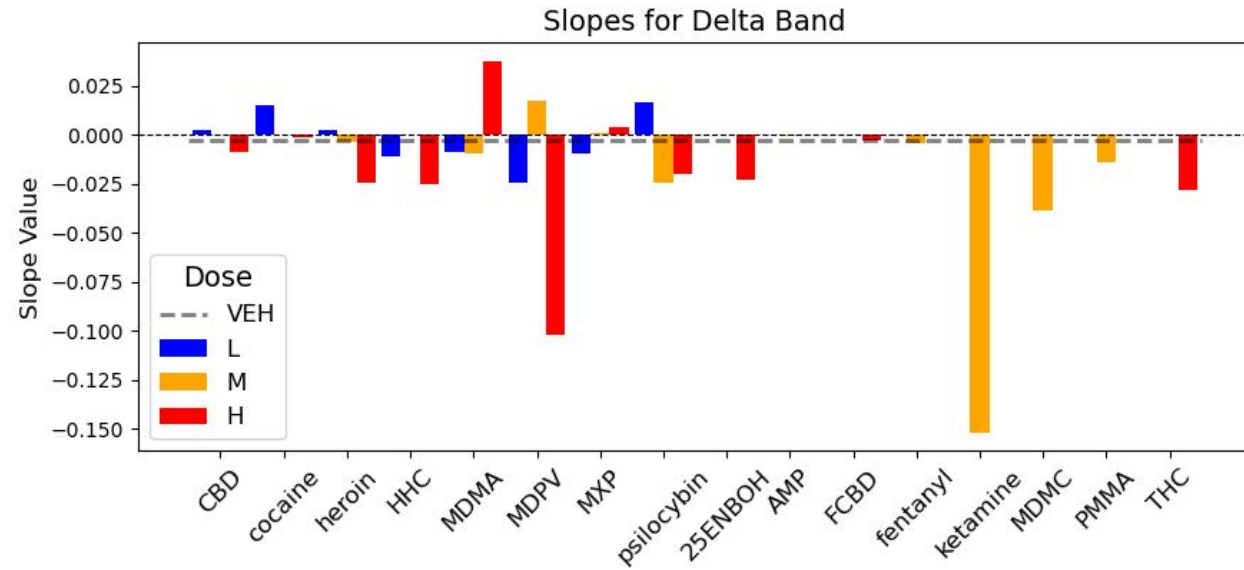
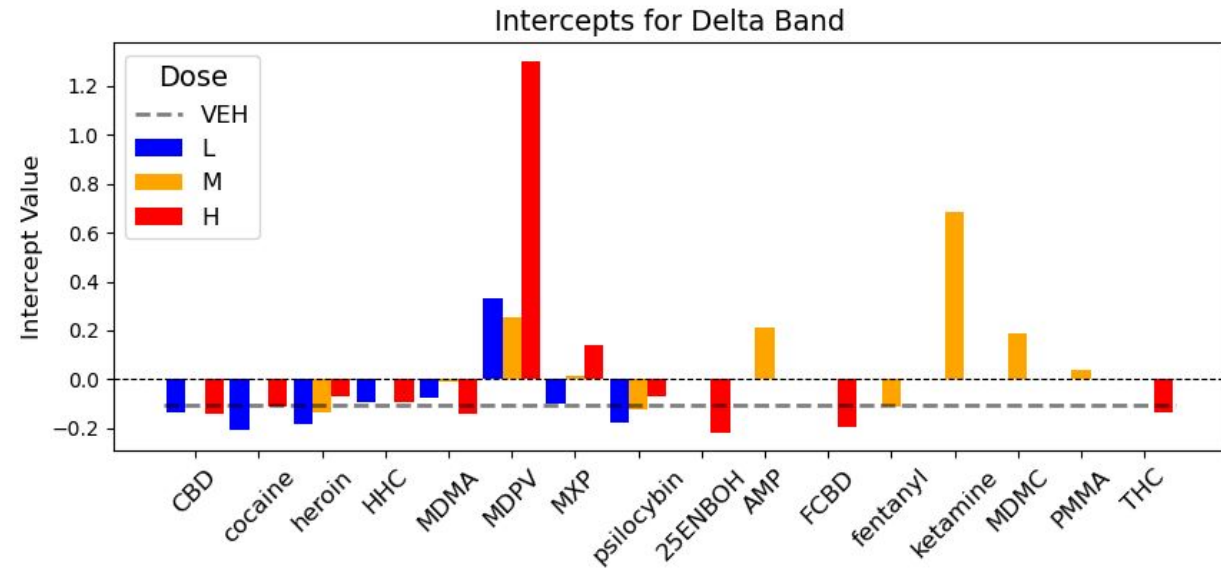




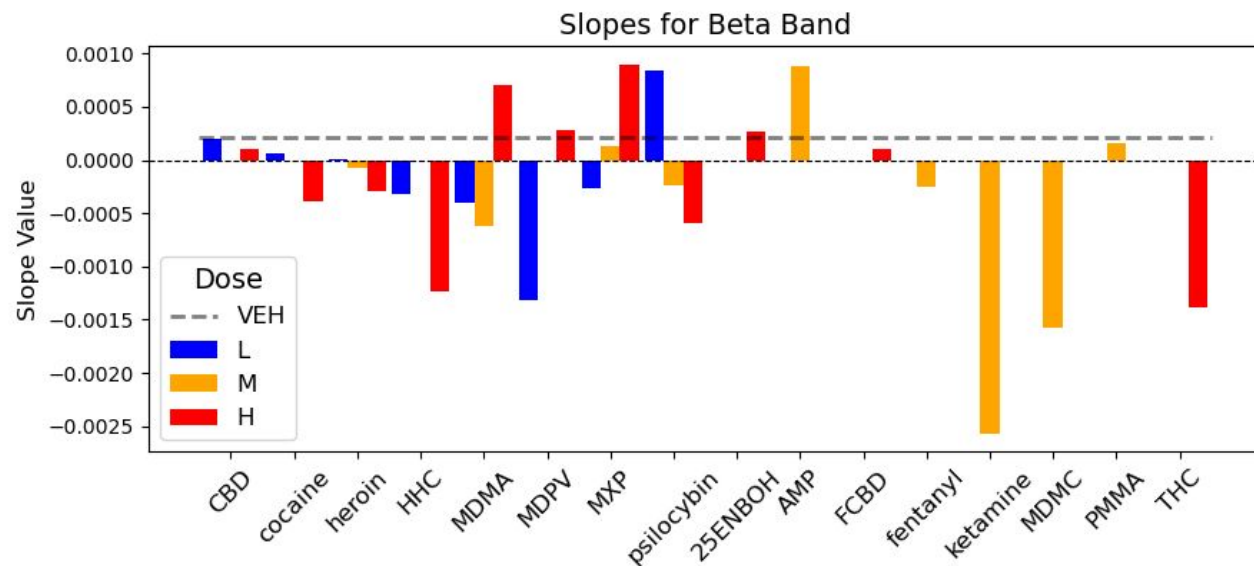
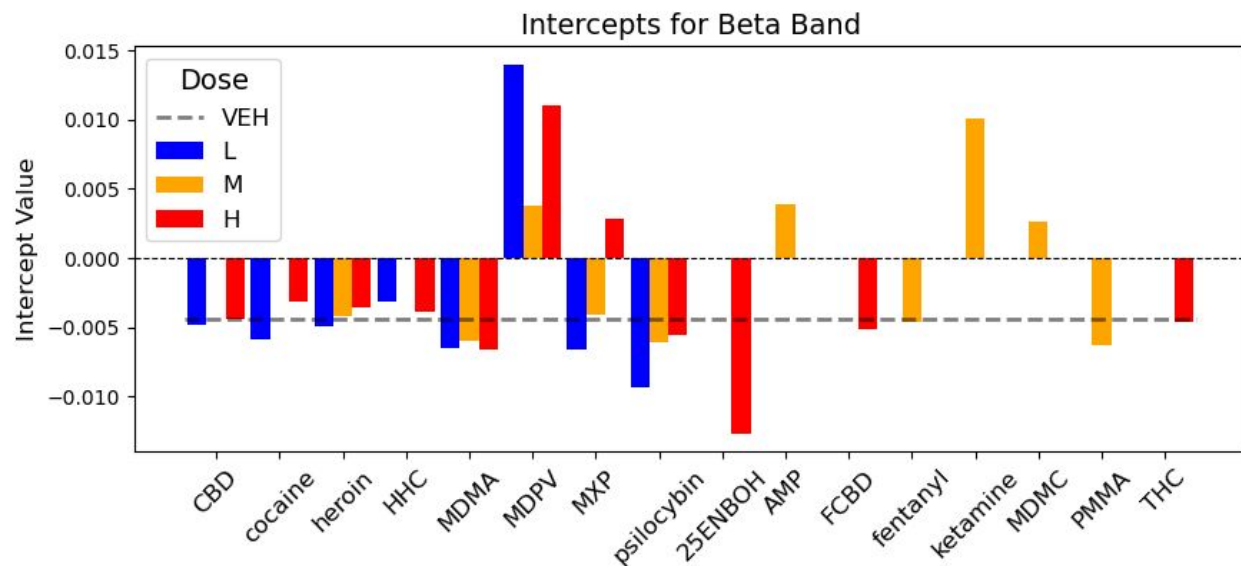
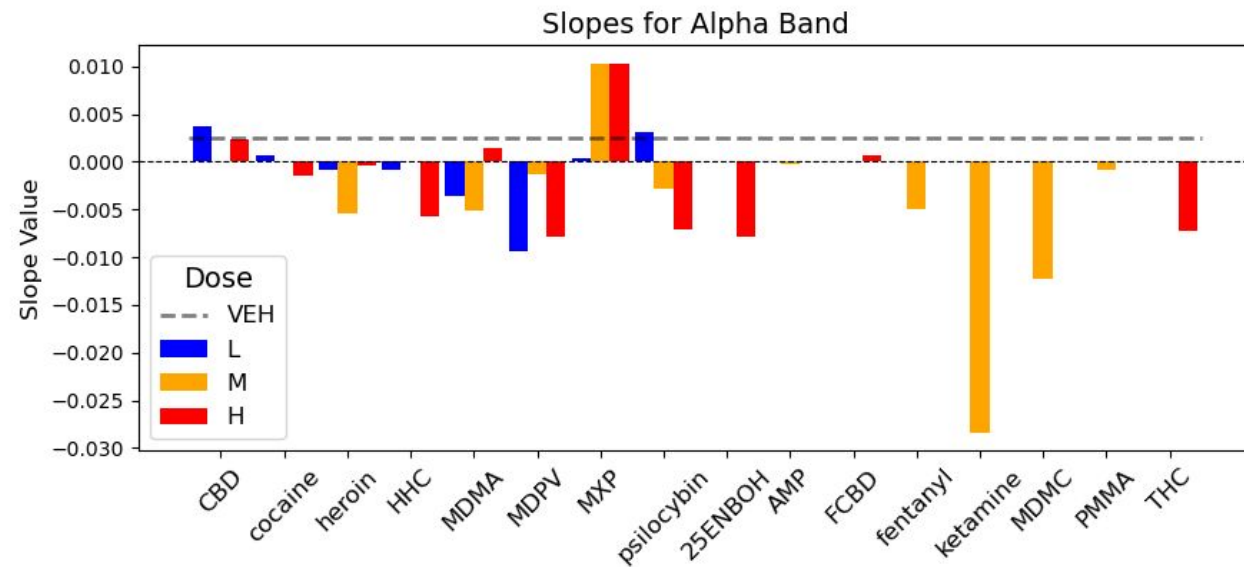
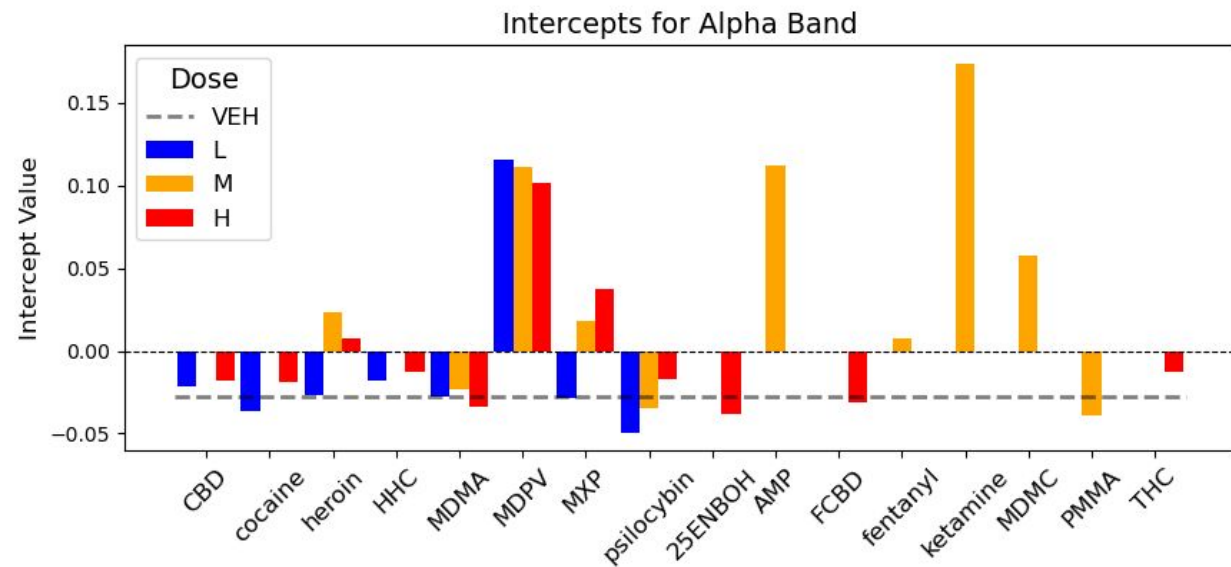
# MDPV



# Intercepts and slopes of created models (Delta and Theta band)

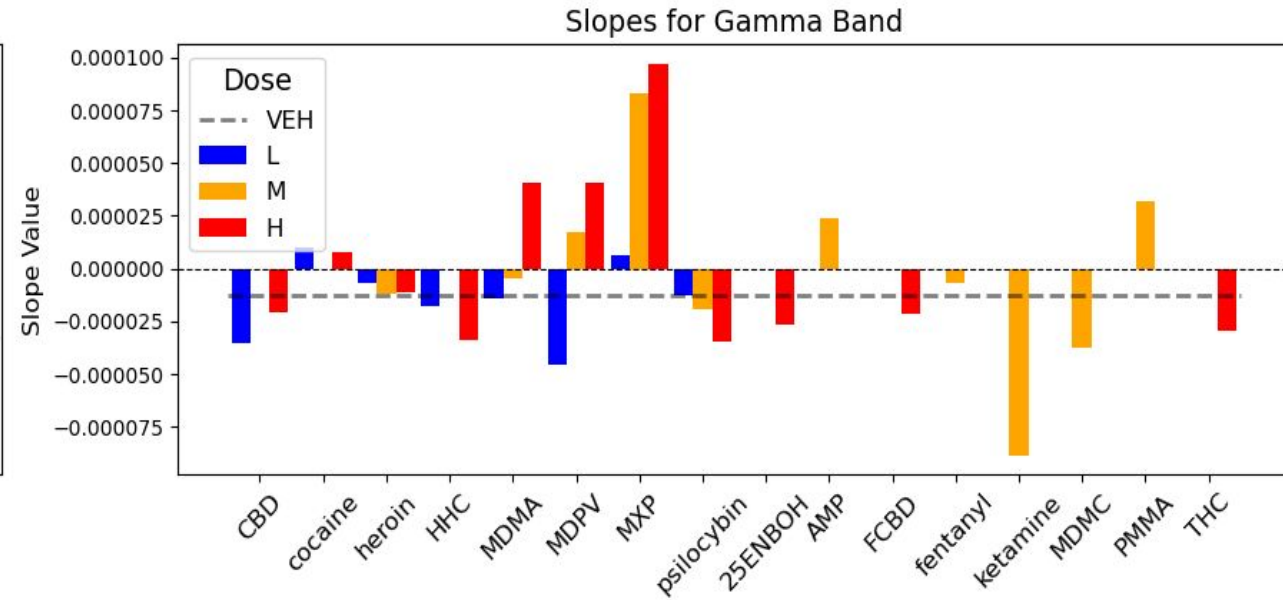
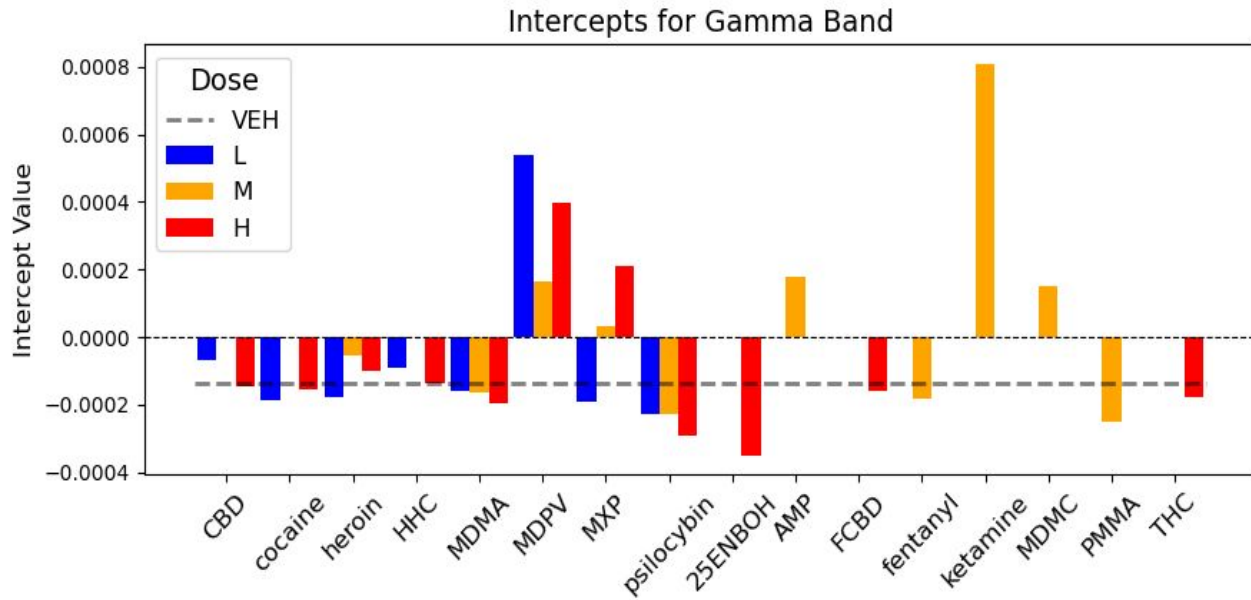


# Intercepts and slopes of created models (Alpha and Beta band)

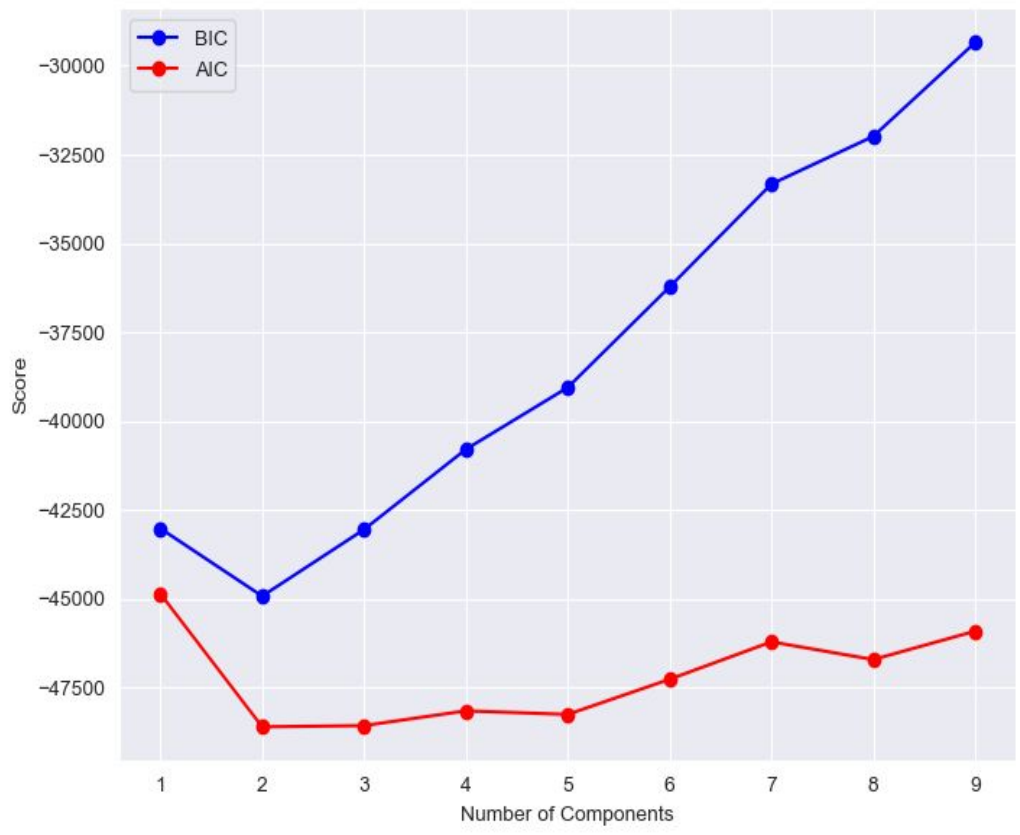




# Intercepts and slopes of created models (Gamma band)



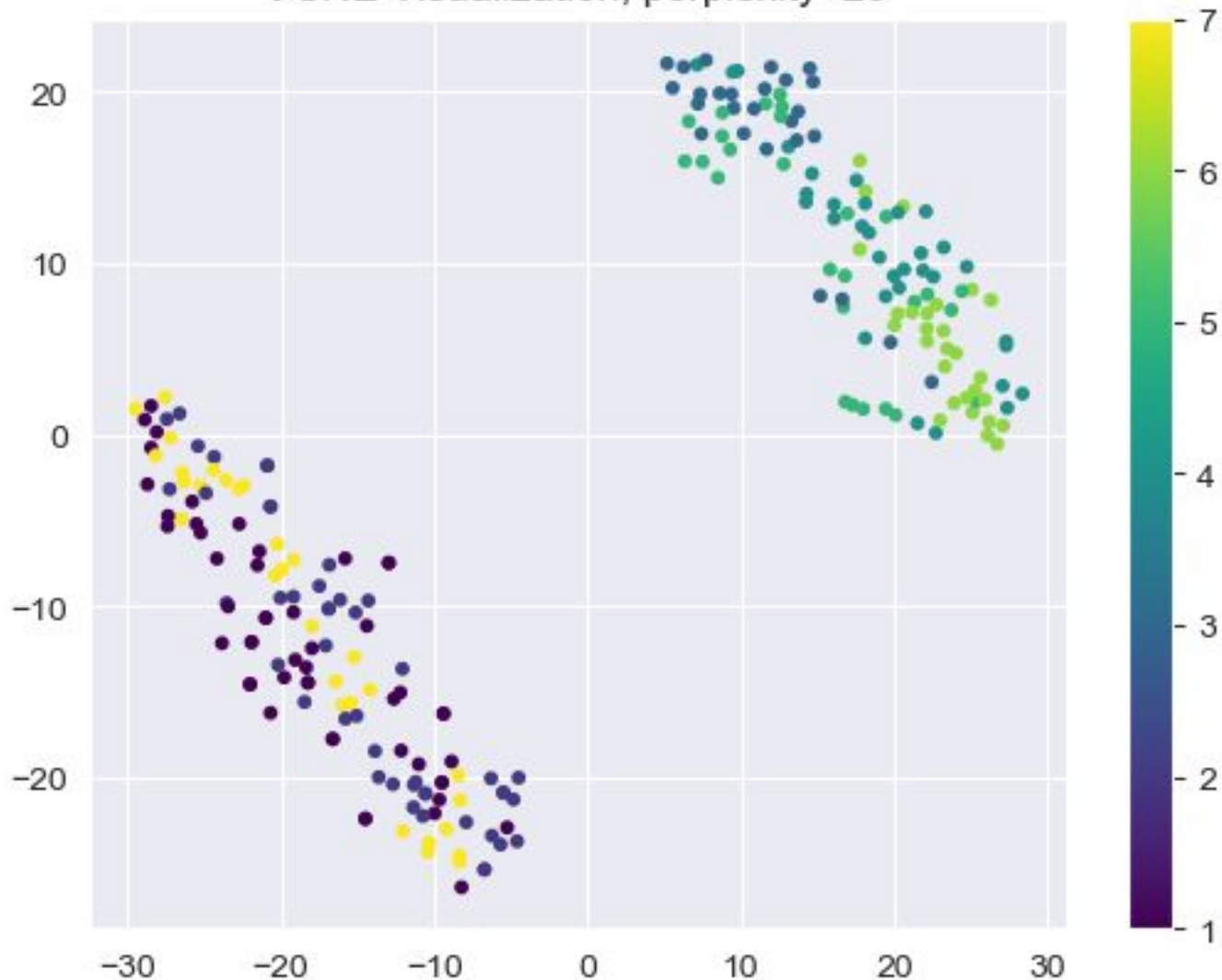
Model Selection: BIC and AIC



**PMMA, ketamine, AMP, MDMA,  
MXP, heroin, fentanyl, and MDPV  
CBD, HHC, THC, FCBD, 25ENBOH,  
and psilocybin**

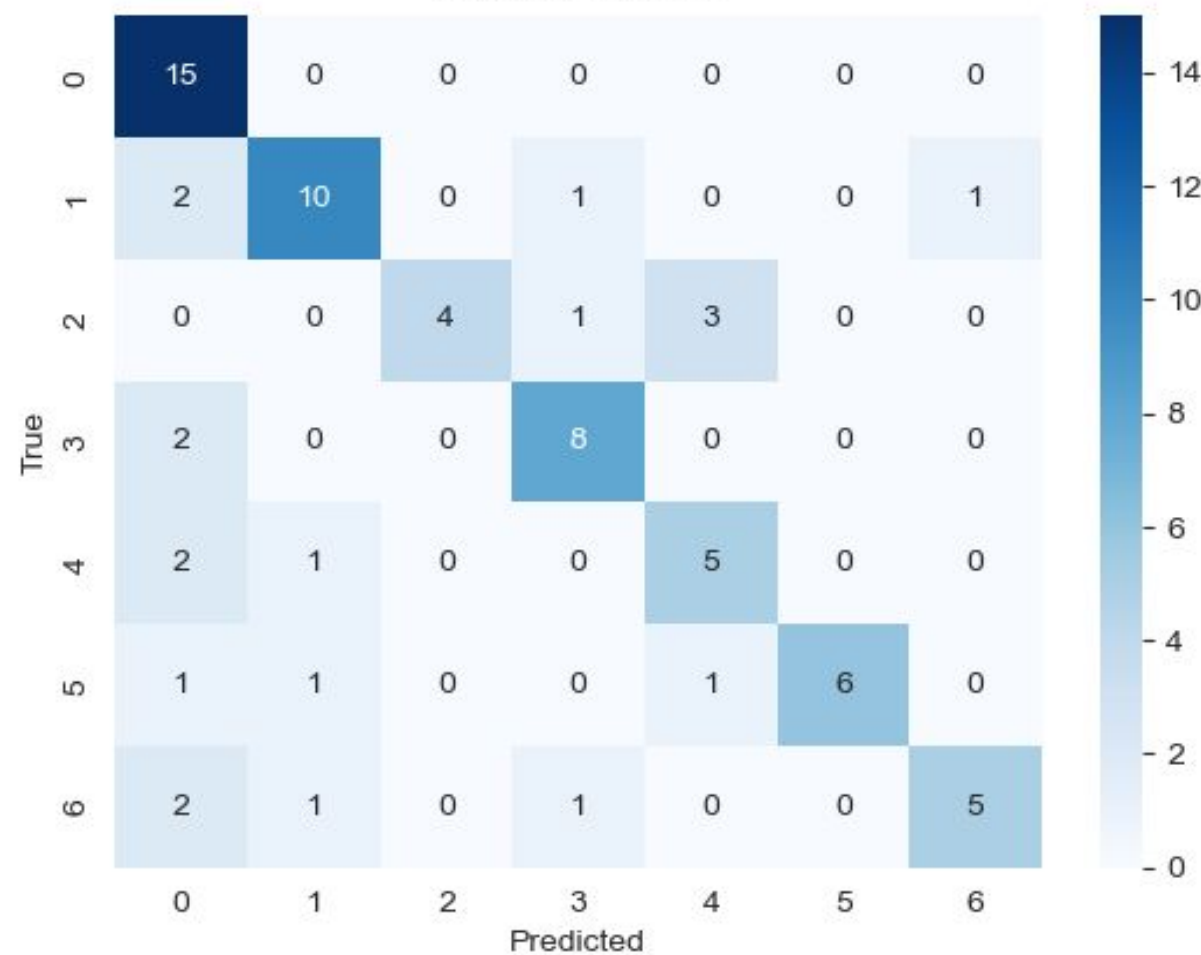
# EM

t-SNE Visualization, perplexity=20

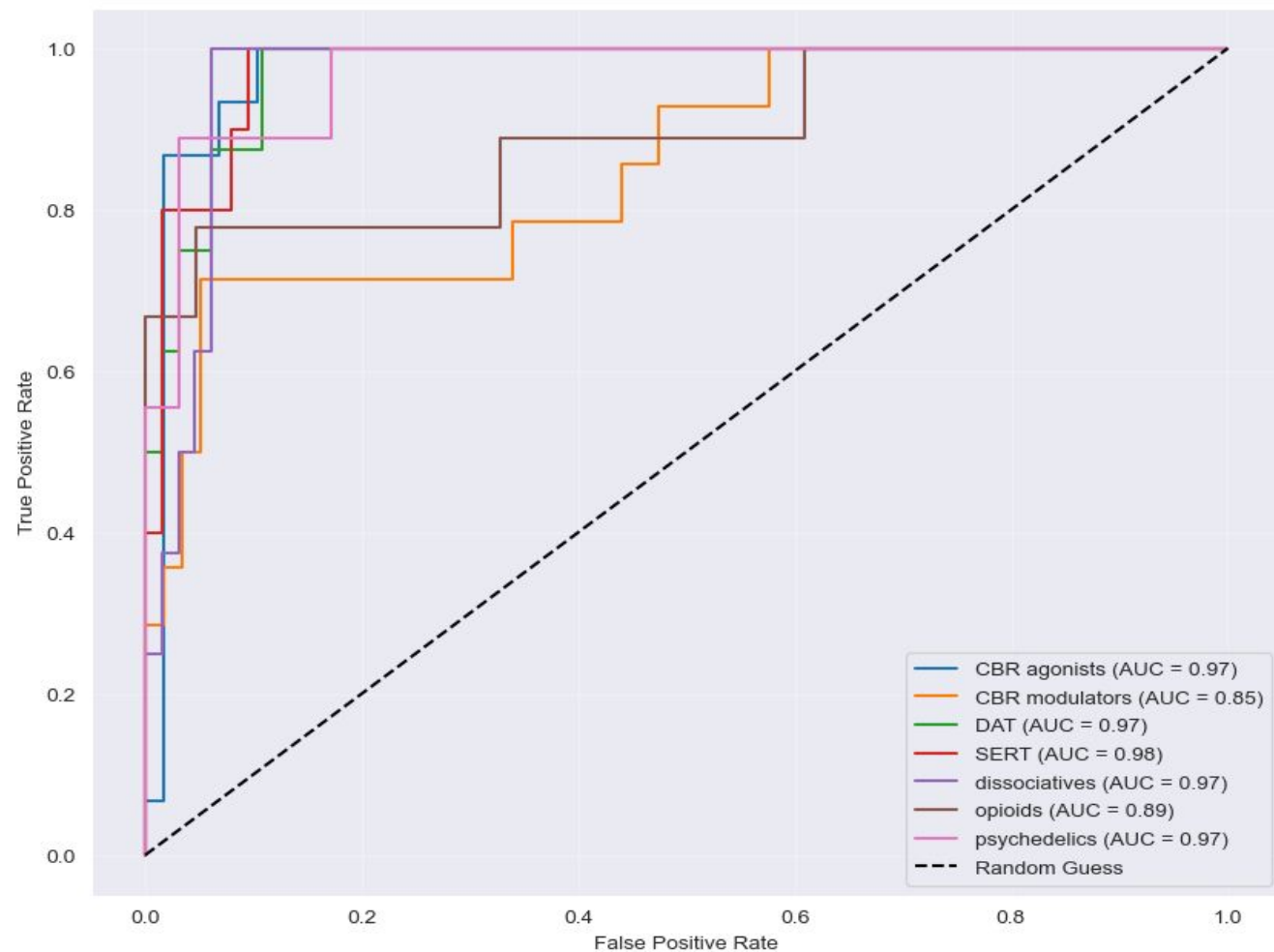


# LDA

Confusion Matrix



ROC Curves



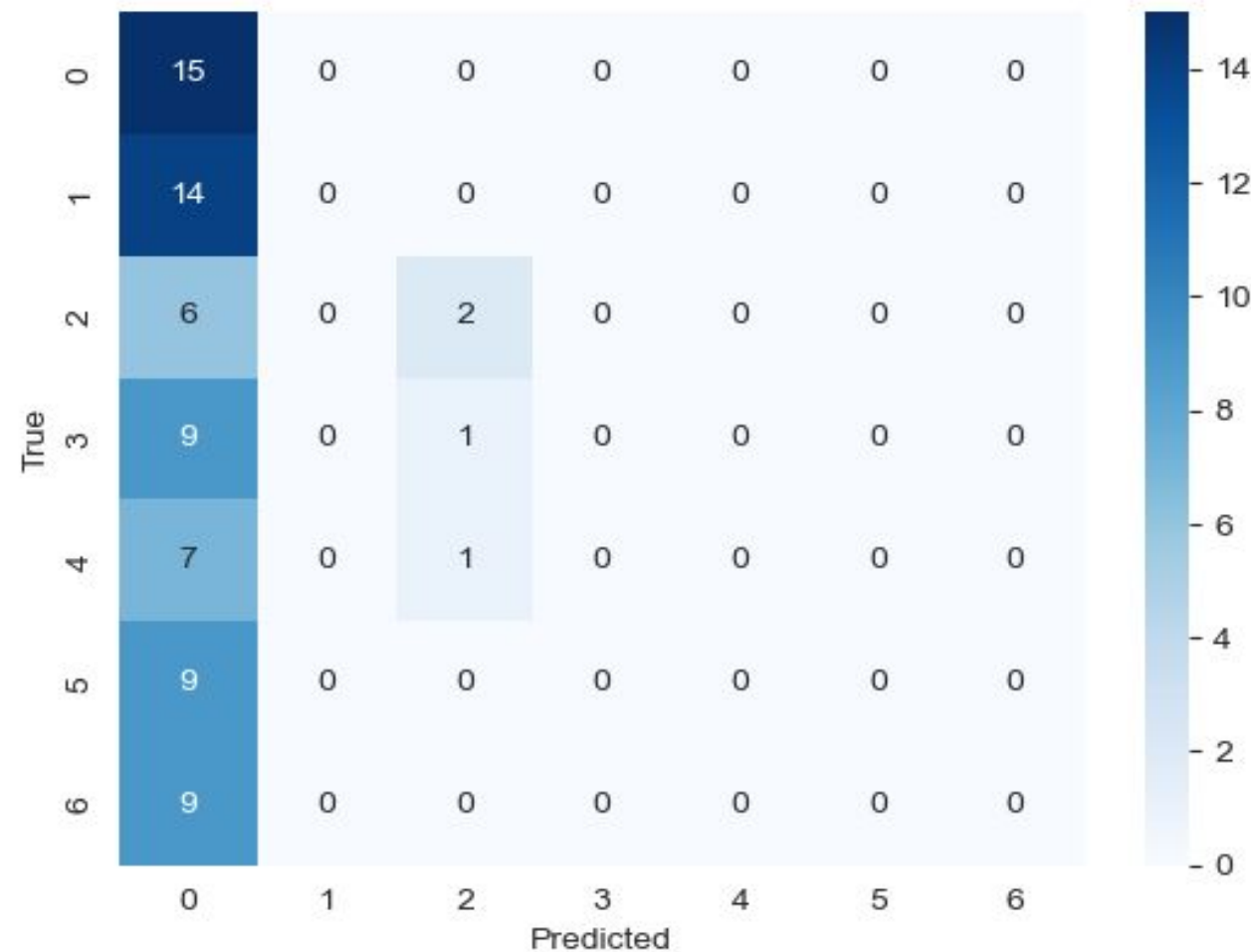




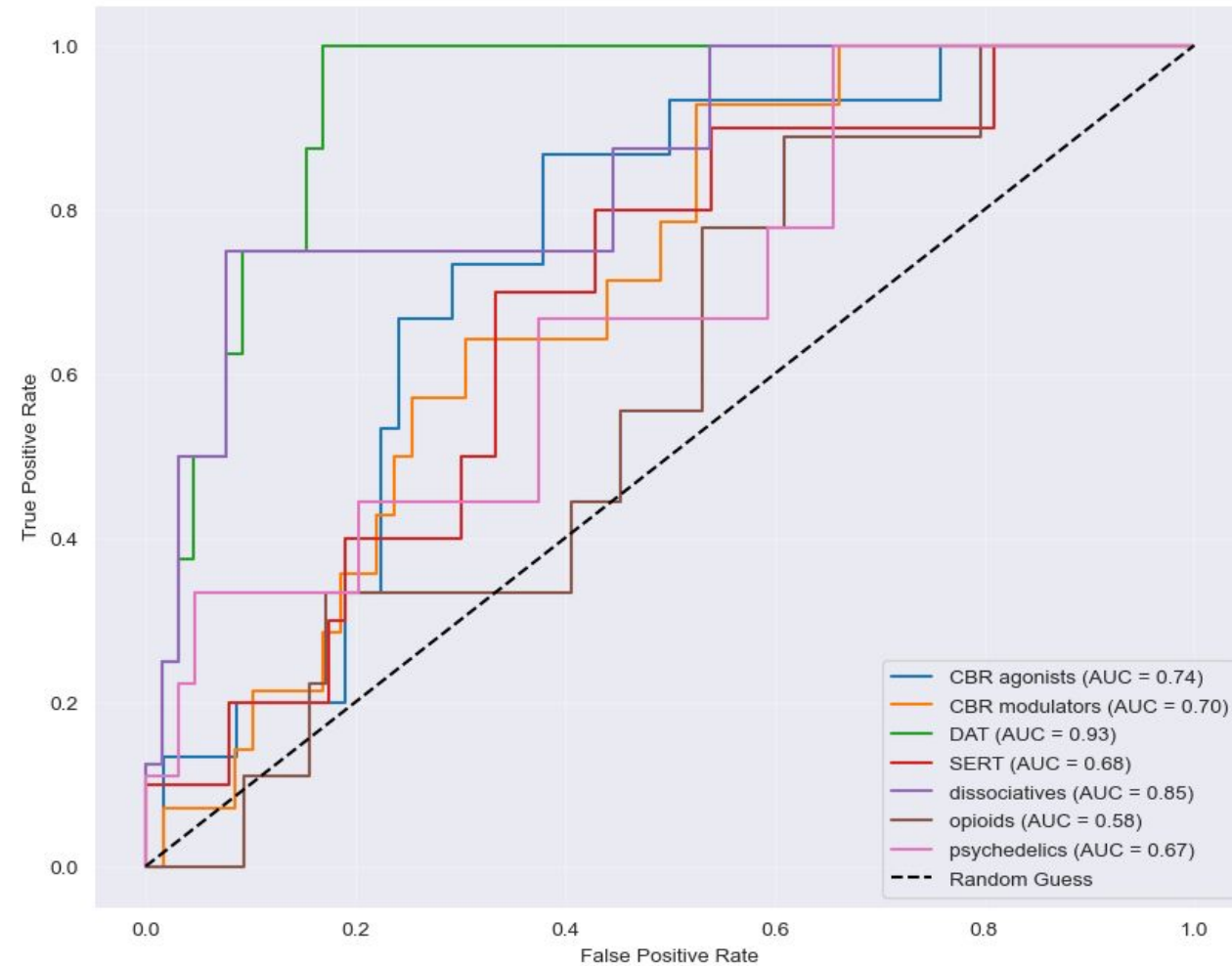
**ČVUT**  
ČESKÉ VYSOKÉ  
UČENÍ TECHNICKÉ  
V PRAZE

# QDA

Confusion Matrix



ROC Curves



# Reviewer's questions

1. Is it possible that the strong time dependence on brain activity (discussed in Section 3.6) was caused by the effect of drugs itself?
2. Why was there such a big spread in the number of recordings for each drug (only 11 for MDPV while 35 for cocaine)? Does this mean that the data used for discriminant analysis was also unequally distributed across the groups? If so, do you think it affected the results?
3. With ethanol needed for solubility, did you account for the potential effect of ethanol on EEG readings?
4. Even though it is far outside the scope of this project, do you have insight into how well these results translate to humans?