Does *efficient value synthesis* in the OFC explain how risk attitude adapts to the range of risk prospects?

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What is *risk attitude*?

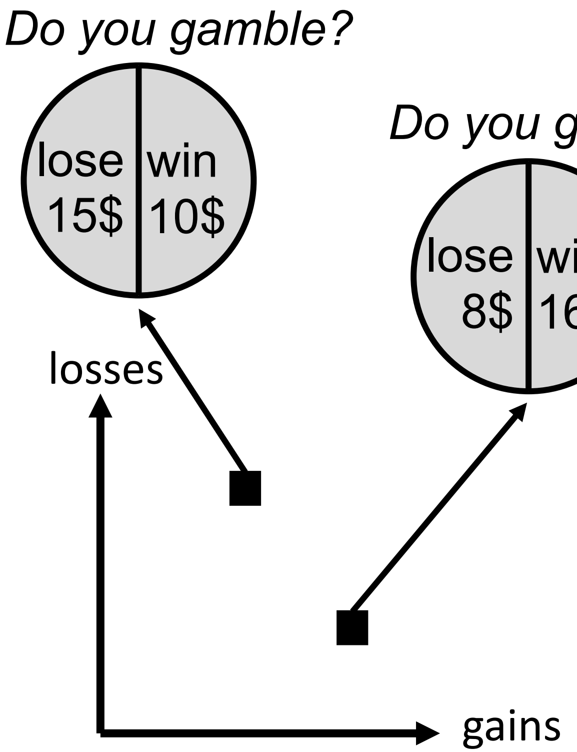
Risk:

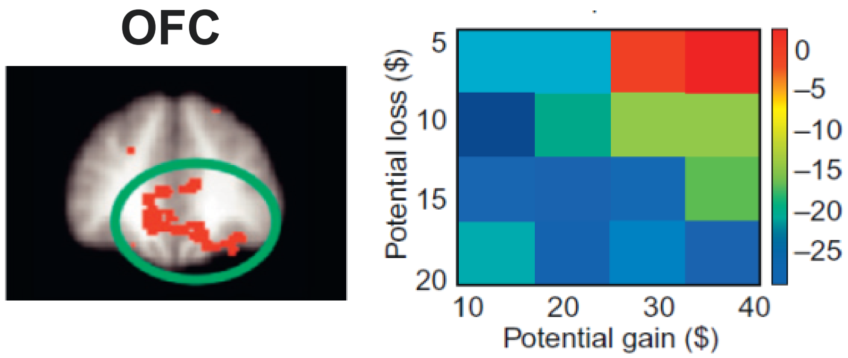
- is the possibility of something bad happening
- involves uncertainty about the consequences of an action

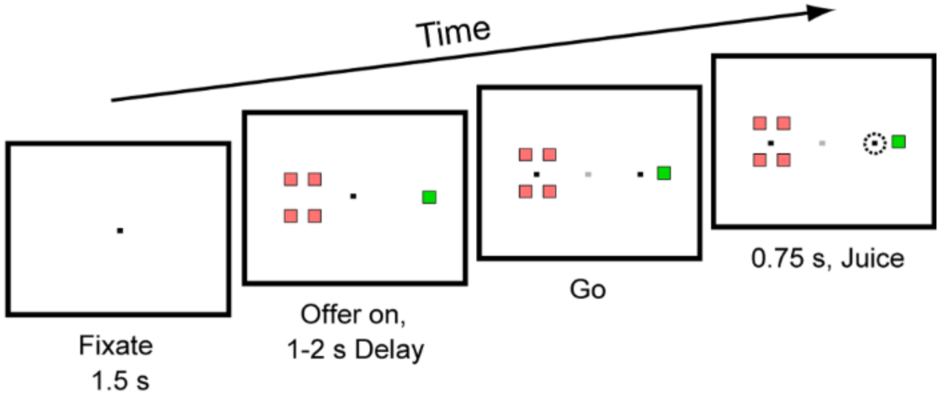
Attitude toward risk:

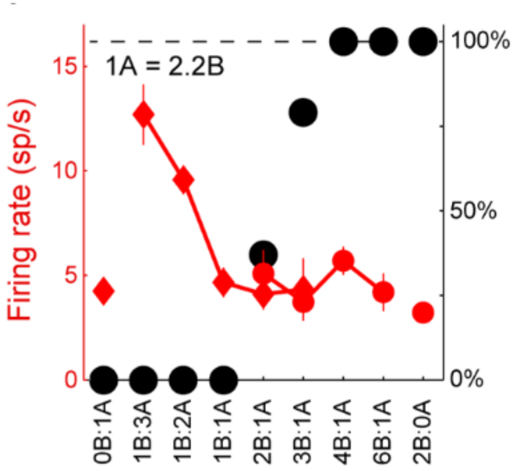
- has many socio-economic implications (health, finance, etc)
- varies across people (risk-seeking vs risk-averse people):
  - ✓ genetic factors (e.g., 5HTTLPR, DRD4)
  - ✓ environmental factors (e.g., childhood harshness)
- determines how rewards are discounted by the prospect of losses:
  - ✓ affective factors (e.g. fear)
  - ✓ cognitive factors (e.g., “framing effect”)

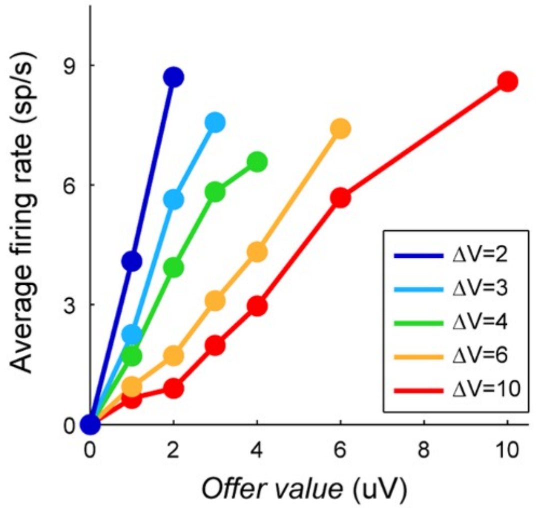
Risk attitude and value coding in OFC neurons





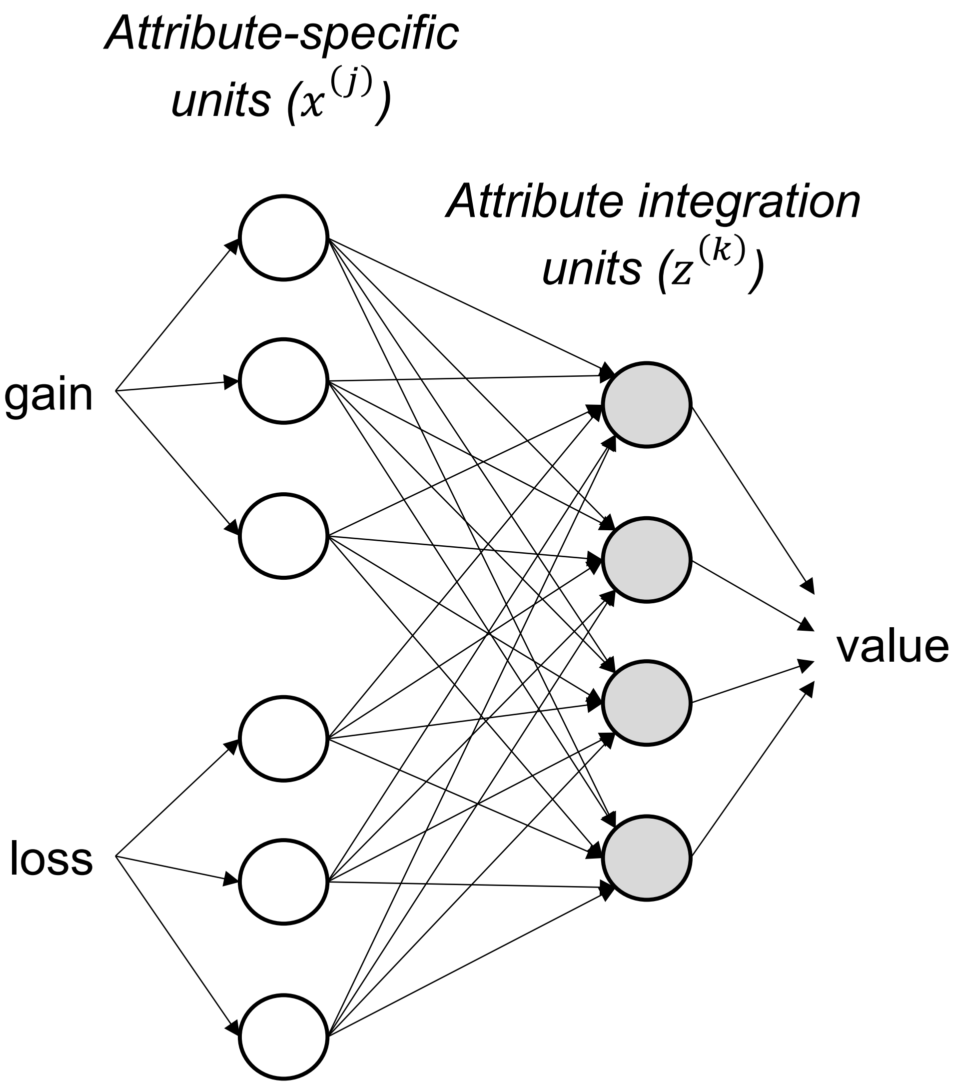






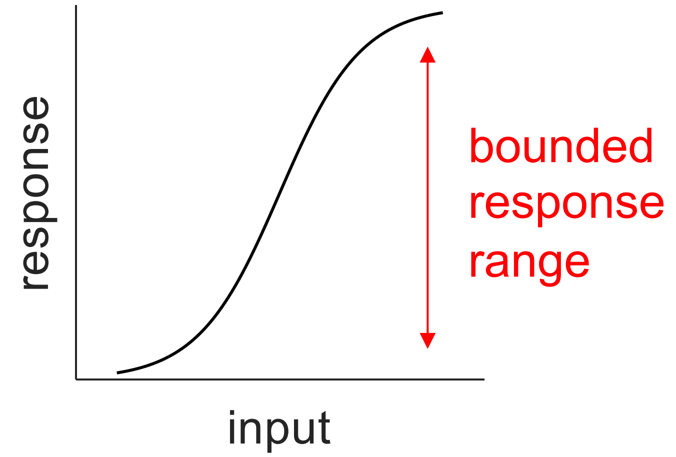
- Why/how do OFC neurons adapt to the value range?
- Can this modify peoples’ risk attitude? If yes, how?

Value synthesis in the OFC: biological constraints



- Neural noise in attribute-integration units:

$$\begin{cases} V_t = \sum_k w^{(k)} z_t^{(k)} \\ z_t^{(k)} = f^{(k)}\left(v_t^{(k)}\right) + \eta_t^{(k)} \\ v_t^{(k)} = \sum_j C^{(j,k)} x_t^{(j)} \end{cases}$$

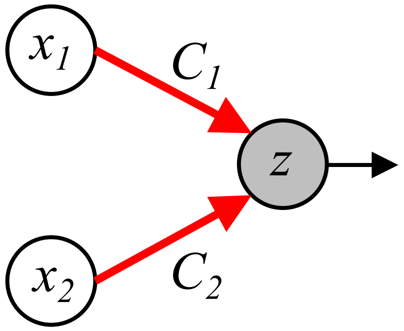


- … induces information loss:

$$IL = -MI\left(z, f_z(v)\right) \xrightarrow[\eta \to 0]{} K - H[f_z(v)] = K - H[v] - \sum_k E\left[ln\left|\frac{\partial f^{(k)}}{\partial v^{(k)}}\right|\right]$$

Efficient value synthesis (EVS)

Self-organized plasticity
upstream integration neurons

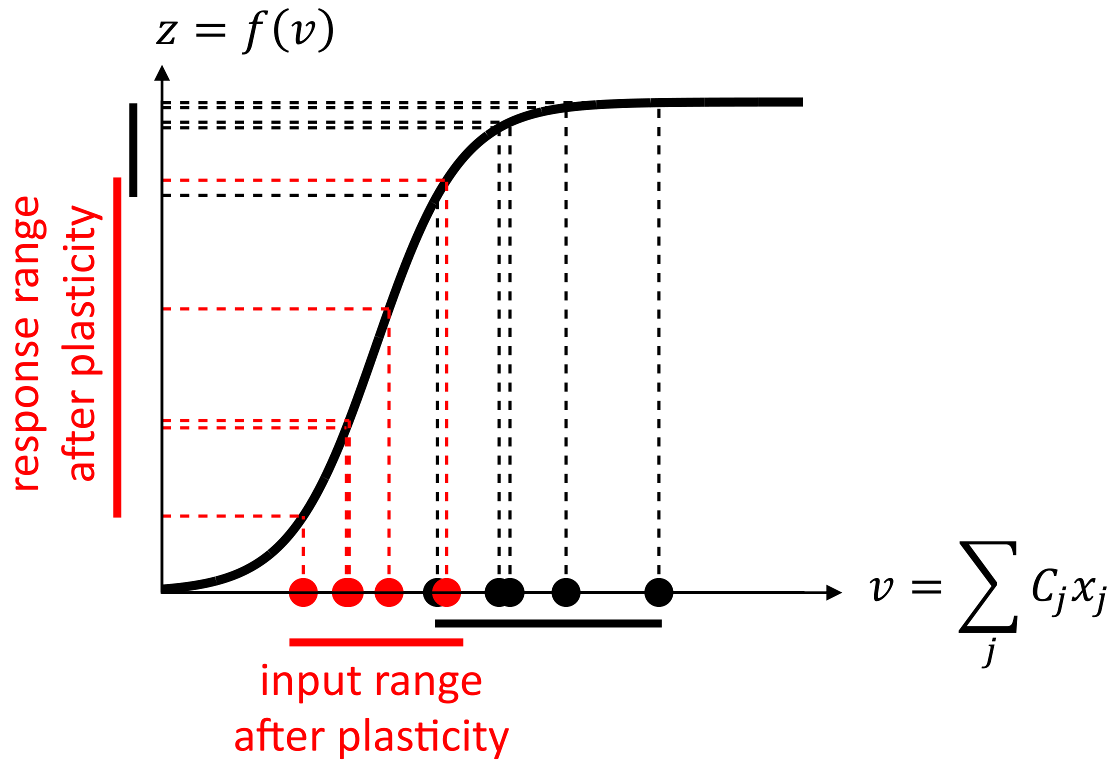


$$\dot{C}^{(j,k)} \propto -\frac{\partial IL}{\partial C^{(j,k)}} \approx \frac{\partial}{\partial C^{(j,k)}} ln \left|\frac{\partial z^{(k)}}{\partial v^{(k)}}\right|$$

$$\Rightarrow \dot{C}^{(j,k)} \propto \lambda\ x^{(j)}\left(1 - 2z^{(k)}\right)$$

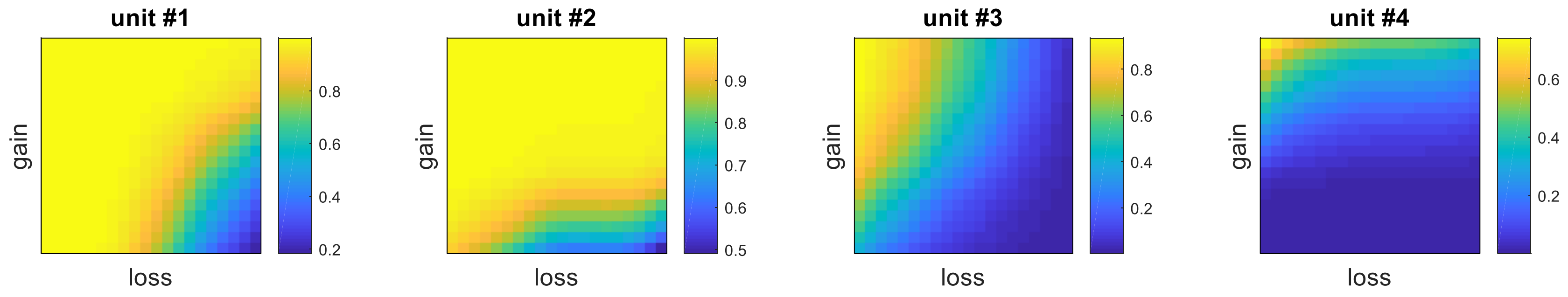
~~anti−Hebbian rule~~

(for sigmoidal integration units)

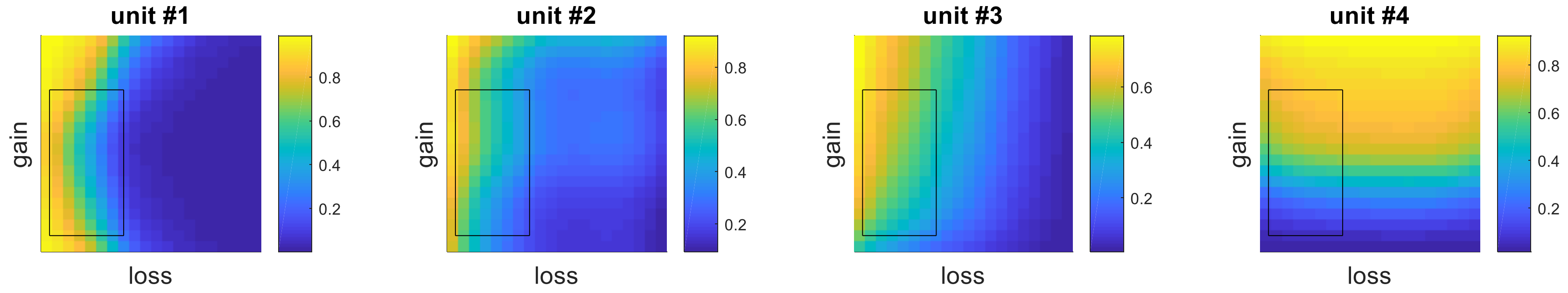


What does self-organized plasticity do to the integration layer?

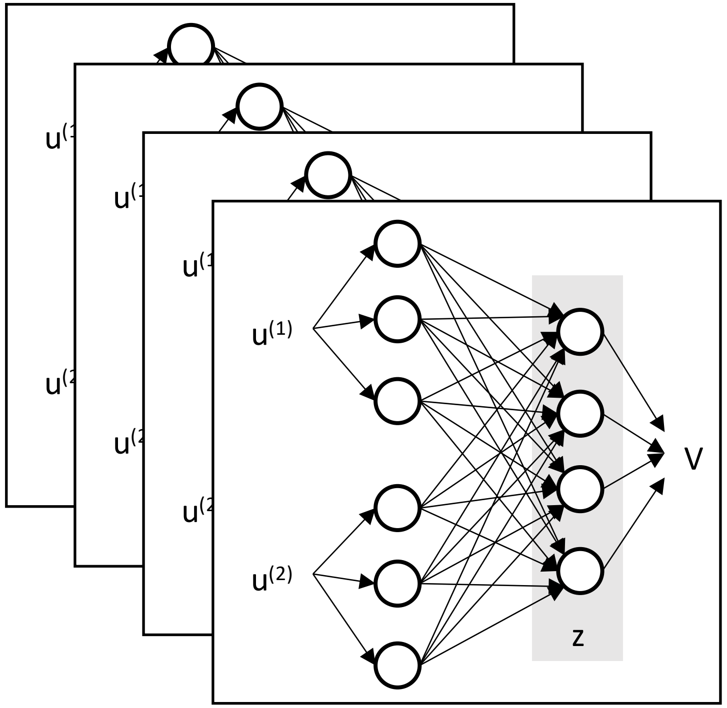
- Train the ANN to perform the synthesis of gambles’ *expected value* : EV = 50% gain – 50% loss

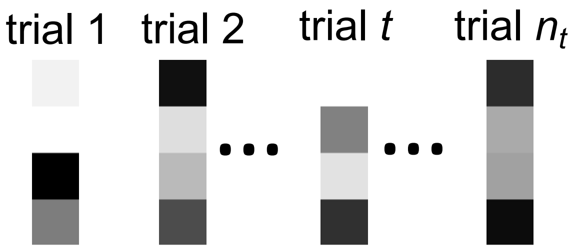


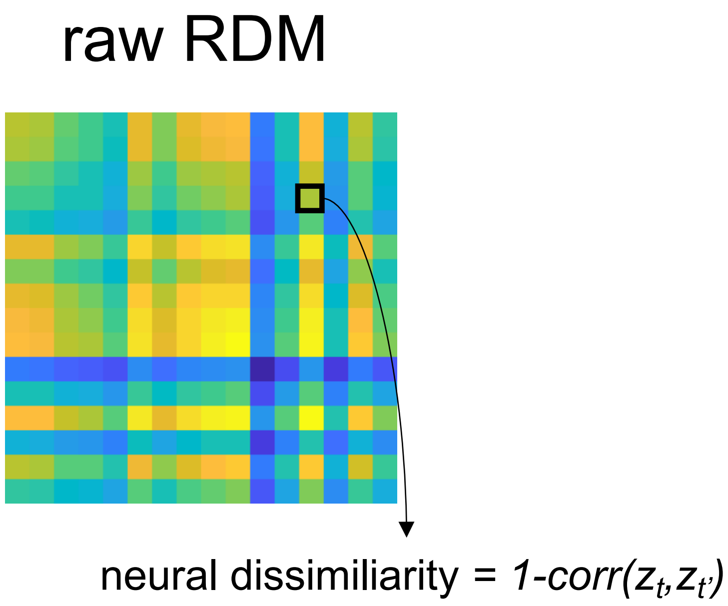
- Let the ANN self-organize while exposing it to a series of prospective gains and losses



Assessing the information content of the integration layer

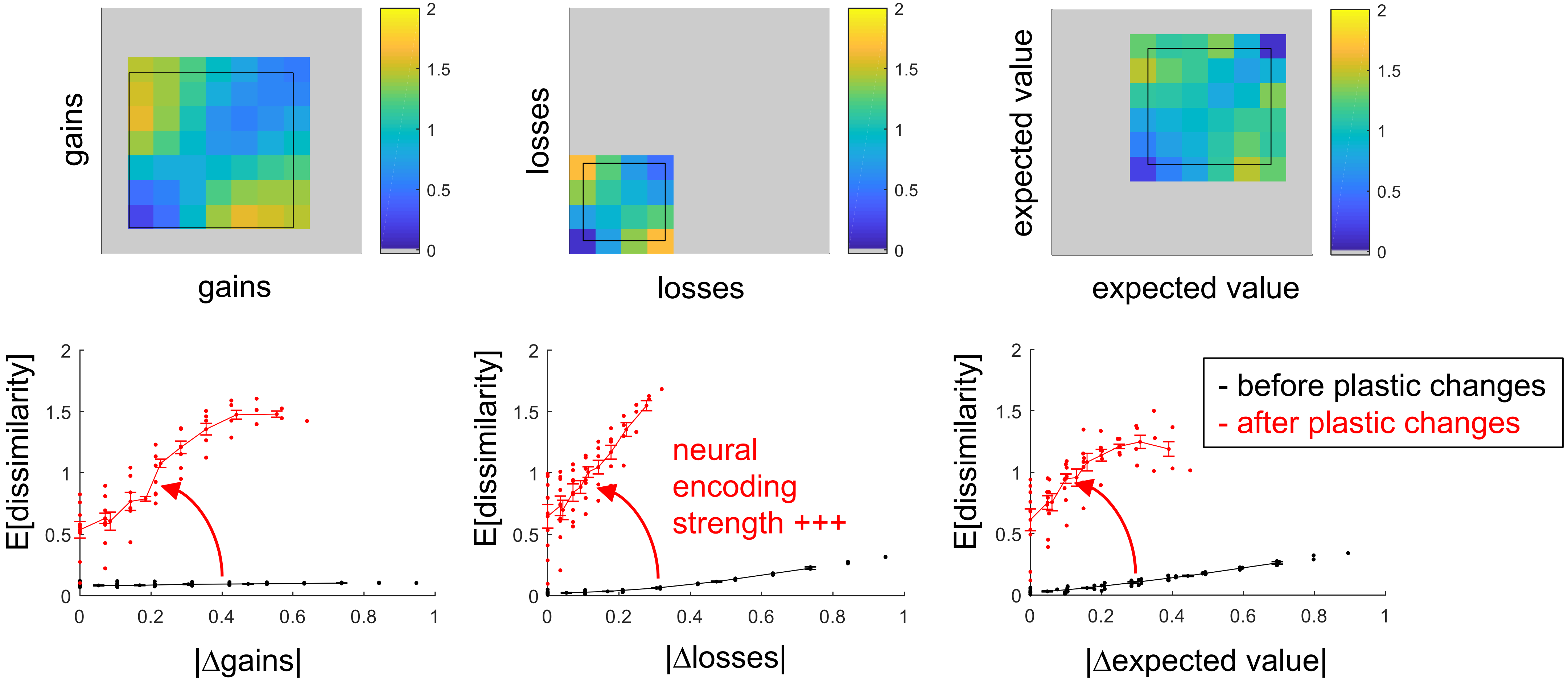






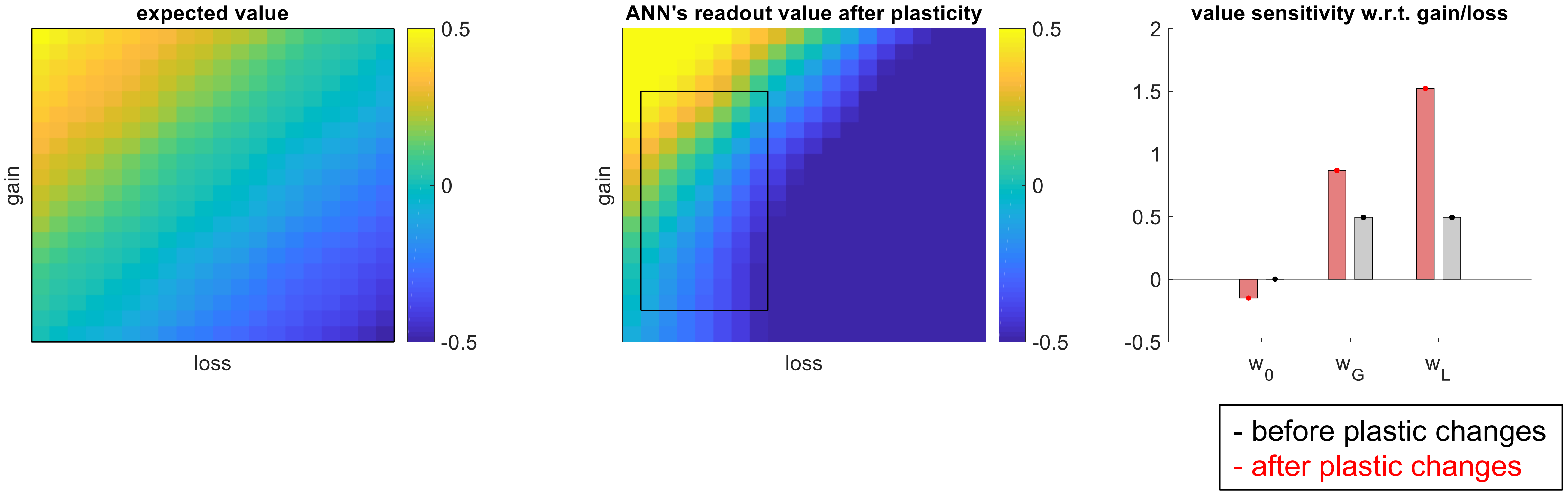
- ➢ bin trials according to variable of interest (VOI: gain, loss, EV)
- ➢ neural encoding strength = ∂ neural dissimilarity / ∂ VOI distance

Self-organized plasticity modifies neural encoding strengths

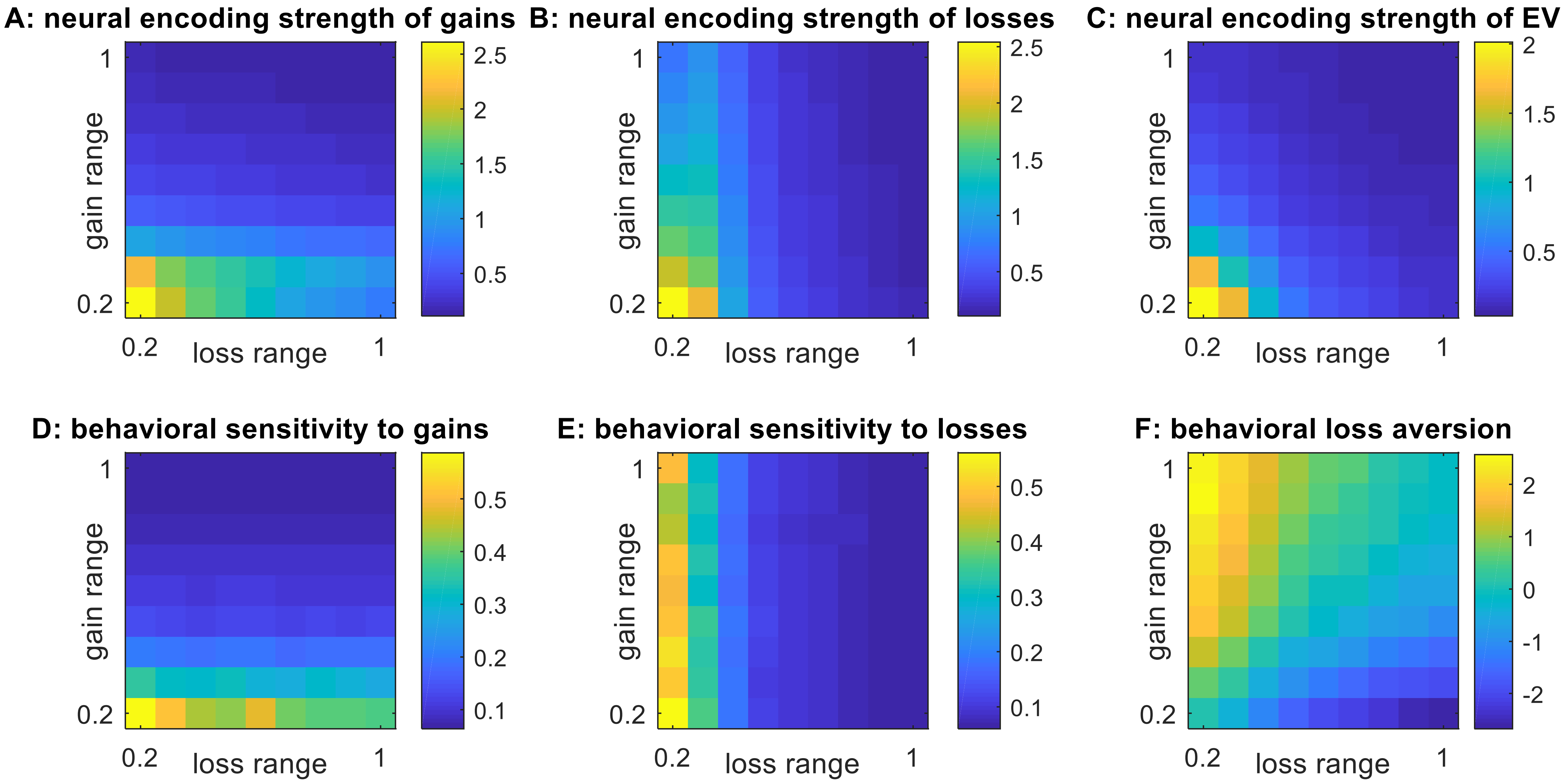


Self-organized plasticity modifies behavioral sensitivity to gains and losses

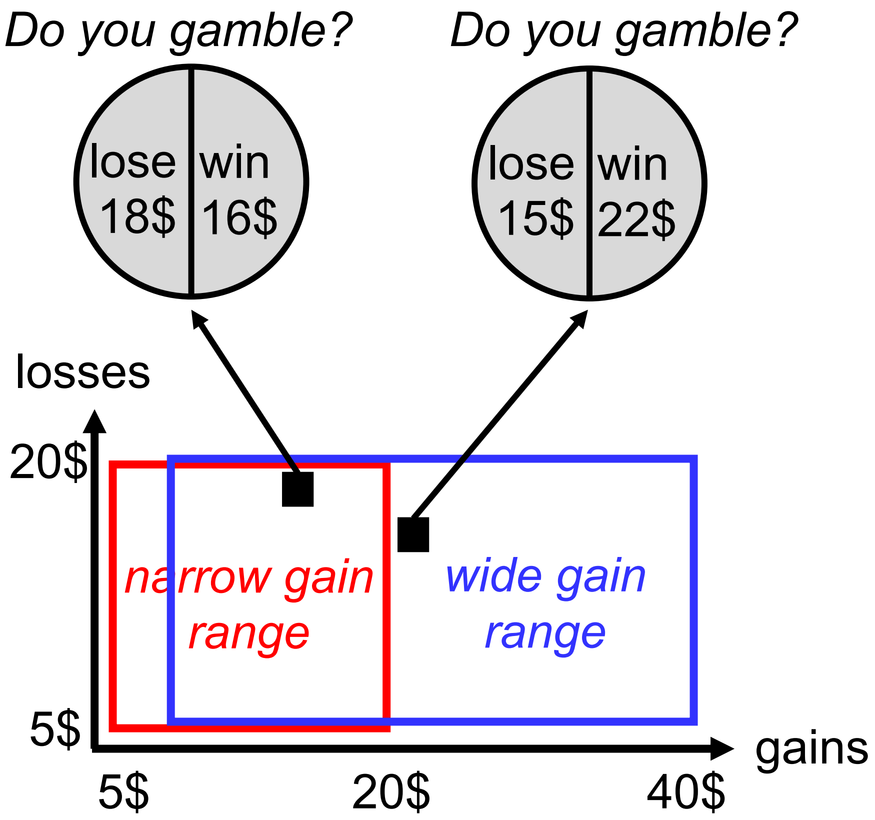
- Risk attitude is determined by the relative impact of attributes (gain and loss) onto value
- behavioral sensitivity = ∂ readout value / ∂ value attribute



What is the impact of gain and loss ranges?



The NARPS fMRI dataset (openneuro.org)



(Gamble outcomes are only revealed at the end of the experiment)

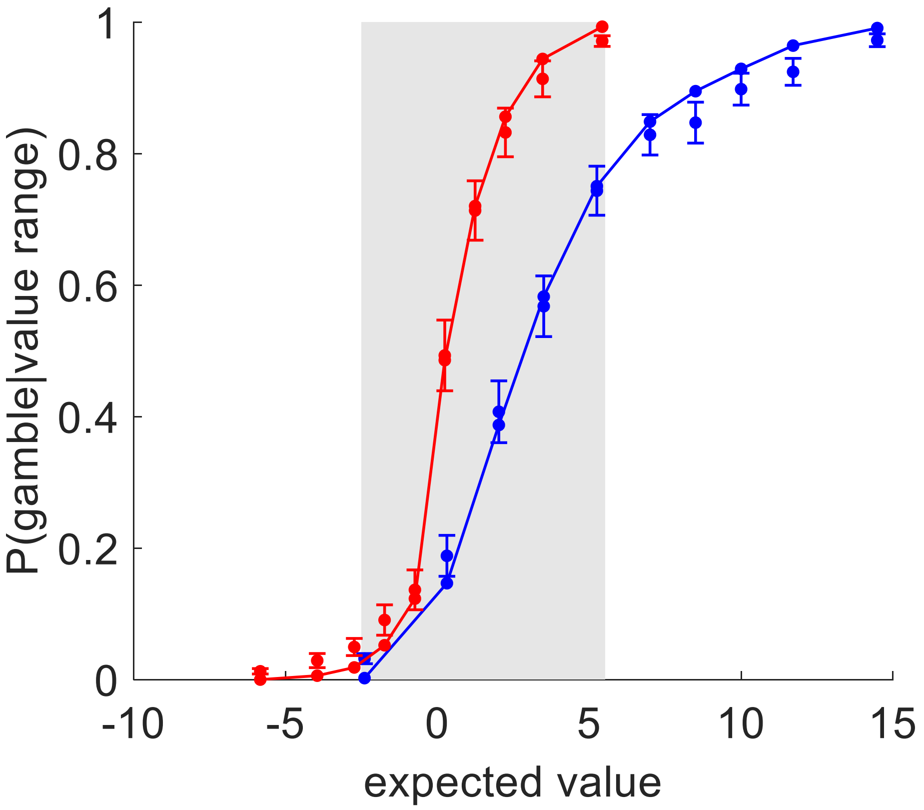
→ Two groups of participants:

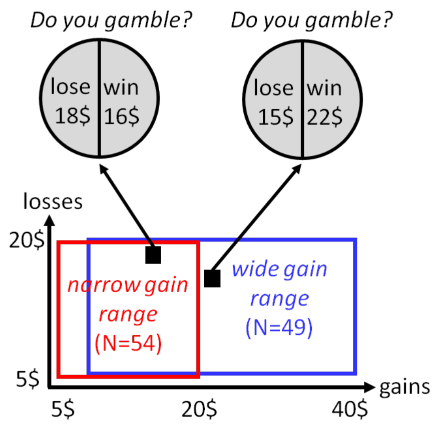
- ✓ « narrow gain range » group (N=54): 5<losses<20, 5<gains<20
- ✓ « wide gain range » group (N=49): 5<losses<20, 10<gains<40

Does risk attitude exhibit range adaption?

→ **Decision theory**:

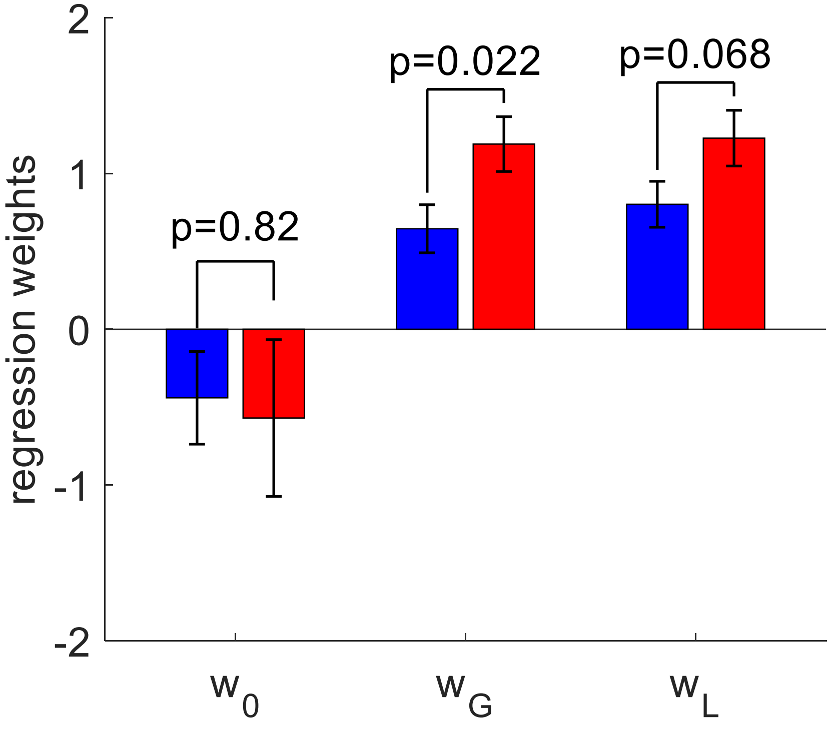
- gamble's *expected value* = 50% gain – 50% loss
- P(gamble): independent from the range of risk prospects

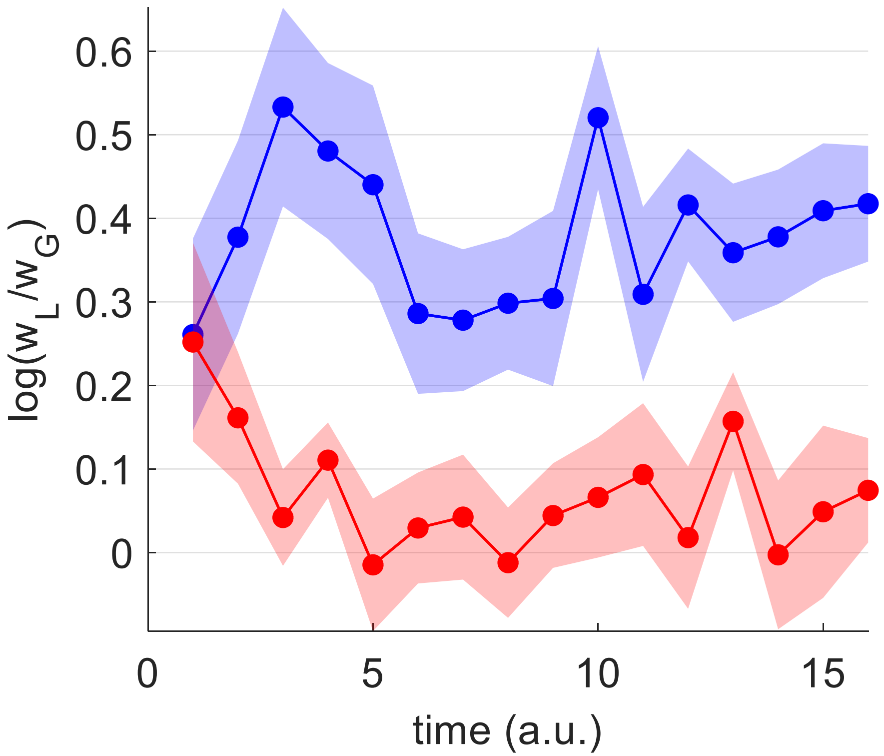




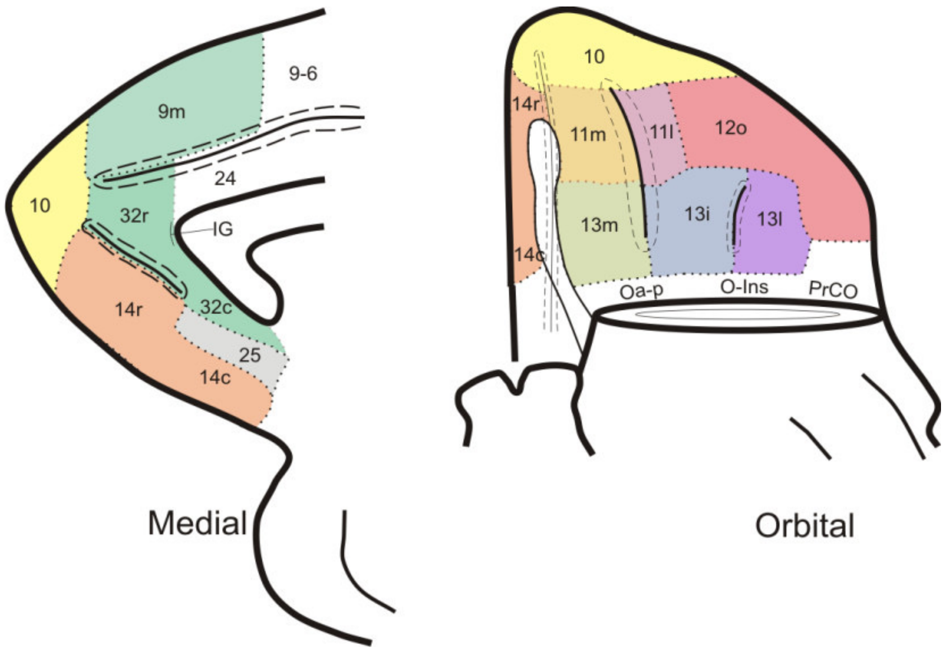
Peoples' behavioral sensitivity to gains and losses

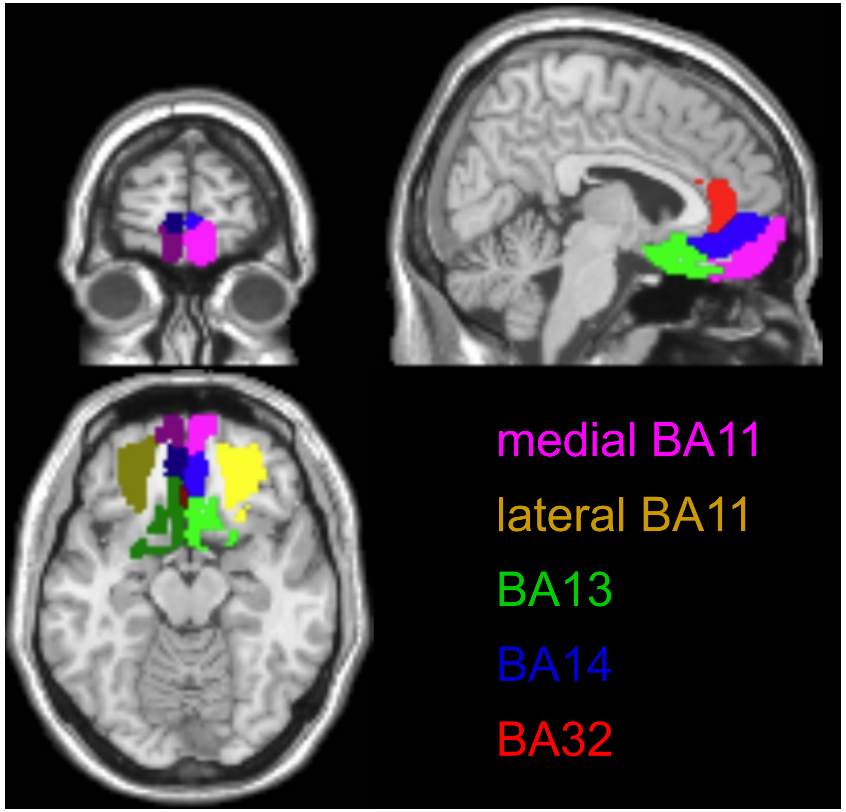
P(gamble) = sigmoid($\mathbf{w_0}$ + $\mathbf{w_G}$×gain - $\mathbf{w_L}$×loss)



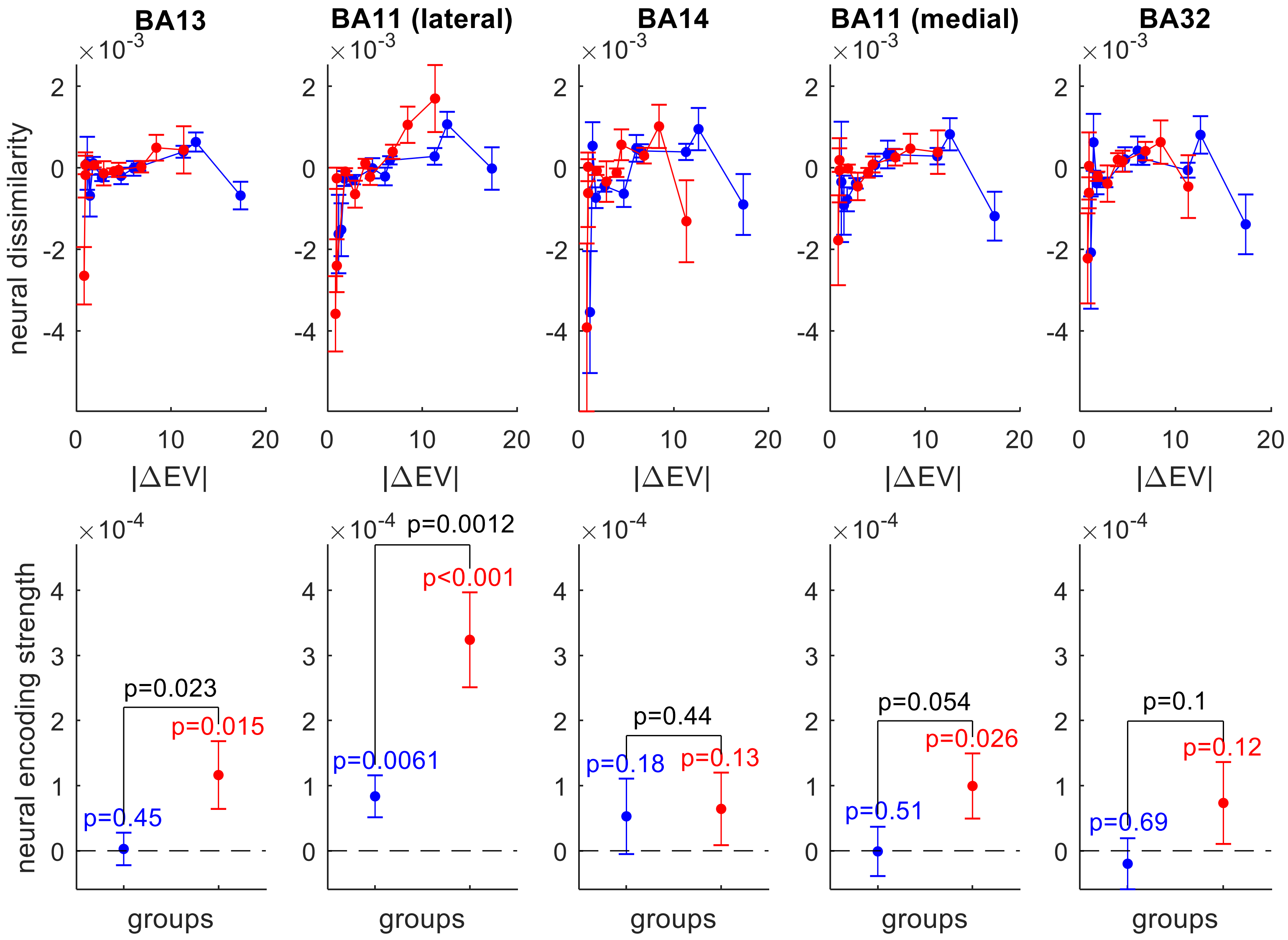


fMRI data analysis: OFC subregions

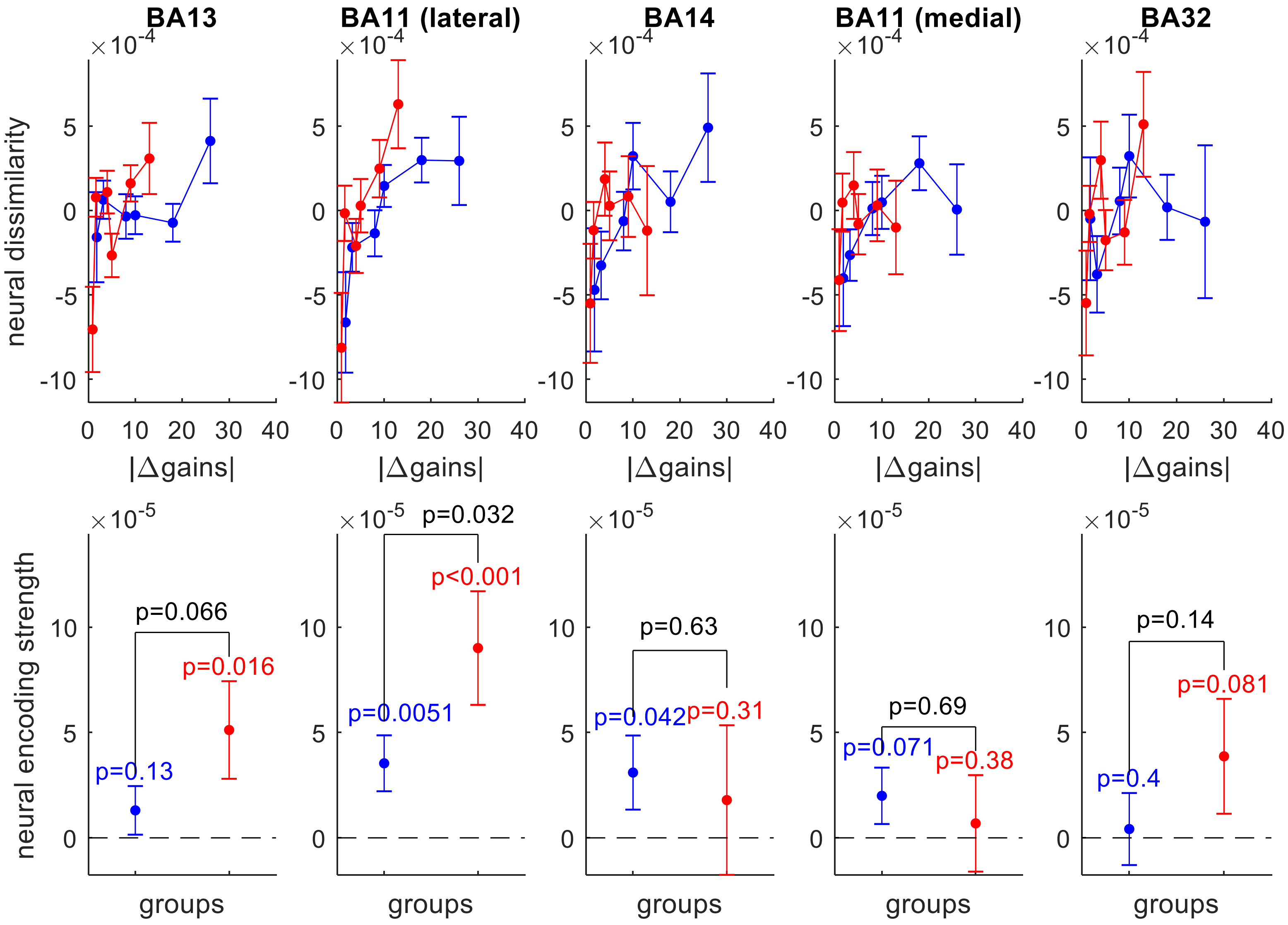




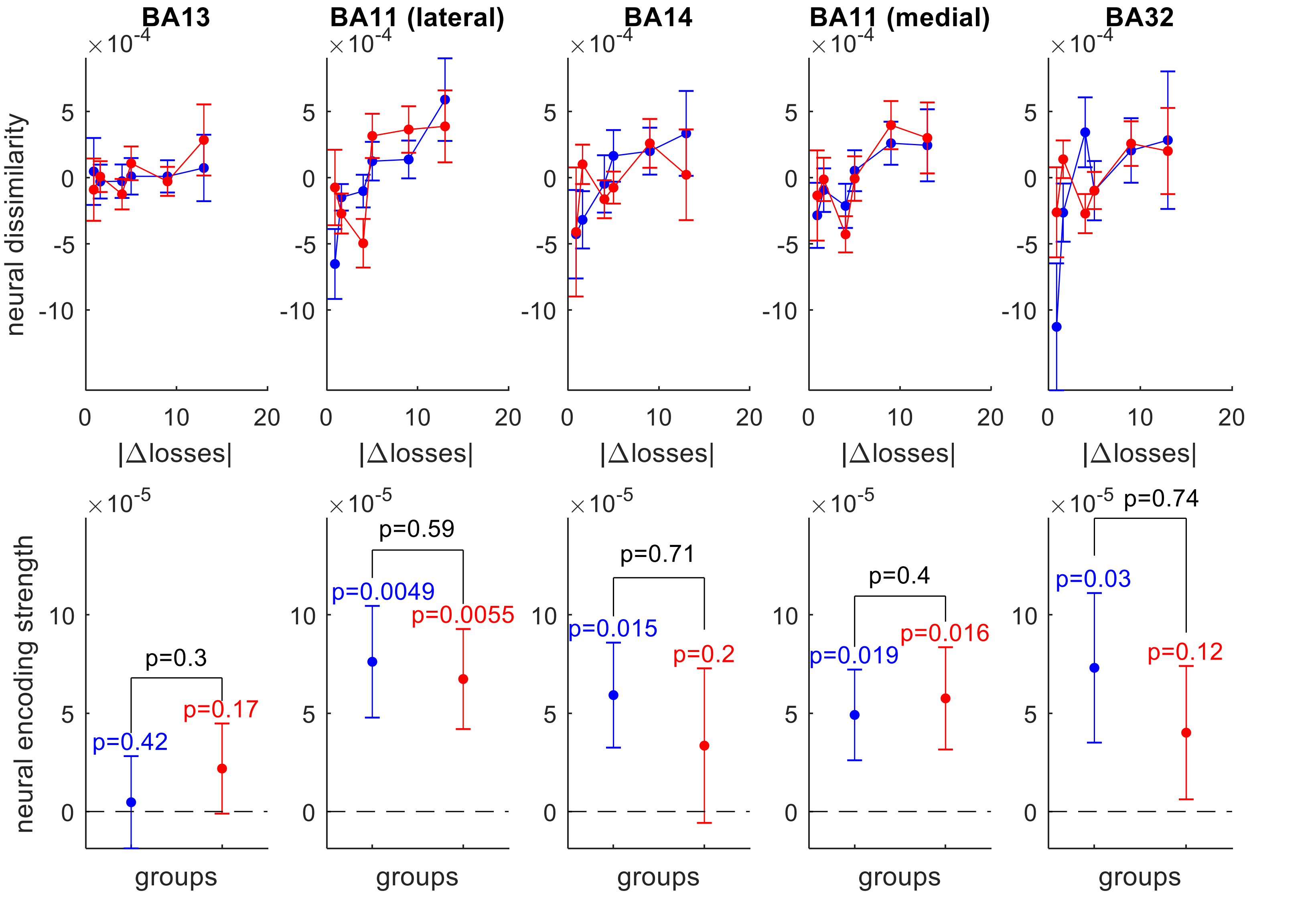
Information content in the OFC: expected value



Information content in the OFC: gains

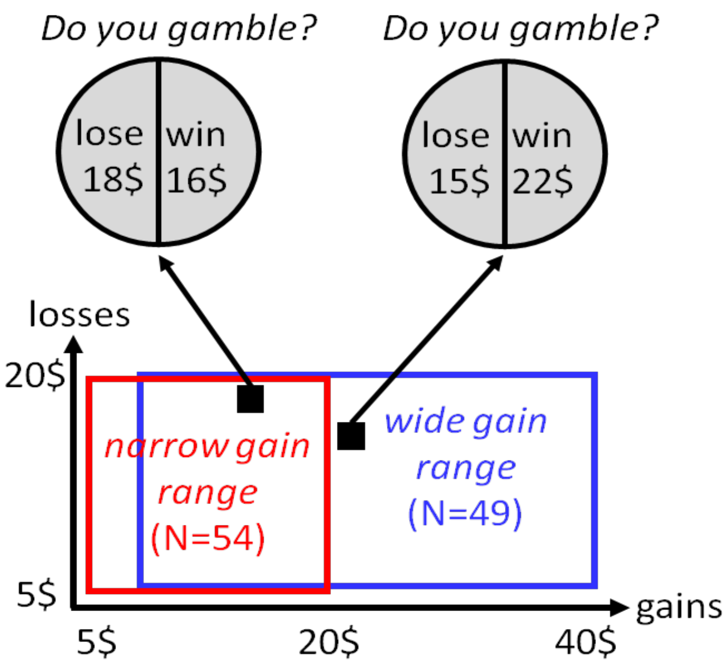


Information content in the OFC: losses



Model generalizability across risk range contexts

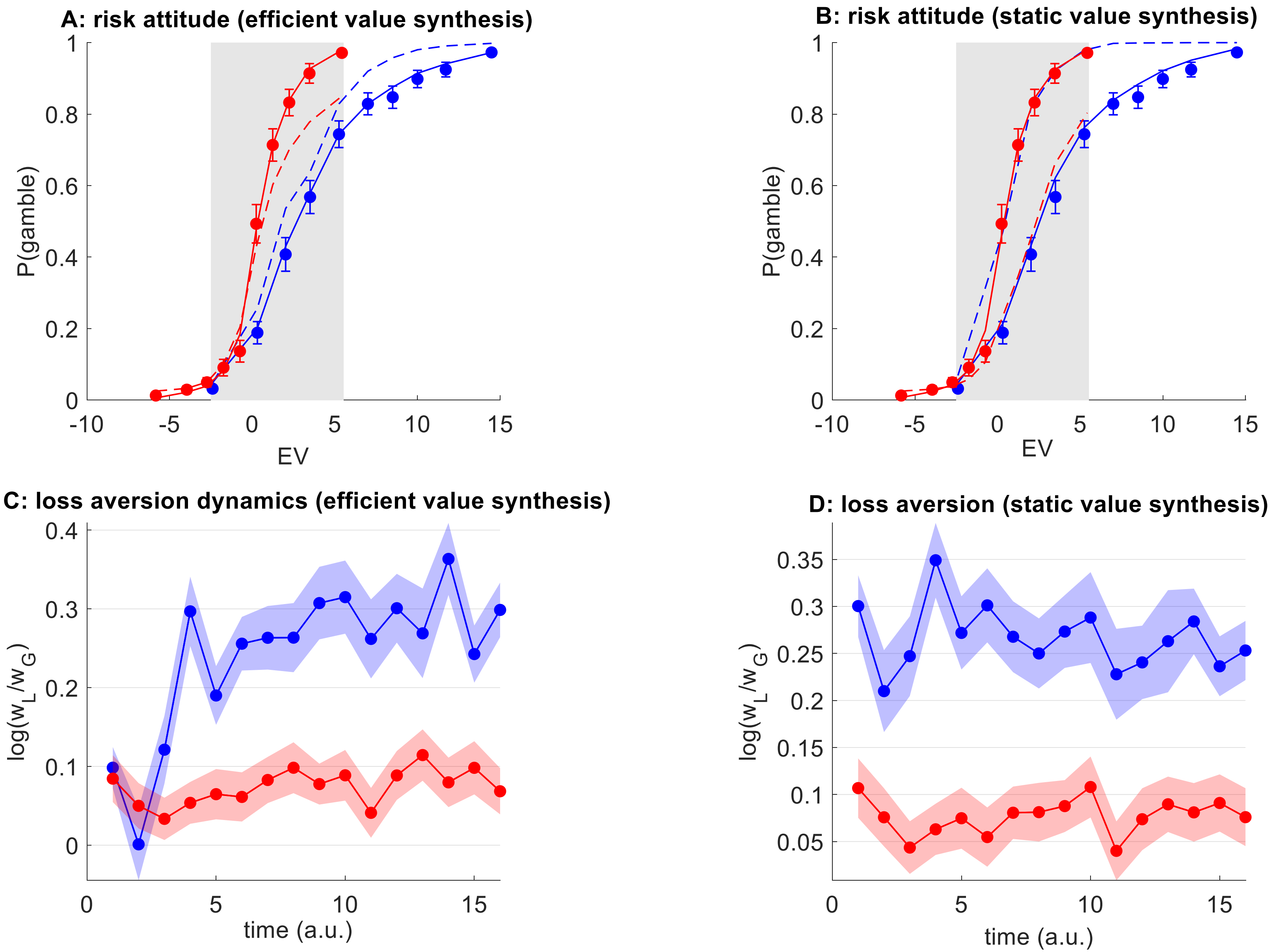
Can we predict (out-of-sample) what the other group would have done, from ANN models of value synthesis?



For each subject:

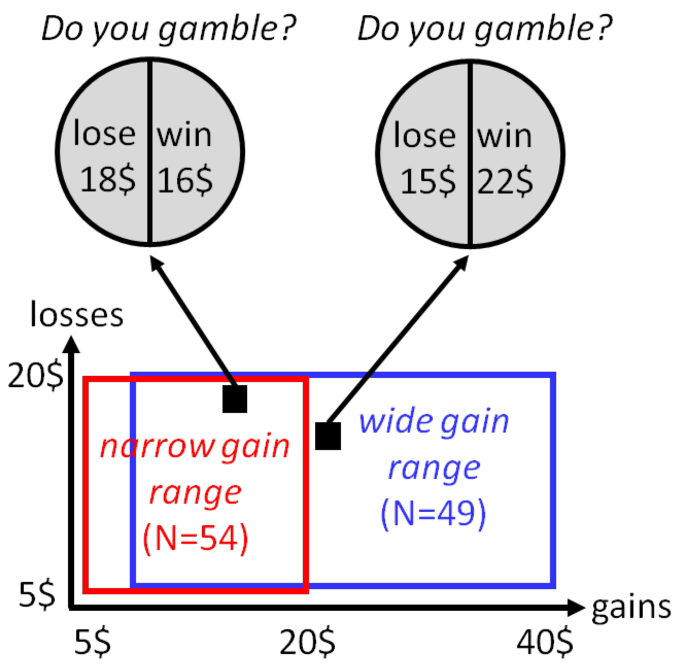
1. Fit ANN model to his/her trial-by-trial gamble decisions
2. Extract fitted ANN parameters and simulate trial-by-trial gambles of each subject *in the other group*
3. Bin trials according to EV and estimate P(gamble|EV)

EVS generalizes over risk range contexts



Model accuracy for OFC's information content

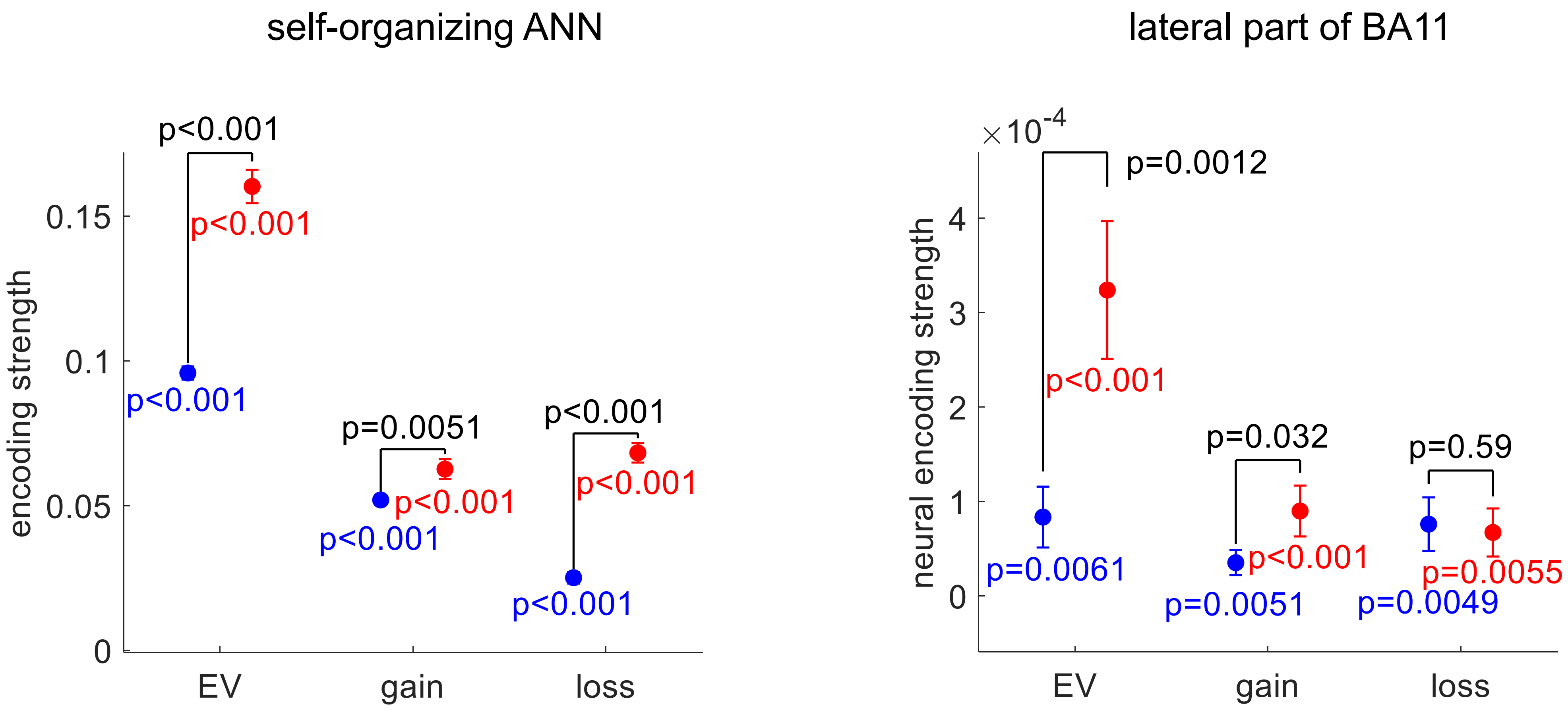
Can we predict (out-of-sample) multivariate fMRI patterns of activity in the OFC, from ANN models of value synthesis?



For each subject:

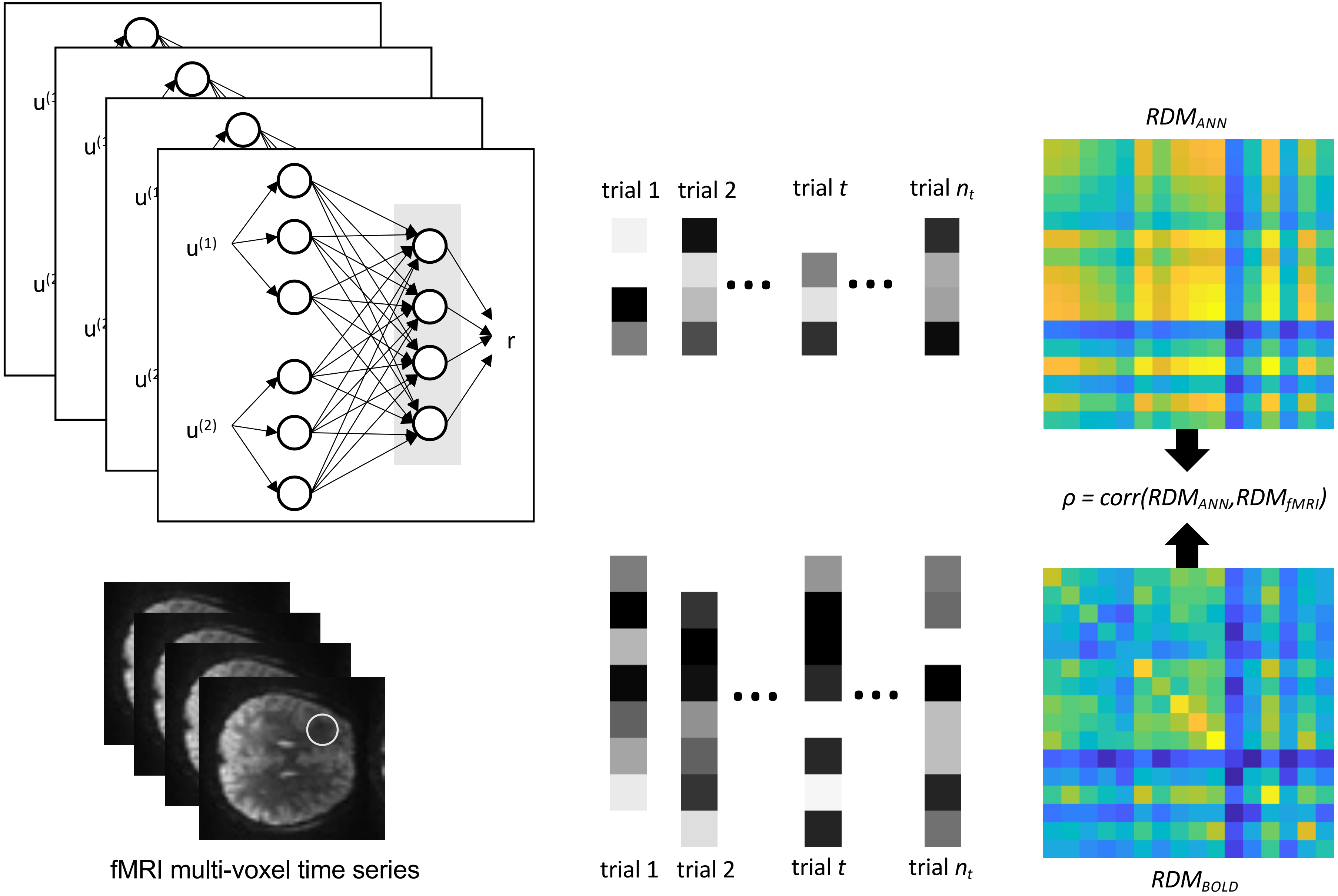
1. (Fit ANN model to his/her trial-by-trial gamble decisions)
2. Extract trial-by-trial activity profiles in the ANNs' integration layer
3. Compare those activity profiles to trial-by-trial fMRI activity patterns in the OFC

Predicted information content of integration units

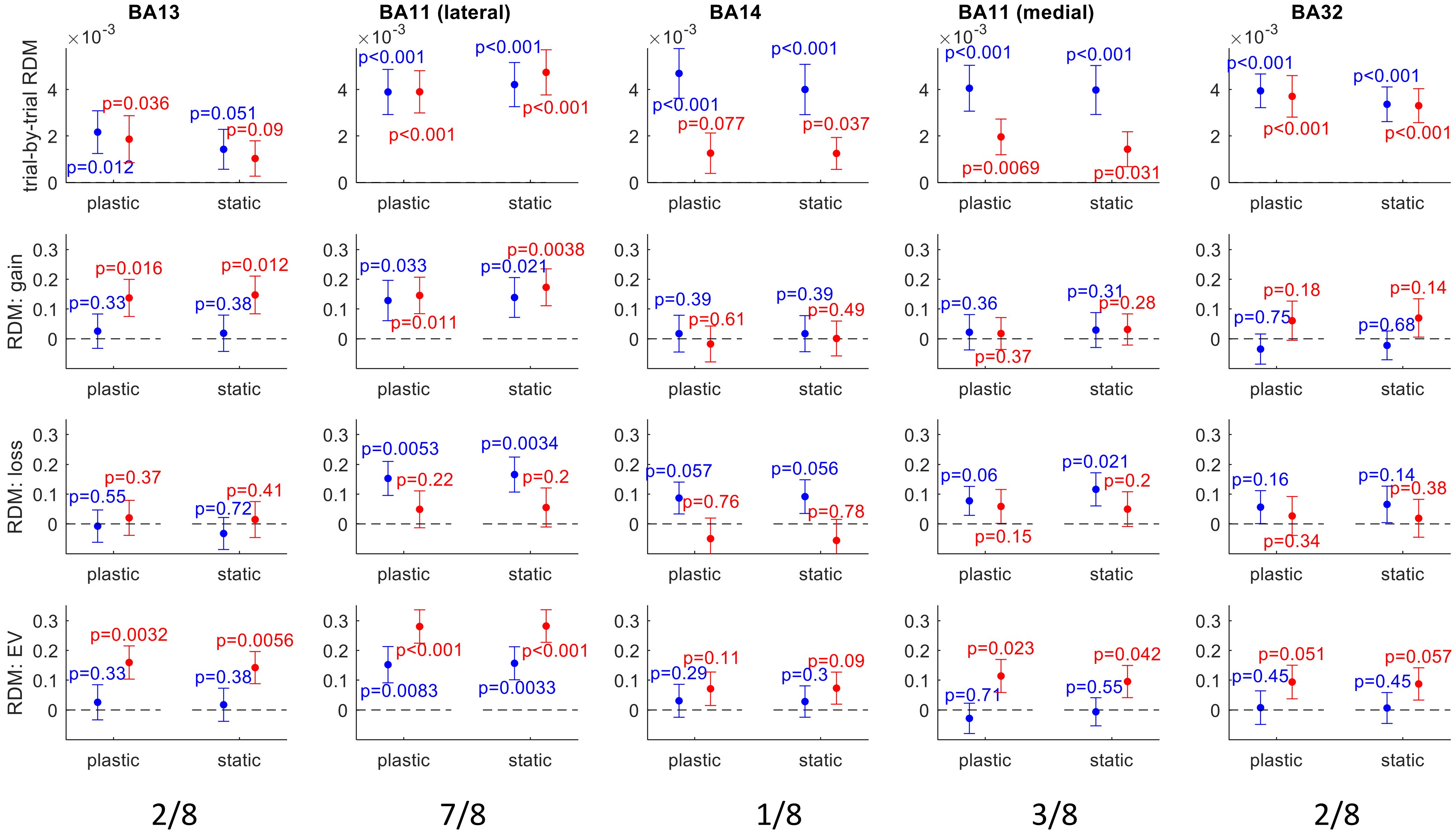


- Self-organizing ANN models reproduce the qualitative pattern of information content in BA11

Representational Similary Analysis



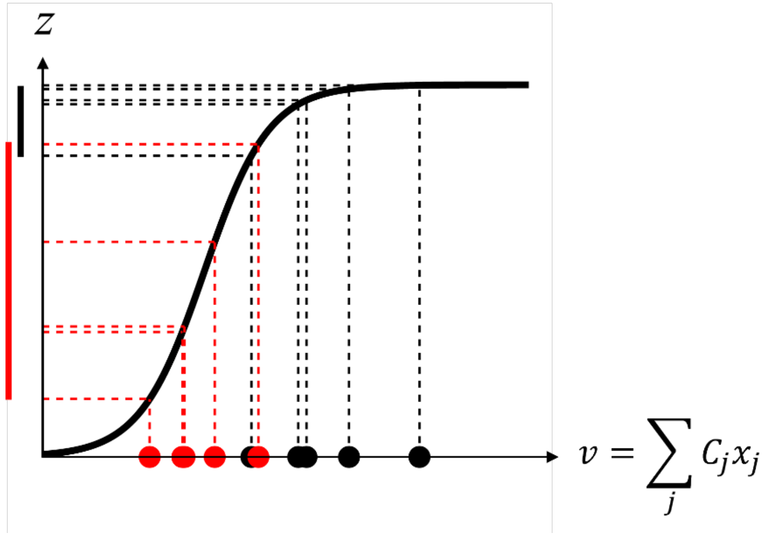
RSA results in the OFC (fMRI)



Discussion

- Value range adaptation mechanistically follows from assuming that (i) neurons have a limited firing range and (ii) neural networks that operate value synthesis self-organize to minimize information loss.

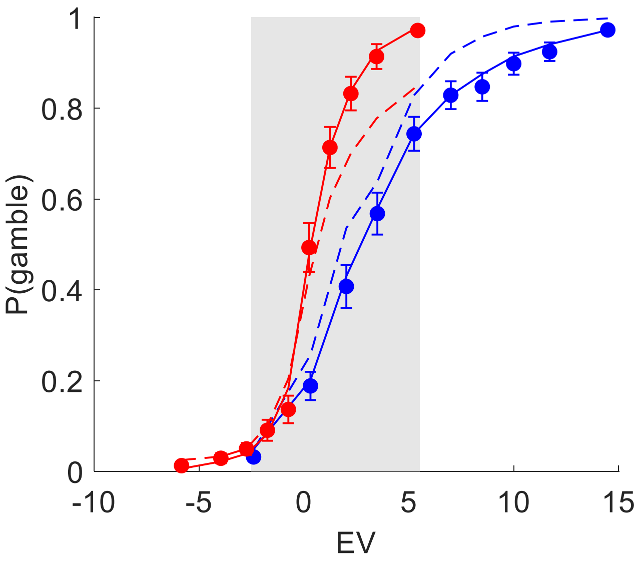
$$\dot{C}^{(j,k)} \propto -\frac{\partial IL}{\partial C^{(j,k)}} \approx \underbrace{\lambda\, x^{(j)}\left(1 - 2z^{(k)}\right)}_{\cancel{anti-Hebbian\ rule}}$$

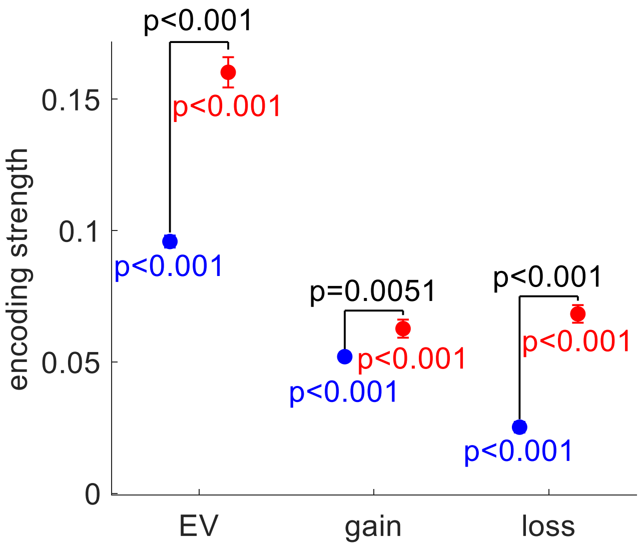


Discussion

- Value range adaptation mechanistically follows from assuming that (i) neurons have a limited firing range and (ii) neural networks that operate value synthesis self-organize to mitigate information loss.

- The ensuing *efficient value synthesis* most likely lies within lateral BA11 and eventually makes risk attitude context-dependent (i.e. irrational).





Discussion

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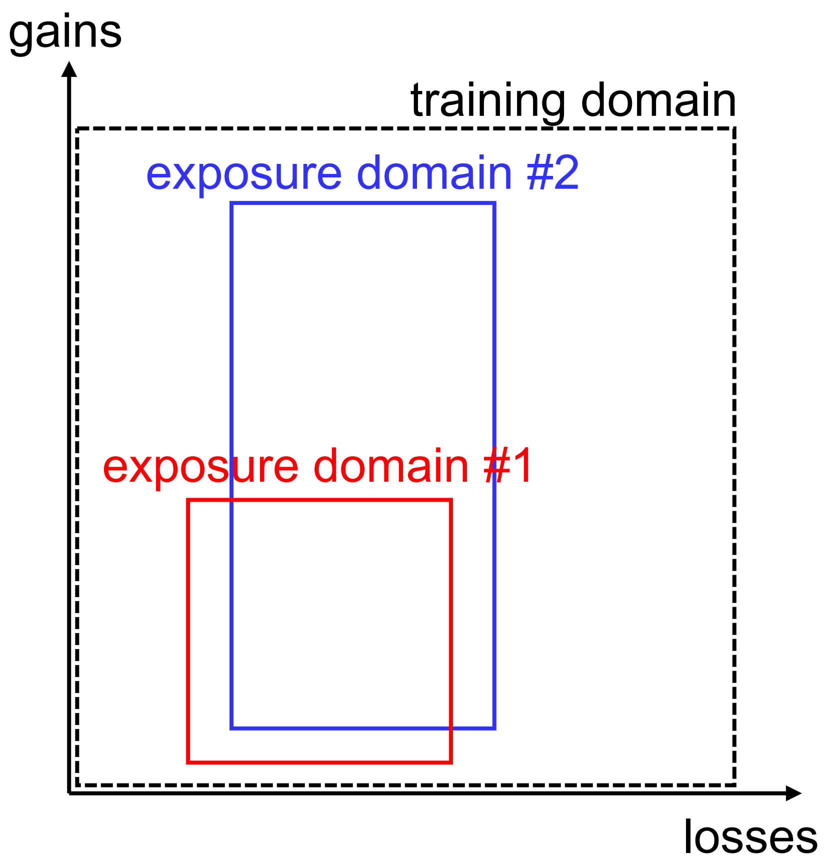
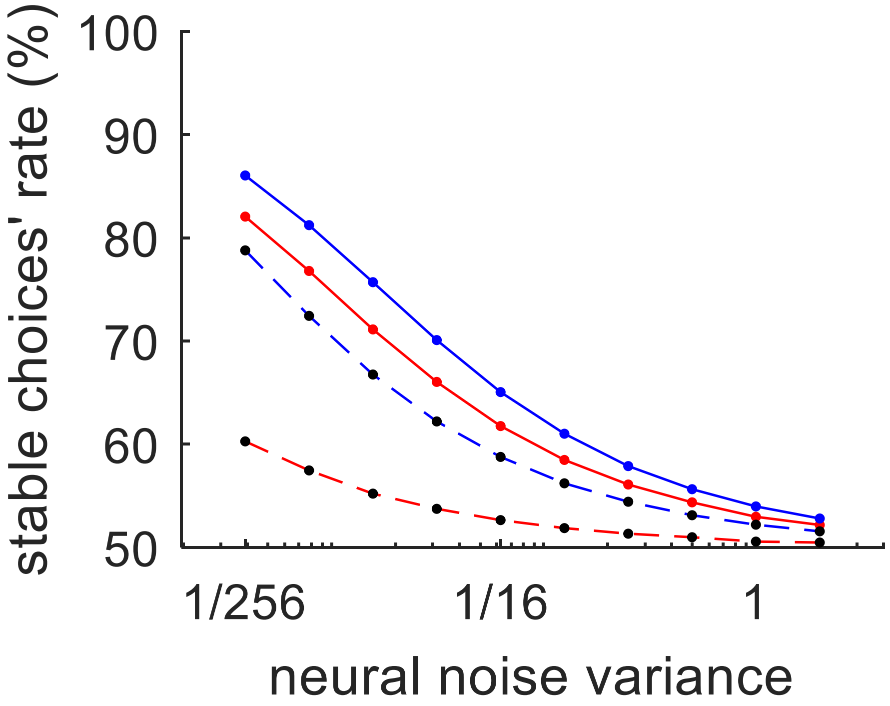
- The ensuing *efficient value synthesis* most likely lies within lateral BA11 and eventually makes risk attitude context-dependent (i.e. irrational).

- ANN models of decision-relevant computations enable the identification of hard-wired biological mechanisms and/or constraints that eventually shape and/or distort decisions.

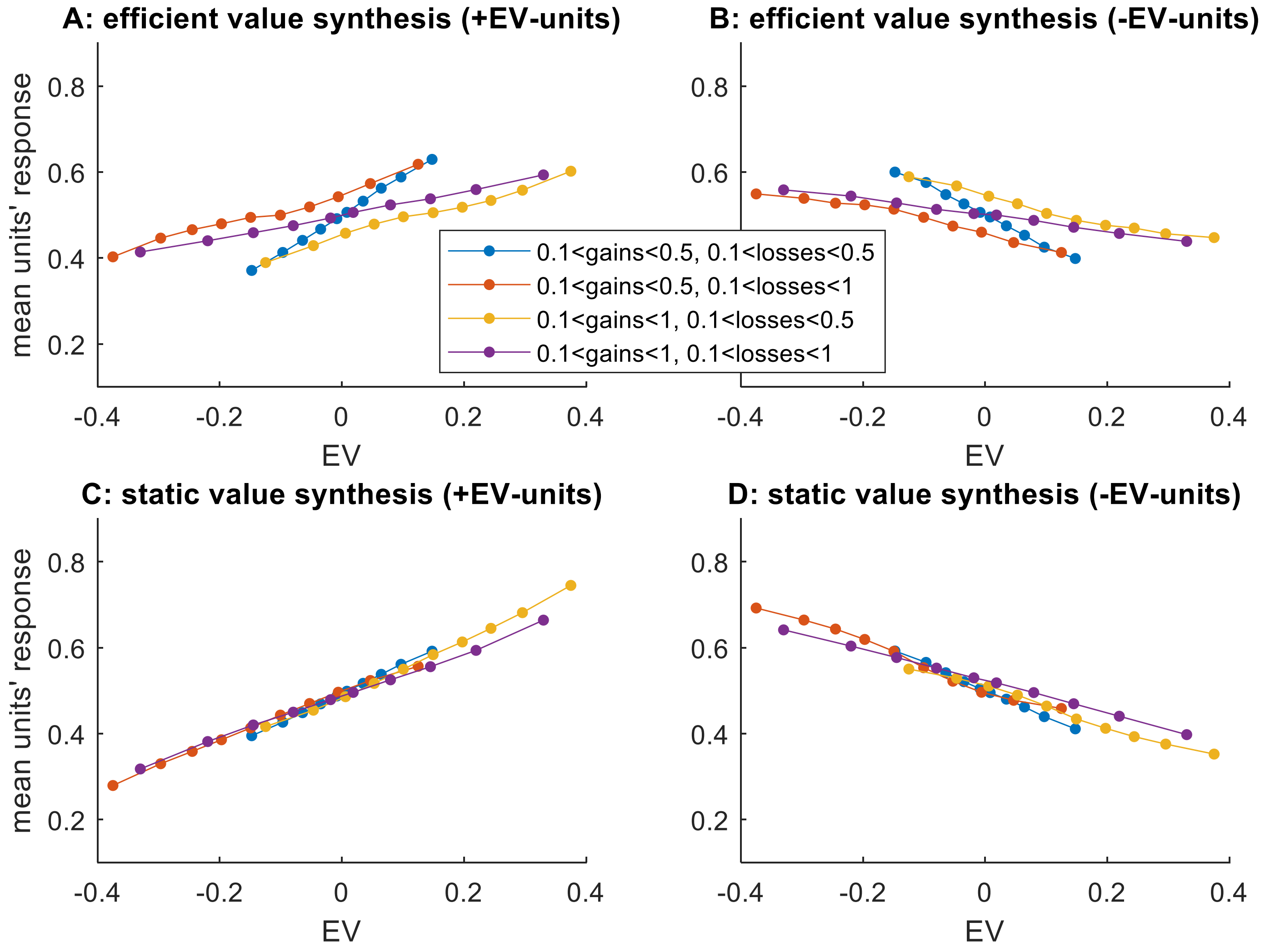
Is efficient value synthesis actually efficient?

- ➢ Let the ANN self-organize while exposing it to a series of prospective gains and losses

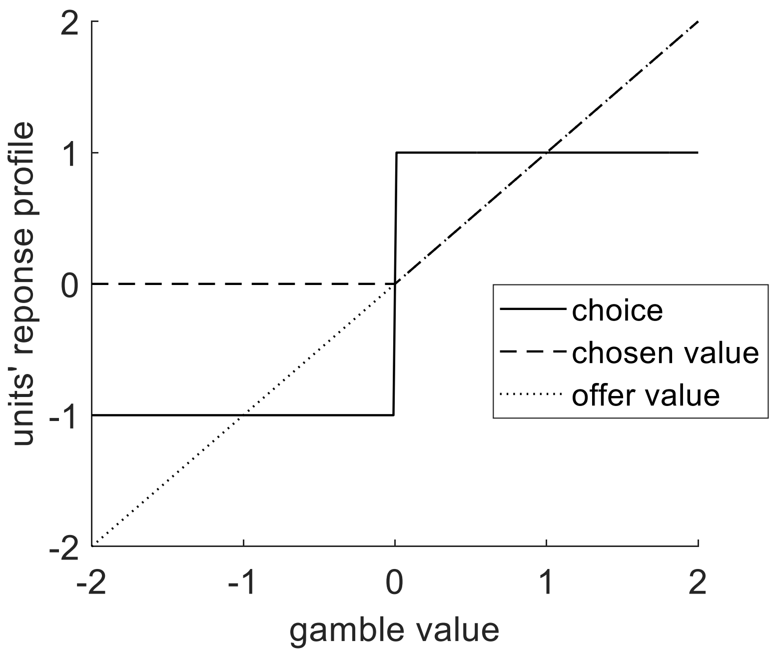


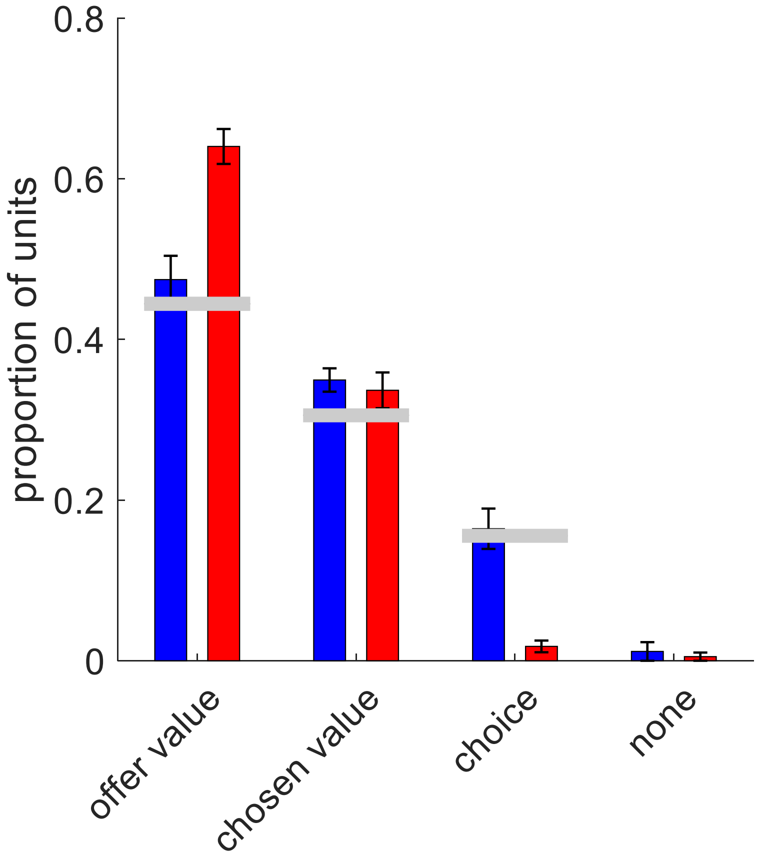


Integration units exhibit apparent value range adaptation



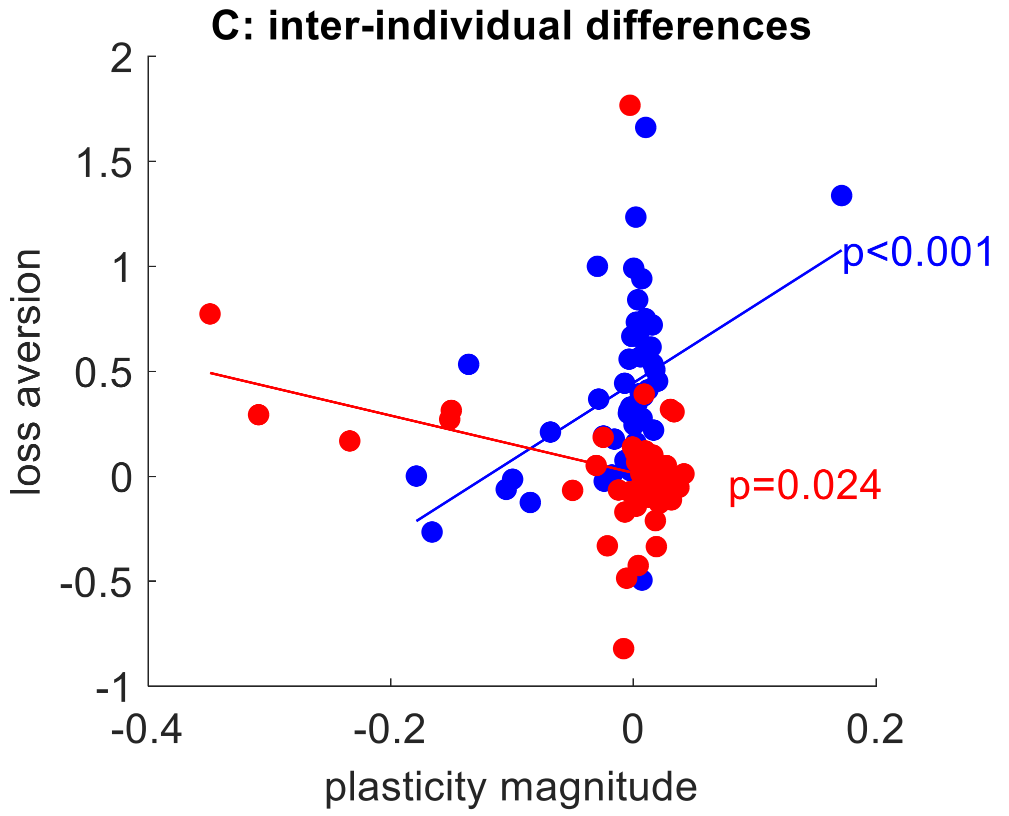
Integration units' response profiles



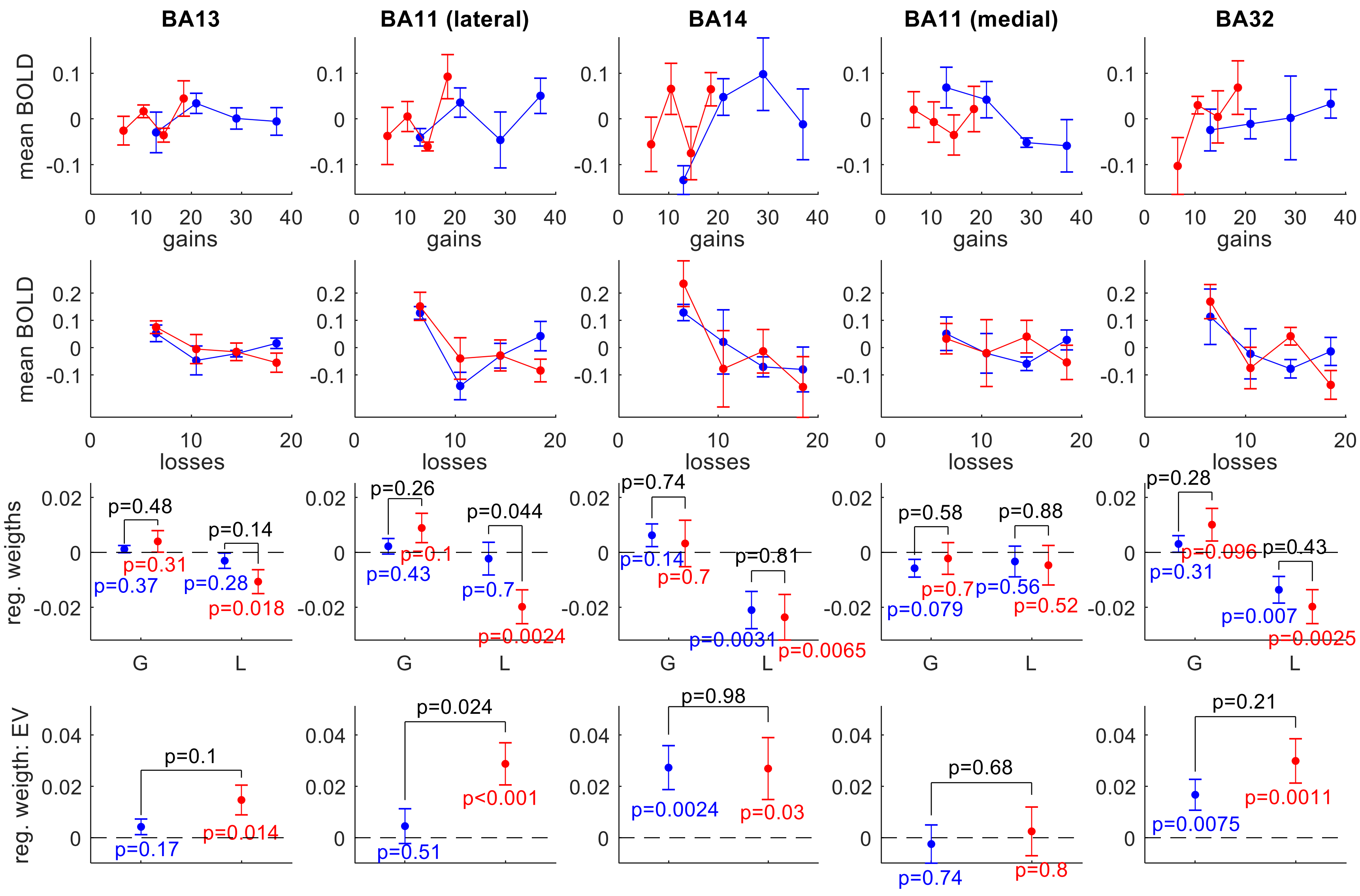


➢ ANN integration units exhibit known properties of OFC value-coding neurons (see Padoa-Schioppa & Assad, 2006)

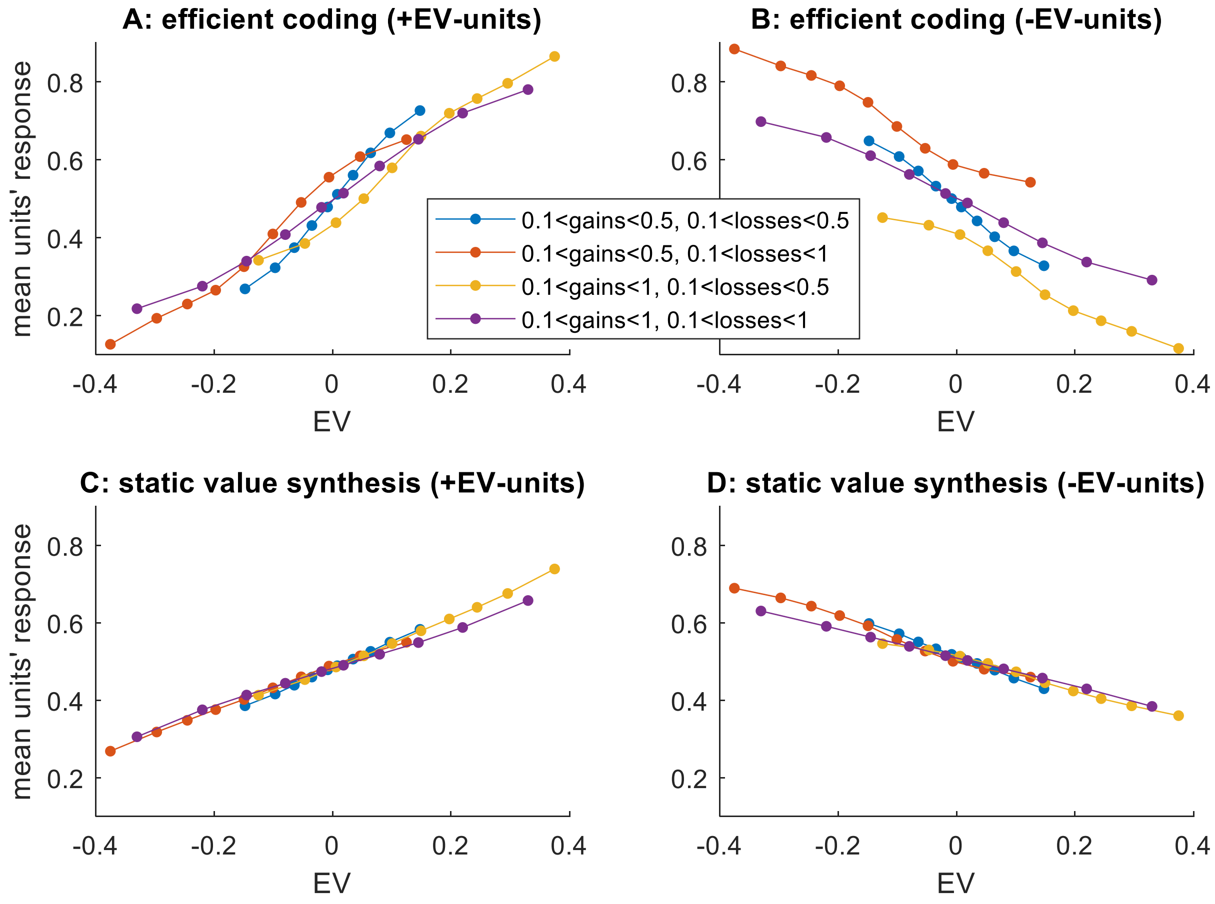
Loss aversion: inter-individual differences



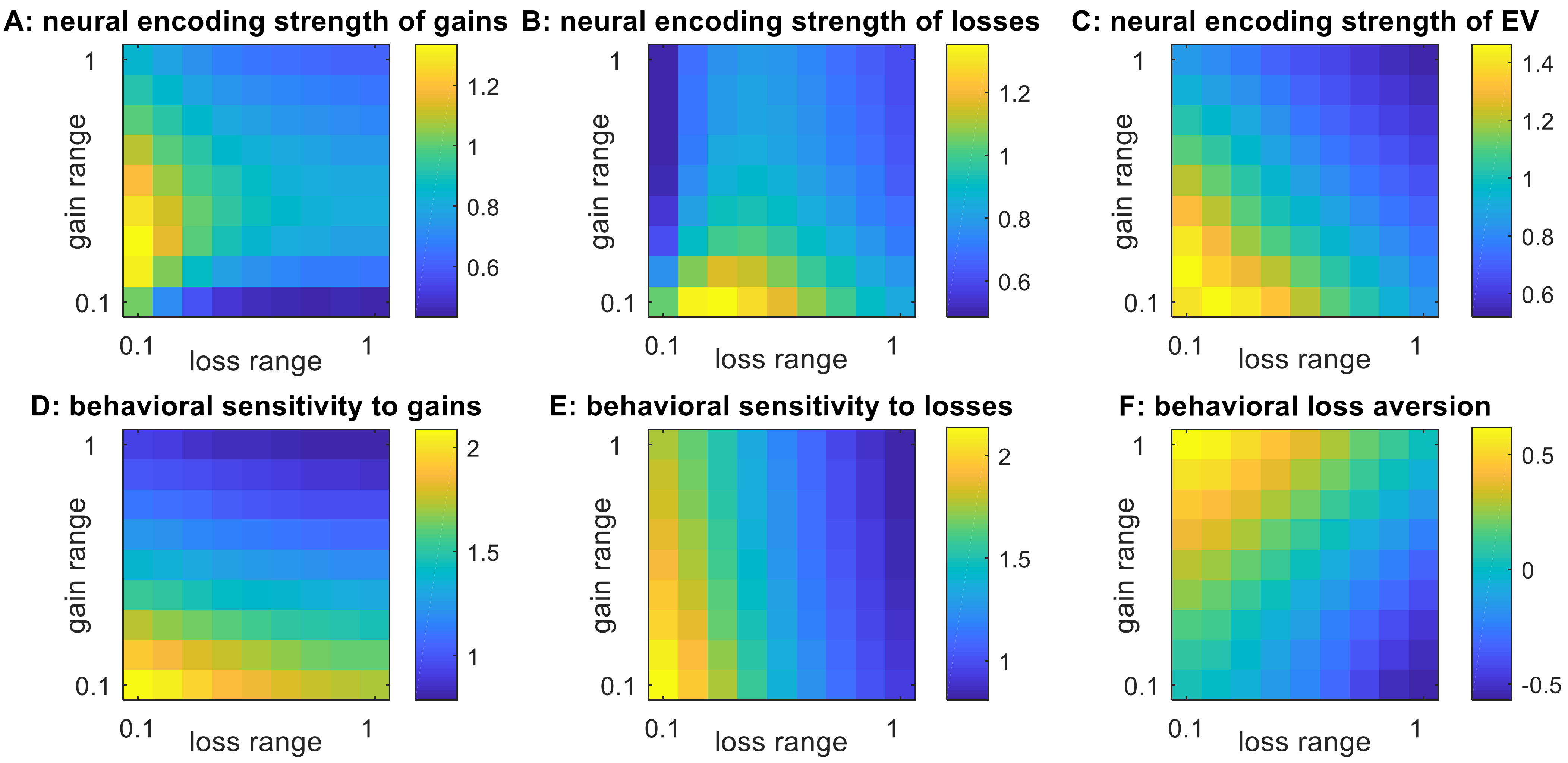
Univariate responses in OFC subregions



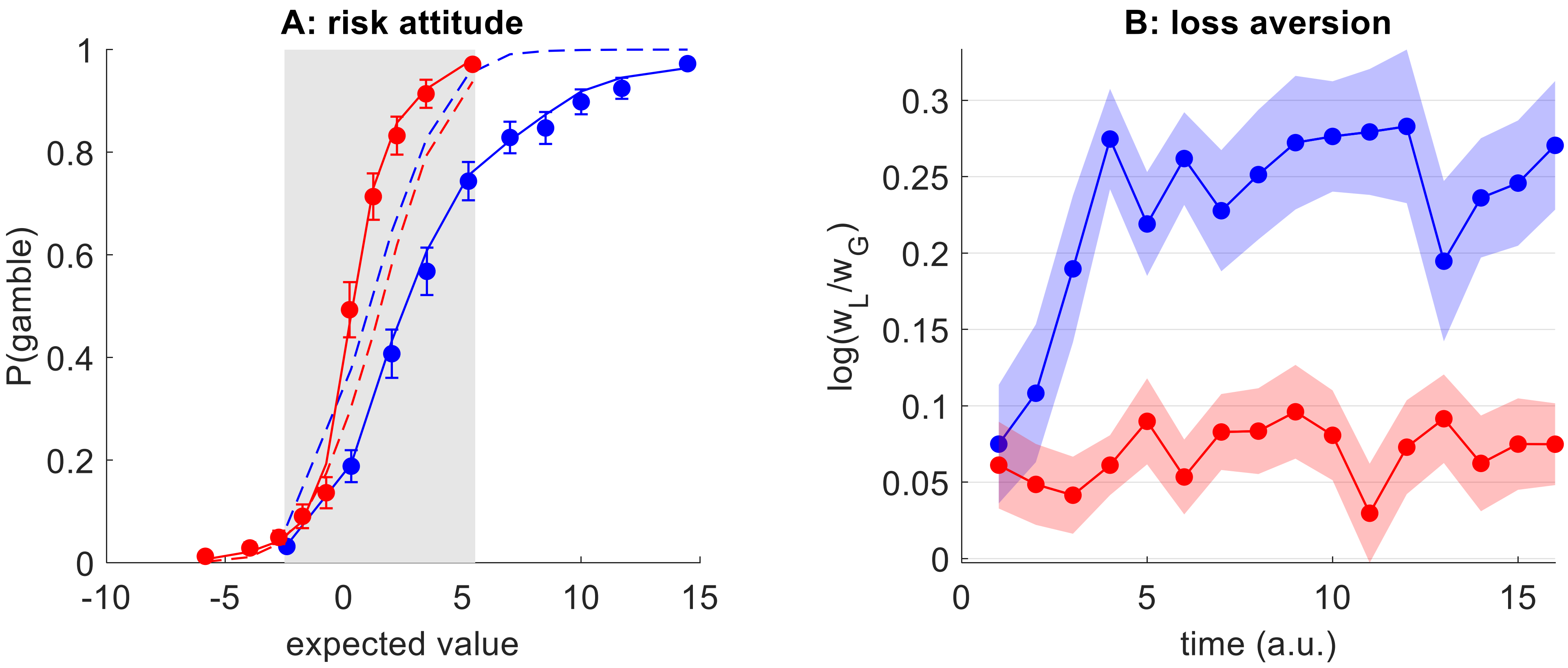
Efficient coding of value attributes (1)



Efficient coding of value attributes (2)



Efficient coding of value attributes (3)



Efficient coding of value attributes (4)