# The Impact of Prior Reward Experience on Current Reward Processing: Activation Patterns and Resting-State Correlates

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# ***First Draft***

# Background

## What we know

The processing of reward and loss is at the heart of goal-directed decision making, and is impacted across many neurological and psychiatric disorders (Pujara & Koenigs, 2014). After two decades of task-based fMRI neuroimaging (Knutson et al., 2003), many brain regions and networks have been discovered to be involved in the processing of reward and loss, including the ventral tegmental area, the ventral striatum and nucleus accumbens, and the orbitofrontal cortex, with roles for the anterior cingulate cortex, dorsolateral prefrontal cortex, thalamus, amygdala and hippocampus (Dugré et al., 2018; Grill et al., 2021). Another approach used recently to investigate the reward network is resting-state fMRI connectivity parameters of the network. A growing literature has established links between resting state networks and task-activated functional networks in fMRI (Nickerson, 2018), with a variety of methods using resting-state functional connectivity data to predict fMRI activations associated with various tasks (Lacosse et al., 2021; Ngo et al., 2020), including reward processing tasks (Mori et al., 2019). It has been observed resting-state reward network connectivity in particular is associated with reward processing (Adrián-Ventura et al., 2019). Supporting the validity of resting-state and task-based approaches to study reward processing, parameters derived from both sets of paradigms are known to be associated with self-reported measures of reward-related behavior (Dong et al., 2018) and dysfunctional reward processing in psychiatric disorder (Keren et al., 2018).

It is also known that different components of reward processing, such as the encoding of reward memory, reward expectations, reward learning and valence, involve overlapping but distinct parts of broader reward networks (Grill et al., 2021; Pessiglione & Delgado, 2015; Shenhav & Karmarkar, 2019). An important part of reward processing is the anticipation of positive or negative rewards, and the influence of the memory effects of prior reward processing on present response to rewarding stimuli (O’doherty et al., 2007). Indeed, the interaction of reward and memory networks has been increasingly recognized in the fMRI literature, with rewarding stimuli influencing memorization and value processing relying on the memory encoding of reward (Frank et al., 2019; Shigemune & Tsukiura, 2017). Notably, evidence has also accumulated that the encoding and anticipation of reward and loss trials involve distinguishable brain activation patterns (Manelis et al., 2016; Oldham et al., 2018; Van de Steen et al., 2020), though the underlying dynamics of these observations remain incompletely understood.

## What we don’t know

Overall, our literature review uncovered little previous research on the encoding of positive and negative reward processing during reward-related task-based fMRI. Specifically, it’s not clear how preceding win and loss trials in a simple gambling task would influence activation patterns in subsequent trials, and which brain regions would be important in encoding this information. By considering sequences of win-win, win-loss, loss-win and loss-loss trials across the gambling task in the Human Connectome Project data, it is possible to train a decoder, perhaps with Multivariate Pattern Analysis (MVPA) after theoretical ROI-selection or data-driven dimensionality reduction using Primary Component Analysis (PCA), to discover brain regions which encode significant information about win or loss trials preceding a present trial. Additionally, this design would allow for the investigation of common and distinct regional activations which underlie brain responses to “surprising” win and loss trials (those preceded by a trial with the opposite reward valence) during the gambling task, potentially also validating our analytical approach if the results align with the fMRI literature on reward prediction error. Furthermore, it might be fruitful to investigate the resting-state functional connectivity patterns of regions discovered to be involved in responding to incongruent trials and those that encode the memory of previous reward. The connections of these regions to reward and memory networks, among others, would provide insights into the neural architecture which enables the dynamic processing of reward and loss processing.

## Keywords: fMRI; human connectome project; reward anticipation; reward encoding; memory; reward processing; loss processing

# Current Project

## Determining the basic ingredients

The results we will attempt to produce during the summer school include the following:

1. Block-level contrasts between mostly loss and mostly win blocks

2. Event-related comparisons between loss and win trials

3. Event-related comparisons between congruent win and loss trials and incongruent ones, and between incongruent win and loss trials

4. Investigating the encoding patterns of the memory of previous win and loss trials (after dimensionality reduction with PCA or theoretical ROI-selection)

\*4.5 Potentially comparing the results of PCA and theoretical dimensionality reduction methods

5. Analyzing the resting-state functional connectivity parameters of regions discovered in steps 3 and 4

## Formulating specific, mathematically defined hypotheses

“Incongruent” or “surprising” trials are Wl trials (win trials with a preceding loss trial) and Lw trials (loss trials with a preceding win trial). Ww and Ll are congruent Win-win and Loss-loss trials, respectively. Explanatory Variable (EV) vectors for these trials have been defined and will constitute the core of this project’s analyses. Regions that are involved in incongruent reward processing (or the processing of trials with “surprising” valence) are defined as those with significant activations in the Ww>Wl and Ll>Lw contrasts.

To test reward encoding, MVPA models will be trained to predict the trial type of a previous trial based on activations during a trial, when the two trials are incongruent. The results of MVPA models will be compared to determine common and distinct substrates involved in encoding win-loss incongruent and loss-win incongruent trials.

To investigate the network connectivites of regions discovered in the previous two steps, resting-state functional connectivity analyses will be conducted with these regions as seeds.

## Future directions

Using task-based and resting-state fMRI activation and connectivity parameters, it might be possible to develop a computational model that links memory, reward and loss processing and their underlying neural activations, if time and resource constraints allow. Recent methods would allow for the analysis of effective connectivity patterns in both task-based and resting-state fMRI (Razi et al., 2017), with sophisticated computational techniques even allowing for the investigation of temporal dynamics in DCM estimates (Zarghami & Friston, 2020). Such approaches would enable an increasingly intricate conceptualization of the neurobiology of reward processing and its various interacting aspects.

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# ***Submitted Abstract***

# Title: Common and Distinct Neural Substrates of Incongruent Positive and Negative Reward Processing in Task-Based and Resting-State fMRI

**Background:** A central aspect of reward processing is the experience of unexpected reward or punishment, which involves the encoding of reward expectations, reward prediction error, and subsequent reward learning. While a growing literature on the processing of reward prediction error exists, not much is known about the relationship of these processes and resting-state neural connectivity patterns. Investigating this relationship may help identify baseline functional connections which support the processing of surprising reward valence.

**Hypothesis:** It is hypothesized that unexpected reward and punishment will involve both overlapping regions which are broadly involved in reward processing, and those which are differently involved in the processing of unexpected reward and unexpected punishment. Furthermore, it is hypothesized that the strength of surprise-related activity in these regions will correlate with their resting-state functional connectivity to brain regions involved in the processing of memory, reward and affect.

**Methods:** Using the large Human Connectome Project (HCP) dataset, reliable activation and connectivity patterns could be identified to evaluate hypotheses and suggest promising avenues for future investigation. Data for 339 HCP participants was obtained from the “HCP 2021” Neuromatch Academy dataset. HCP participants had been scanned during two consecutive runs of a "gambling" task, consisting of interspersed, deterministic “win” and “loss” trials. To evaluate the impact of unexpected reward and punishment, trials preceded by a trial with a similar reward valence were termed “congruent” trials, and “incongruent” trials were defined as those immediately following a trial with an opposite valence (i.e., win trials preceded by a loss trial, and vice versa). After fitting subject-level GLMs, parameter estimates were obtained for incongruent win>congruent win, incongruent loss>congruent loss, and incongruent win>congruent win contrasts across the sample. Taking these as seed regions, their resting-state functional connectivity to every other brain parcel was subsequently measured and canonical correlation analysis (CCA) is used to estimate the correlation between their task-related activation and connectivity to every other ROI.