



# Timing along the cardiac cycle modulates neural signals of reward-based learning

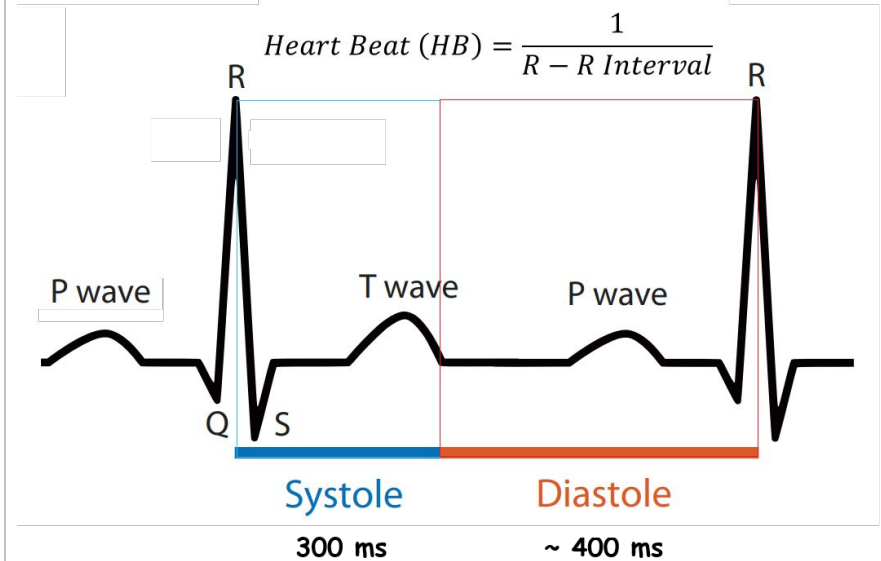
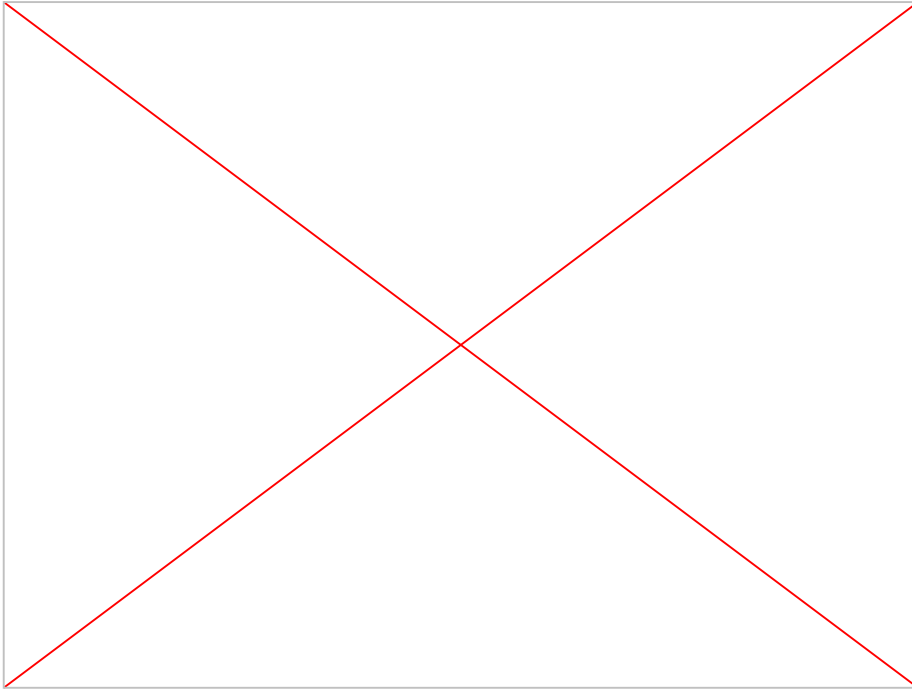
Received: 4 July 2022

Accepted: 14 March 2024

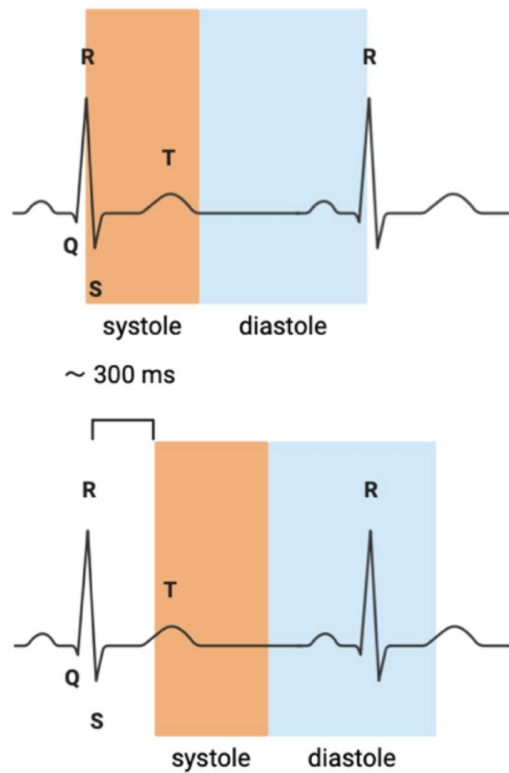
Published online: 06 April 2024

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Matthew Rushworth <sup>1,6</sup> & Alejandra Sel <sup>1,4,5,6</sup>

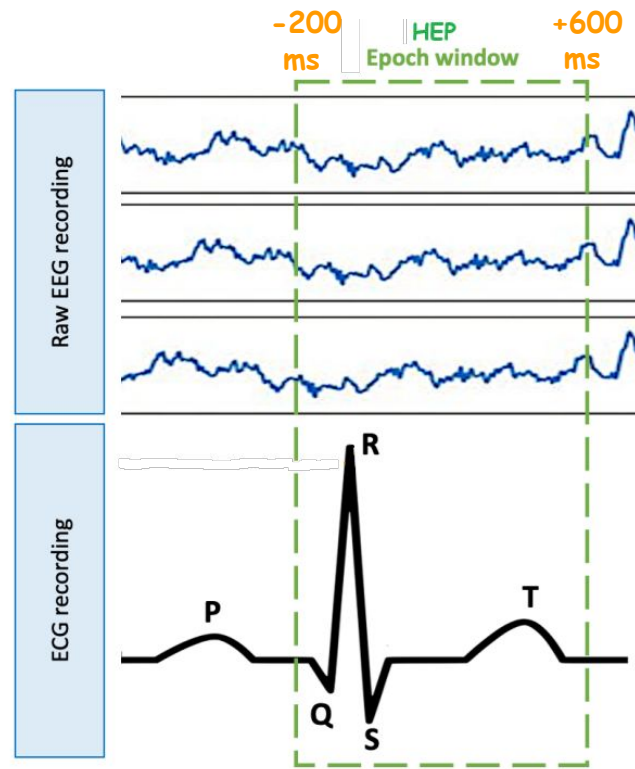
## 1. Animation



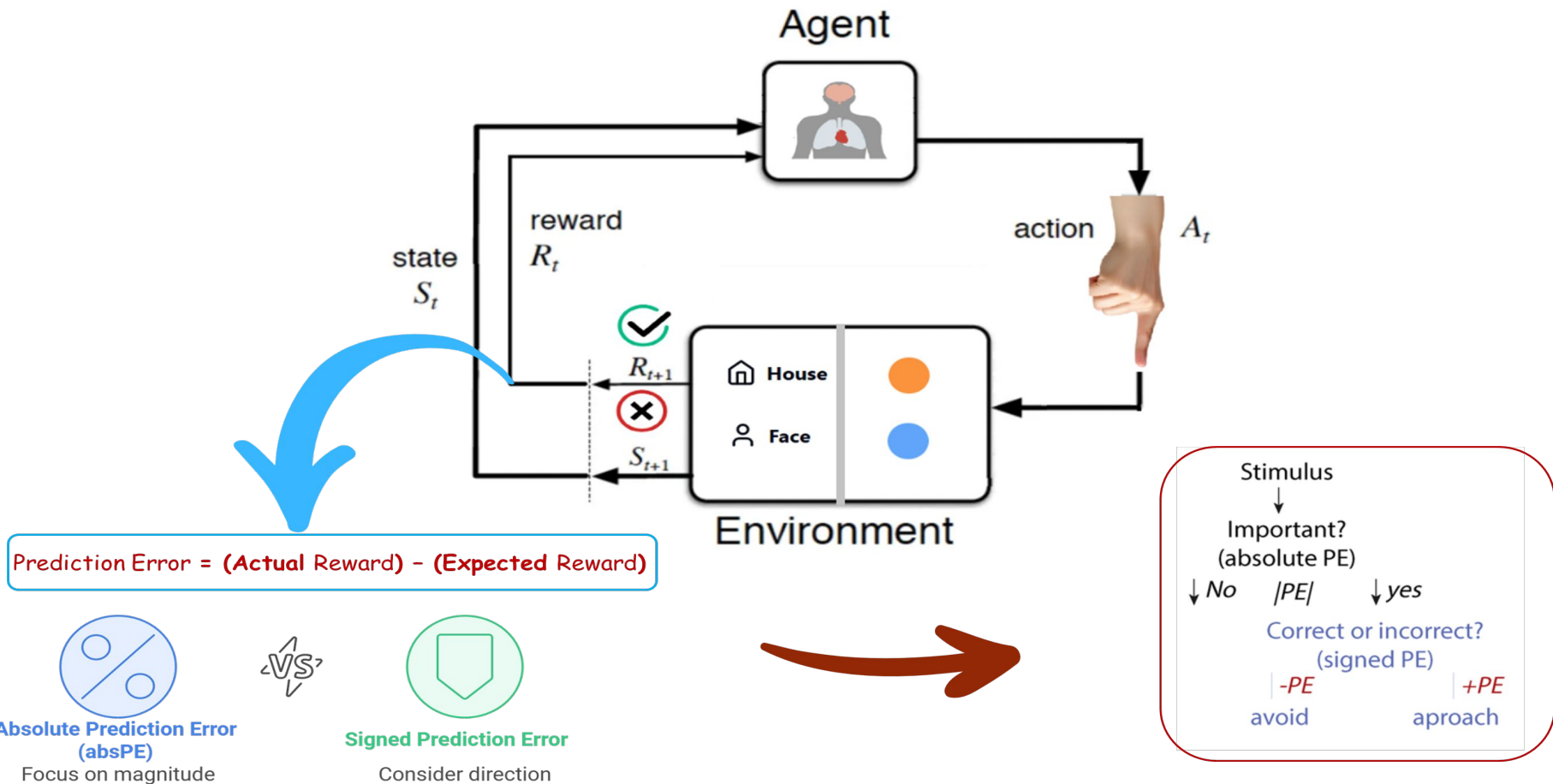
## 1. Debate on ECG Cycle Phases



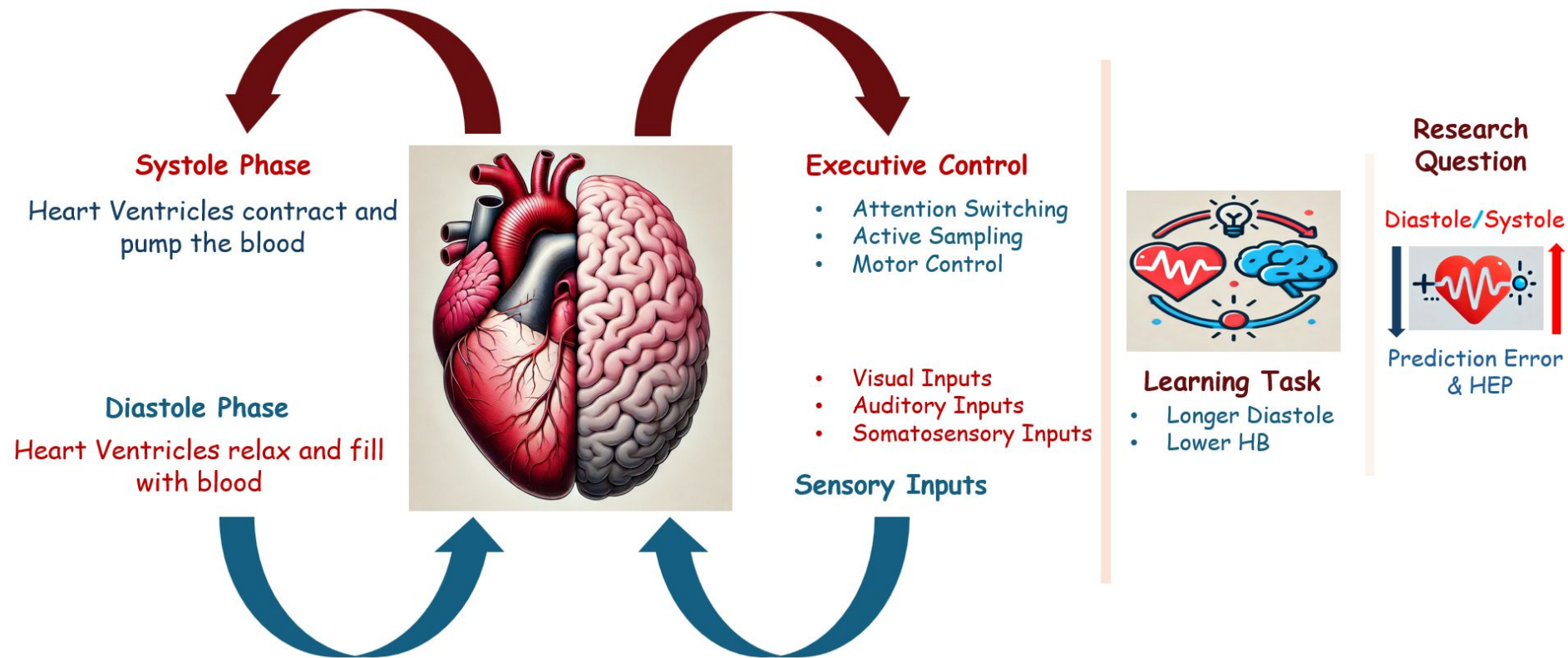
## 2. HEP (Heartbeat Evoked Potential)



# Preliminaries : RL + Prediction Error



# Previous Studies - - - > Research Question

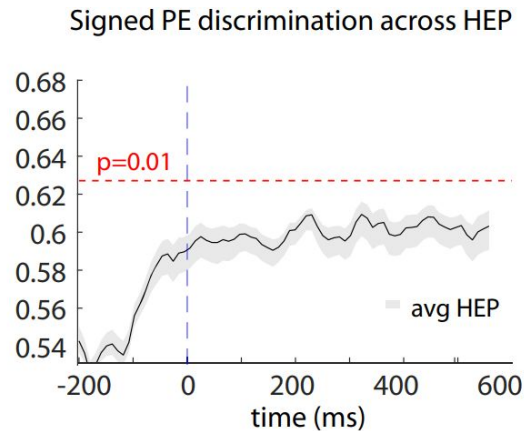
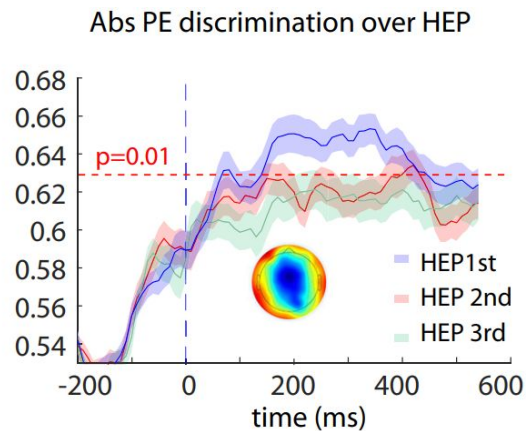
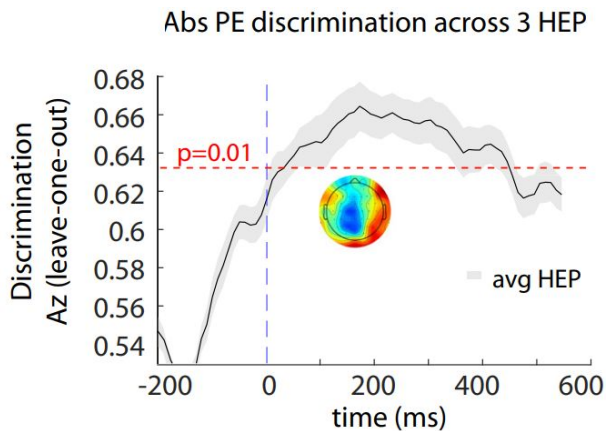


# Hypothesis

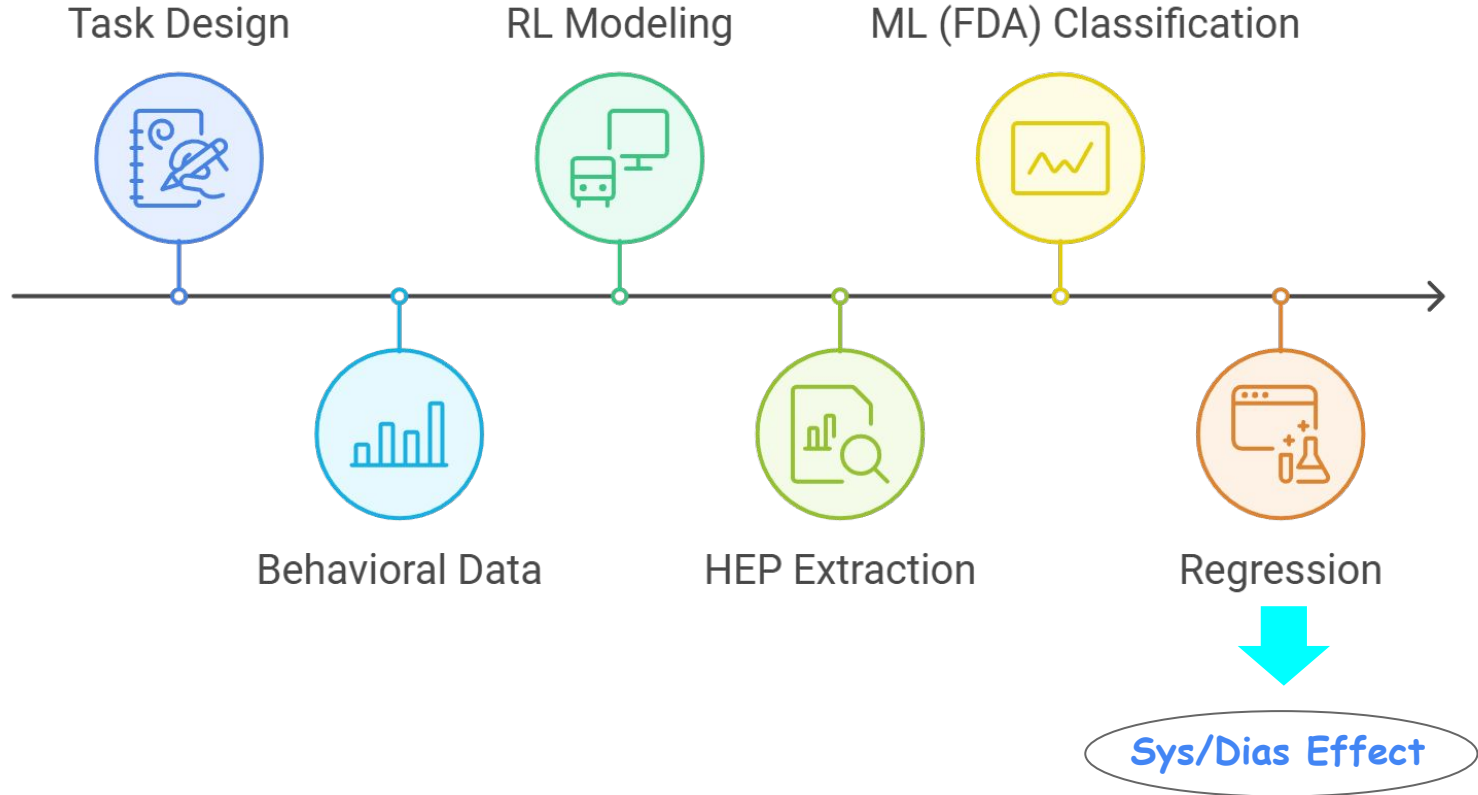
## H: Cardiac Phases Impact on absPE-HEP and Learning

*The timing of outcome presentation in cardiac cycle affects the strength of absPE-HEP and Learning*

*absPE-HEP Concept*

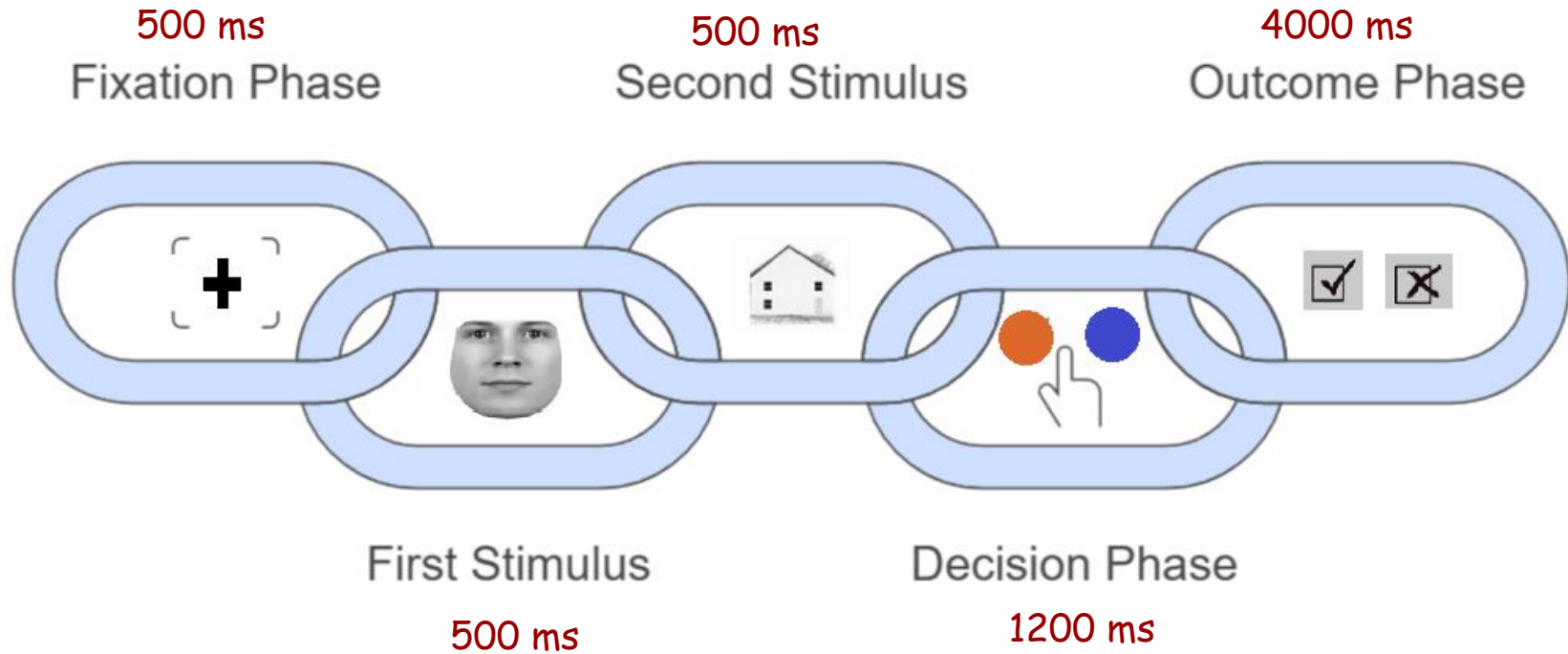


# Paper Outline



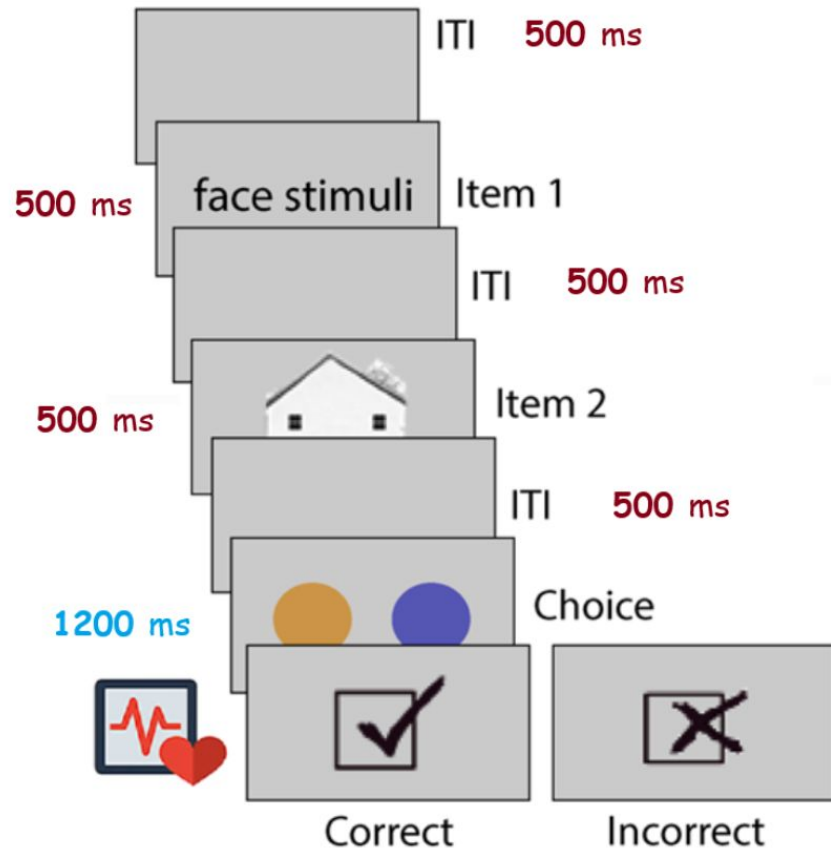
## Experimental Design: As Described in "Methods"

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# Experimental Design : As shown in Fig. 1

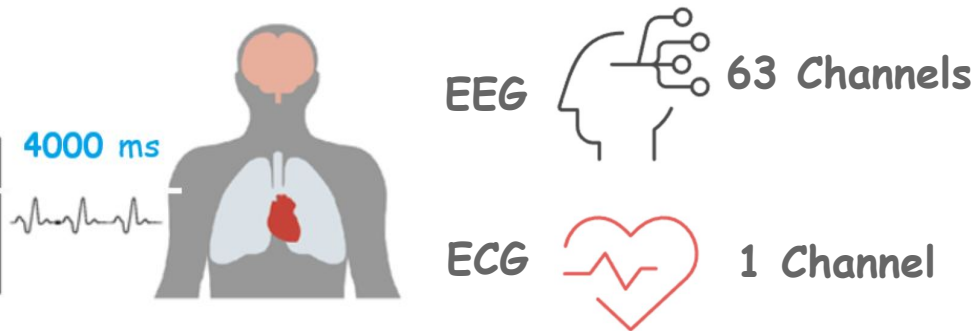


8 X 60 trials

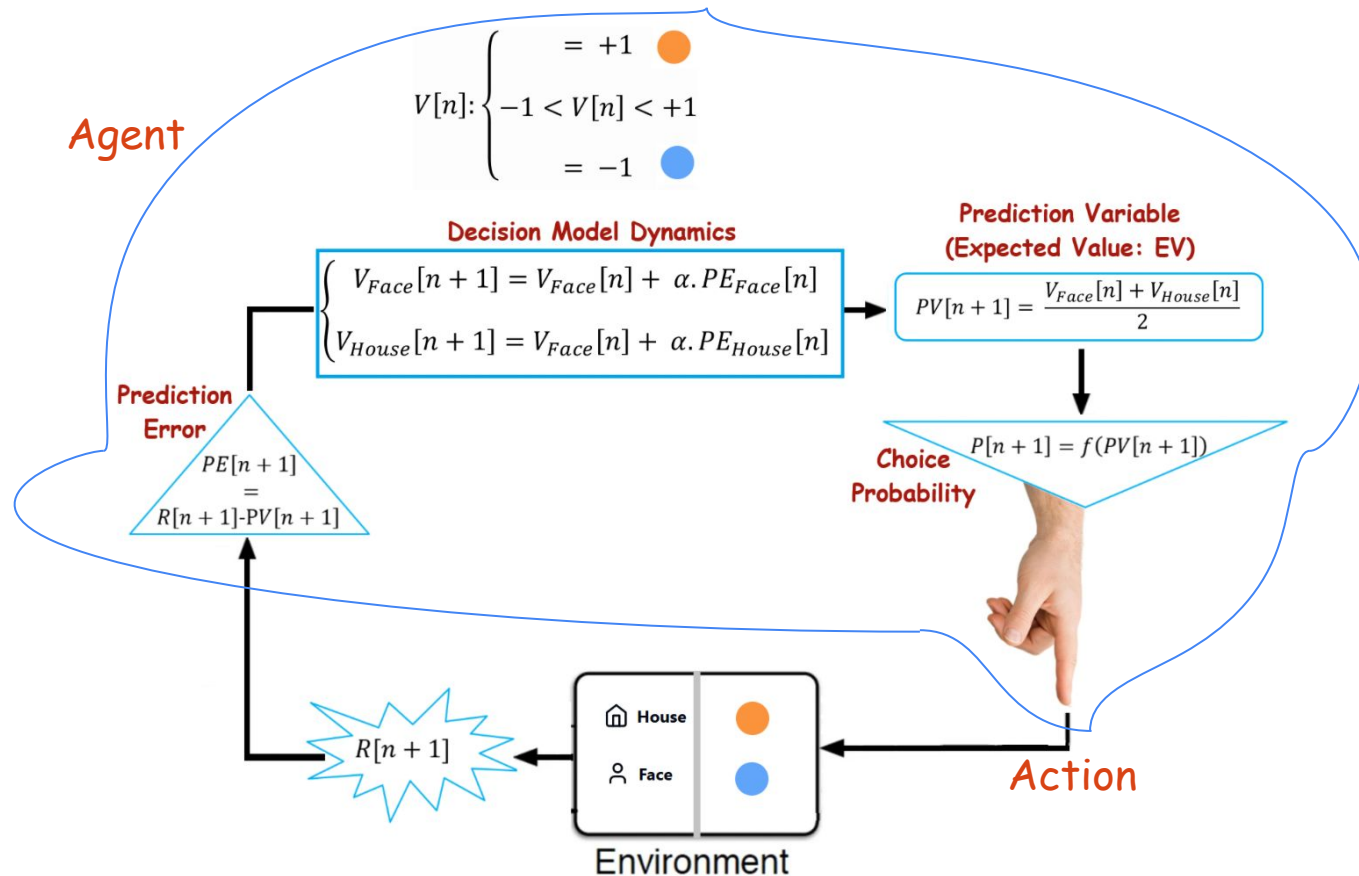
Highly Predictive Anticorrelated			Single Predictive		
House	Face		House	Face	
1	0	Orange	1	0.50	Orange
0	1	Blue	0	0.50	Blue

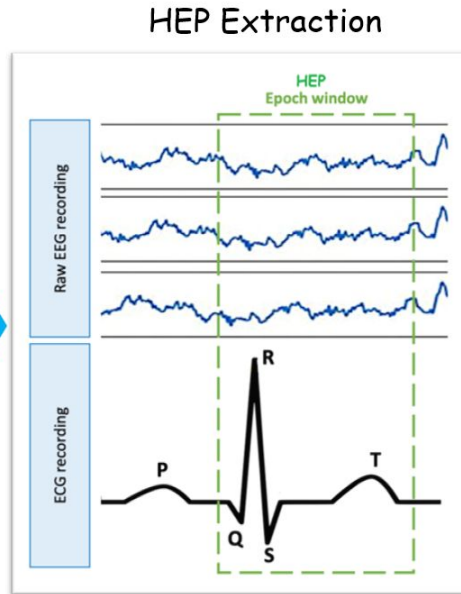
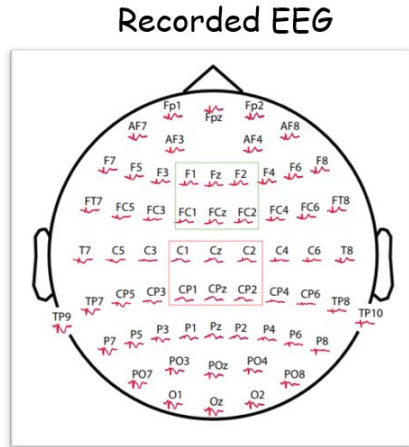
Highly Predictive Correlated			Non-Predictive		
House	Face		House	Face	
1	1	Orange	0.50	0.50	Orange
0	0	Blue	0.50	0.50	Blue



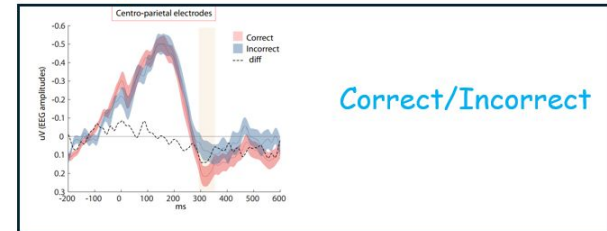
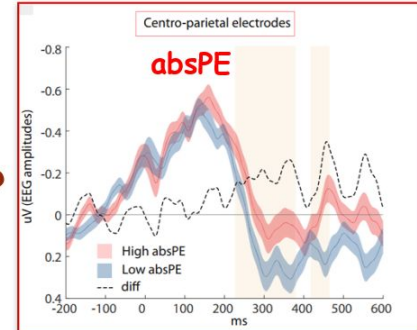
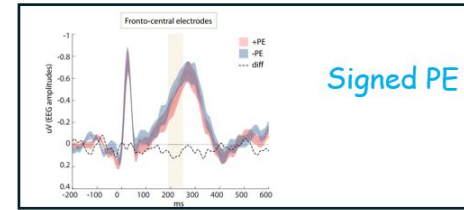
# RL Mathematical Modeling



# HEP Extraction Over Trials



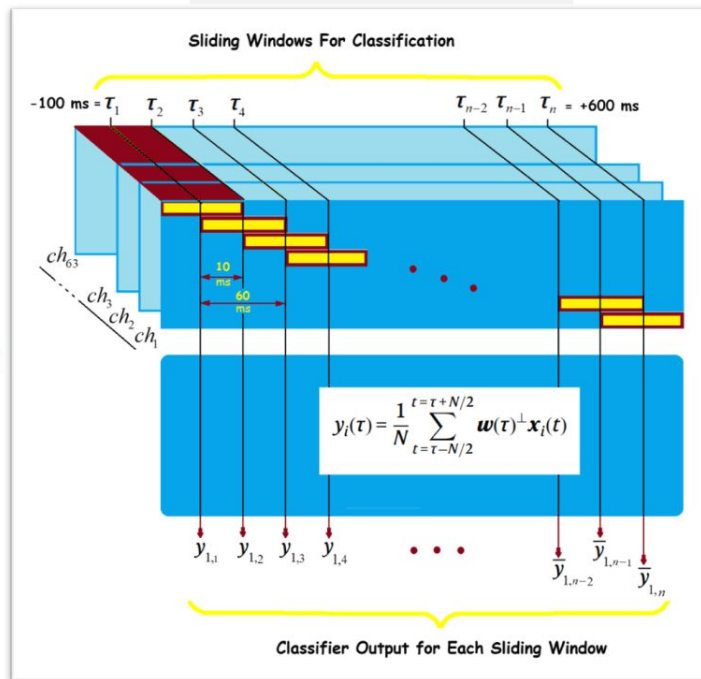
## Effect Finding



# absPE-HP Discriminative Strength Detected by ML Classifier

## Fisher DA Classification

### All EEG Channels



Class 1

High AbsPE

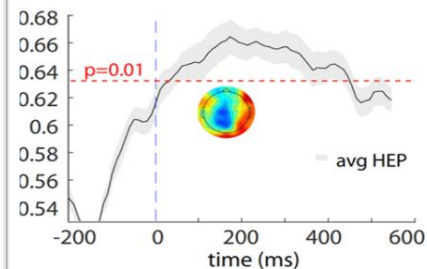


Class 2

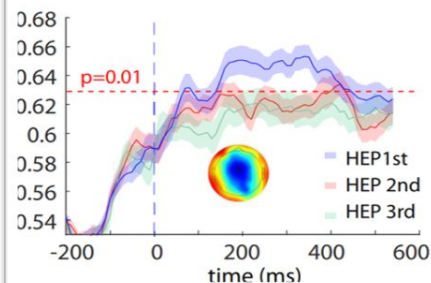
Low AbsPE

## Discrimination Strength

### Abs PE discrimination across 3 HEP



### Abs PE discrimination over HEP

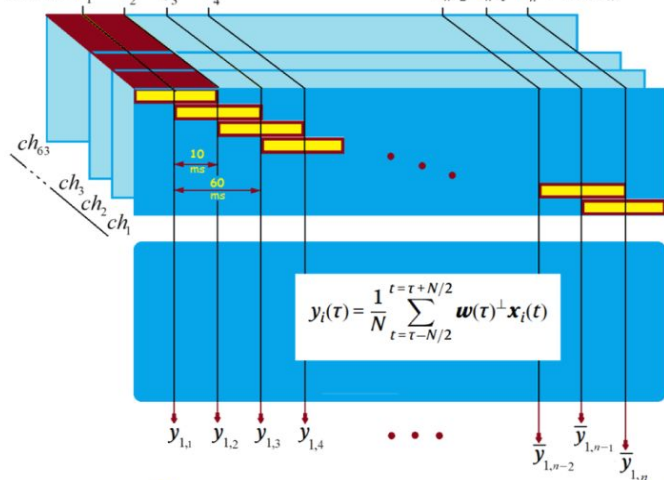


# Signed PE-HP Discriminative Strength Detected by ML Classifier

## Fisher DA Classification

Sliding Windows For Classification

-100 ms =  $\tau_1$   $\tau_2$   $\tau_3$   $\tau_4$   $\tau_{n-2}$   $\tau_{n-1}$   $\tau_n$  = +600 ms



Classifier Output for Each Sliding Window

Class 1

Positive PE

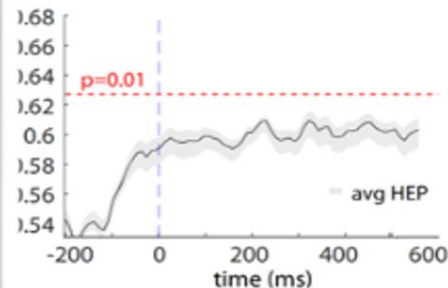
Class 2

Negative PE

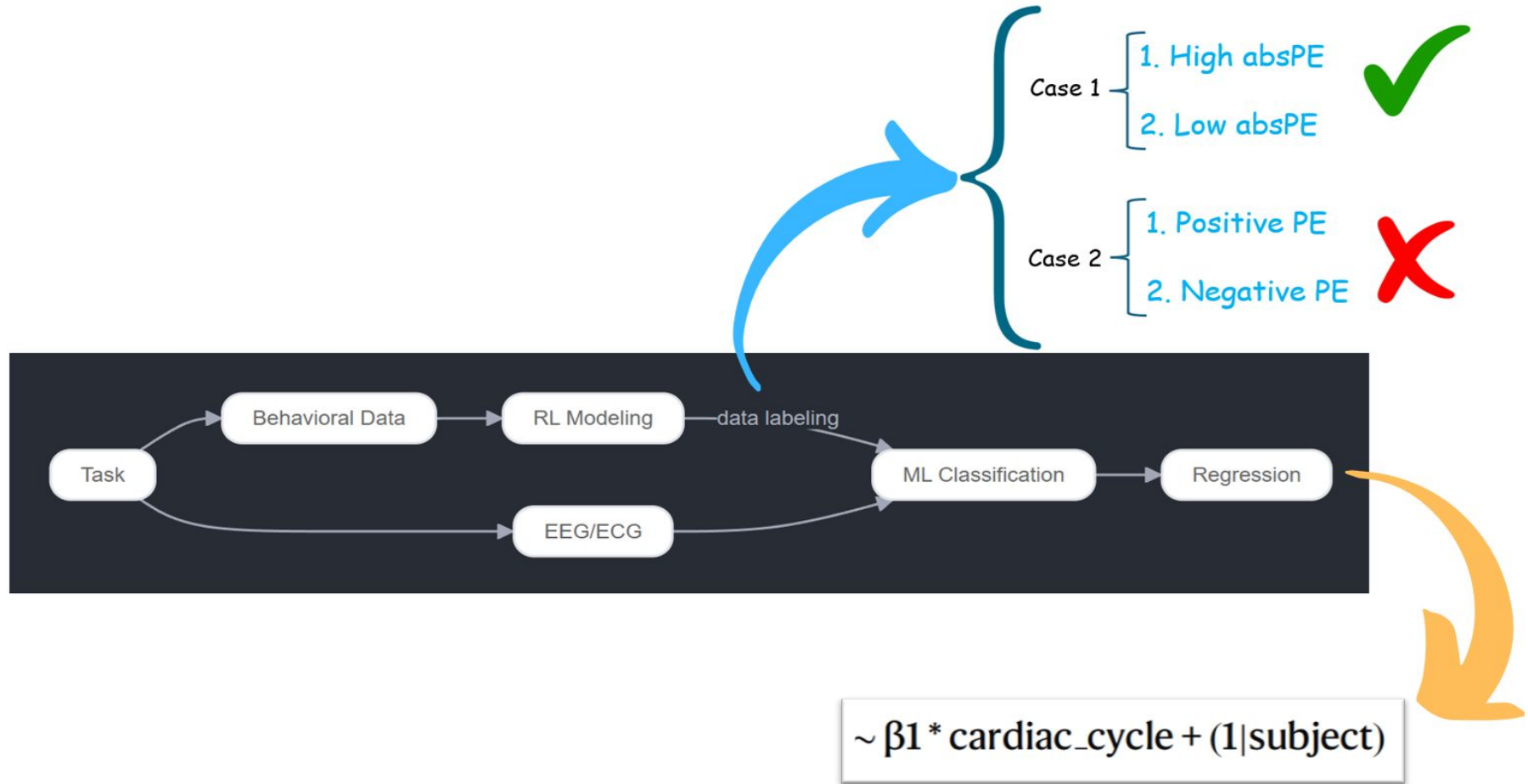
## Discrimination Strength



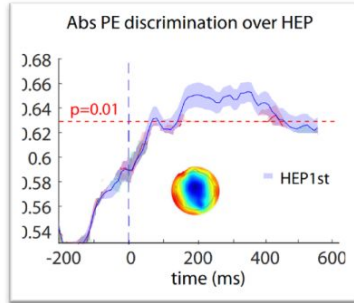
Signed PE discrimination across HEP



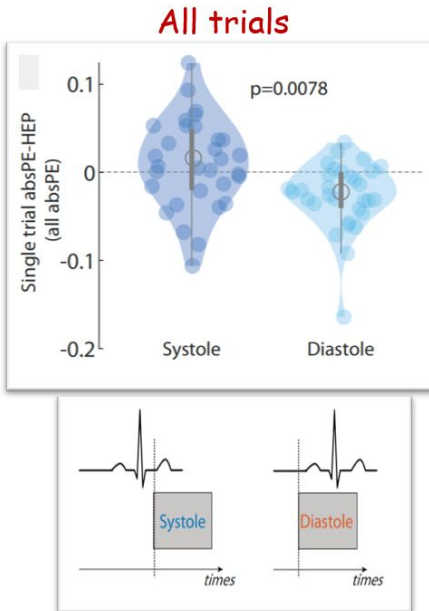
# Progress Overview



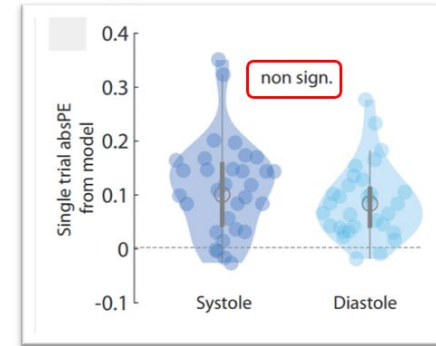
# Cardiac Cycle Effect on First absPE-HEP via Regression



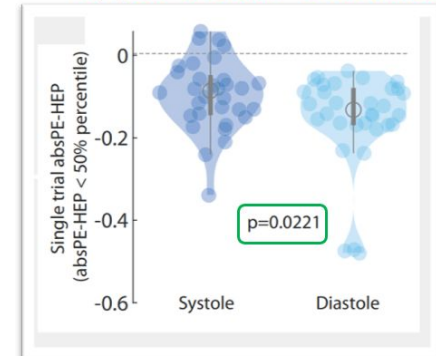
$$\text{HEP} \sim \beta_1 * \text{cardiac\_cycle} + (1|\text{subject})$$



Trials with:  
1. High Salient Outcomes



2. Low Salient Outcomes



# Real-time Setup in EEGLab-241

