



Painstaking choices: Distinguishing neural representations of subjective value, conflict, magnitudes, and contextual biases in deterministic decision making with mixed outcomes

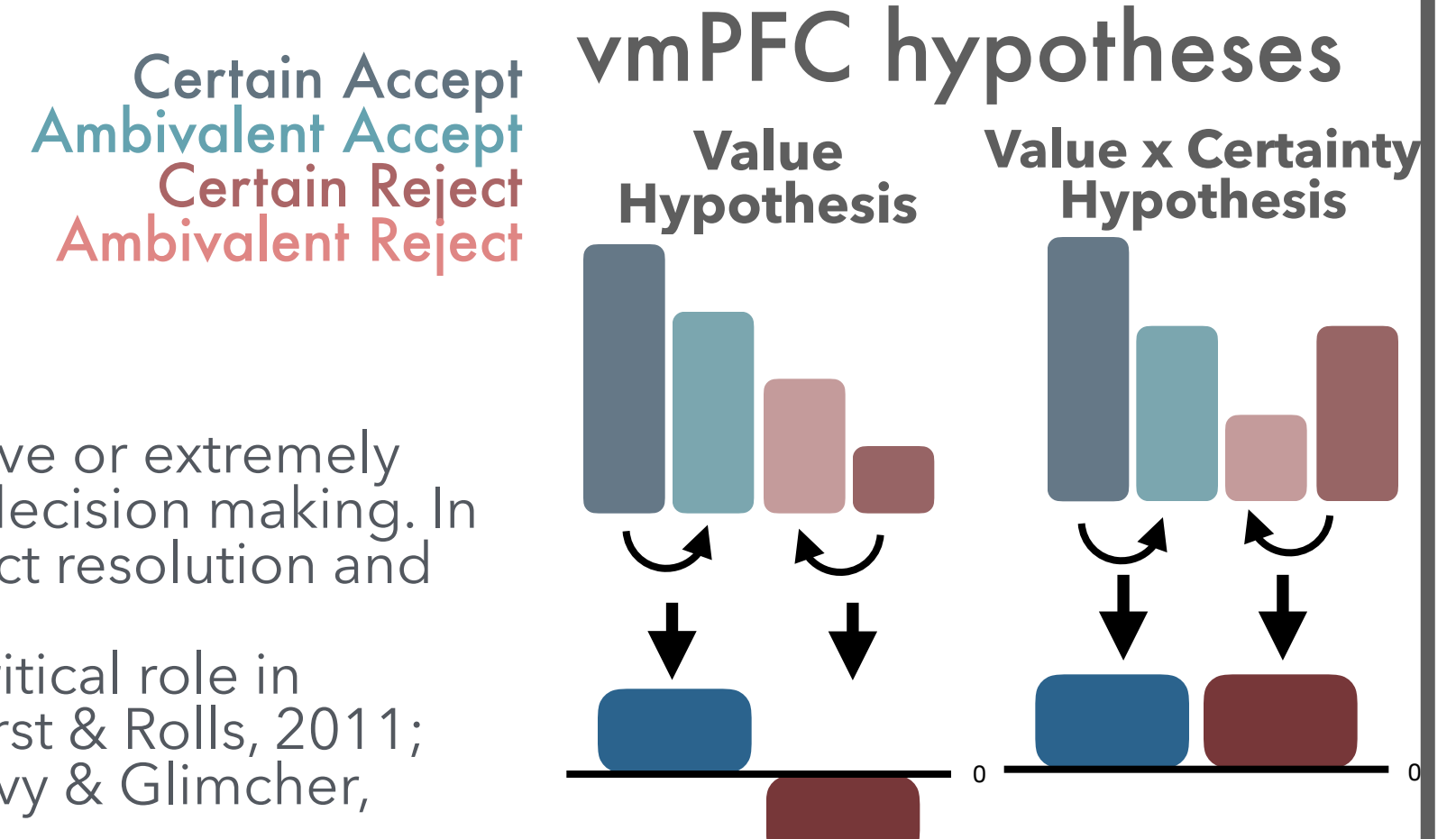
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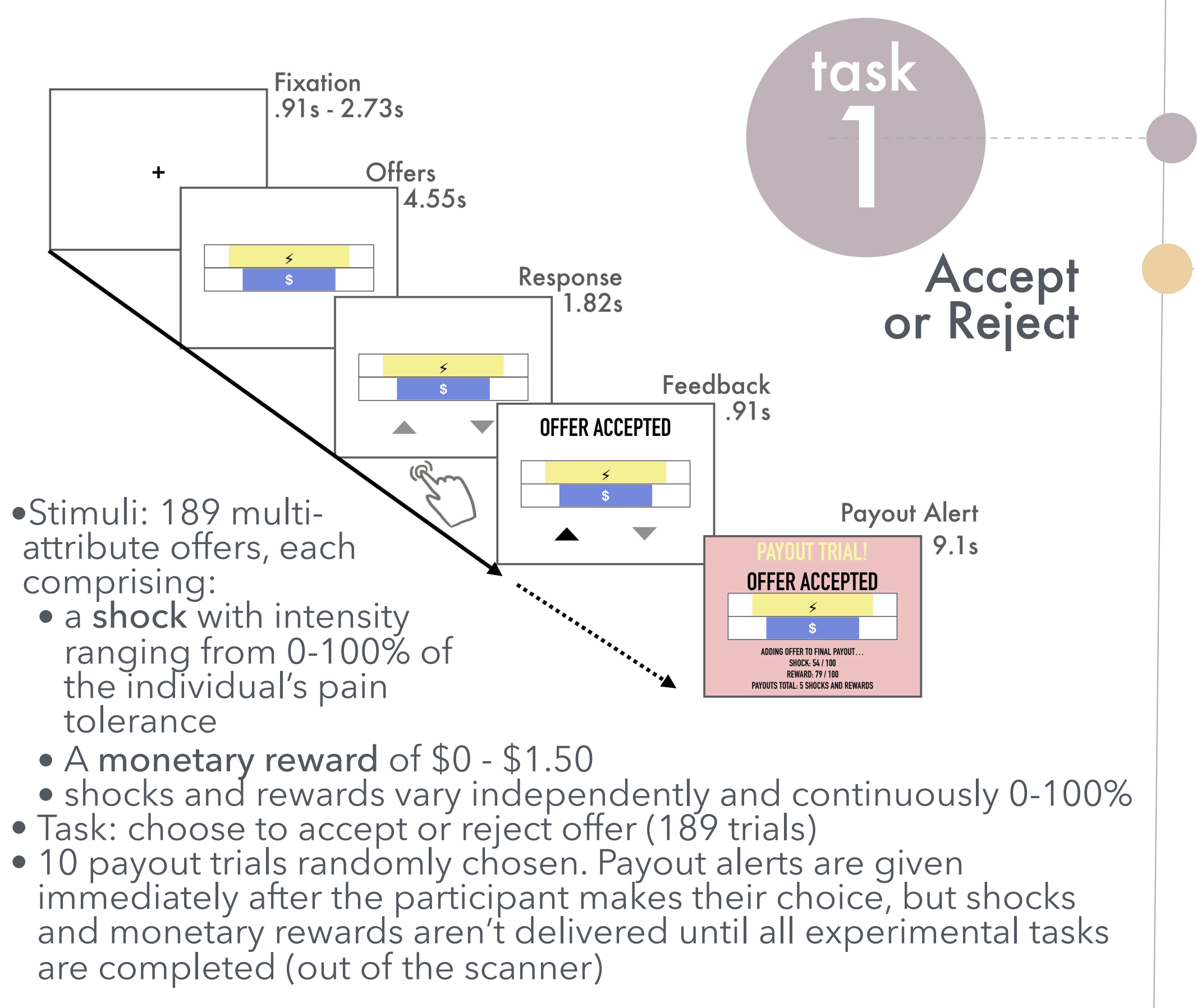
BACKGROUND

- Decision making entails evaluating contingent costs and benefits of competing choice alternatives
- The overall subjective value (SV) of a given option is determined by combining its positively- and negatively-valued attributes.
- When the SV of a given choice alternative is extremely positive or extremely negative choices are relatively easy and lead to certainty in decision making. In other cases, when SV is close to 0, choices entail more conflict resolution and lead to ambivalence and decision making.
- Much progress has been made in understanding vmPFC's critical role in representing SV in value-based decision-making (Grabenhorst & Rolls, 2011; Park, Kahnt, Rieskamp, Heekeren, 2011; Hunt et al., 2012; Levy & Glimcher, 2012).
- More recent work is beginning to show that this region may also represent choice certainty (De Martino et al., 2013; Lebreton et al., 2015). However, it is still unclear how mPFC integrates these signals when certainty and value are inversely related (i.e. when we are certain of decisions to reject negative SV choice alternatives)
- We found that vmPFC engages for high-certainty choices, even for decisions about low SV choice alternatives.



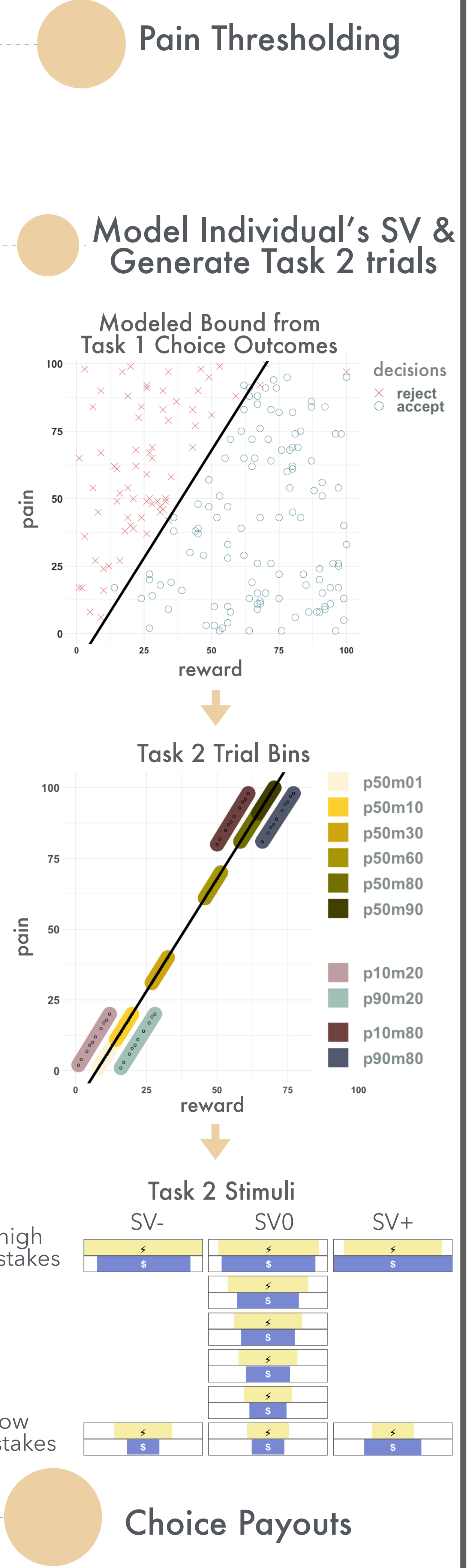
EXPERIMENTAL DESIGN

Session Overview



- Stimuli: 189 multi-attribute offers, each comprising:
 - a shock with intensity ranging from 0-100% of the individual's pain tolerance
 - A monetary reward of \$0 - \$1.50
 - shocks and rewards vary independently and continuously 0-100%
- Task: choose to accept or reject offer (189 trials)
- 10 payout trials randomly chosen. Payout alerts are given immediately after the participant makes their choice, but shocks and monetary rewards aren't delivered until all experimental tasks are completed (out of the scanner)

- Stimuli: 200 trials, each comprising 2 shock/money offers
- Trials are tailored to the individual's sense of SV, estimated from decision behavior from task 1
- The two offers on a given trial vary on 2 dimensions:
 - SV: SV+ (offers with $p(ACC)_{task1} > 0$)
 - SV0 (offers with $p(ACC)_{task1} = 0$)
 - SV- (offers with $p(ACC)_{task1} < 0$)
- Stakes: distance along decision boundary corresponding to overall magnitude of the offer
- In the stakes-only condition, both offers are equal in value but vary in stakes (0-100%)
- In the stakes*value condition, offers vary in both SV and stakes
- 10 payout trials randomly chosen. Payout alerts are given immediately after the decision but delivered after the task.



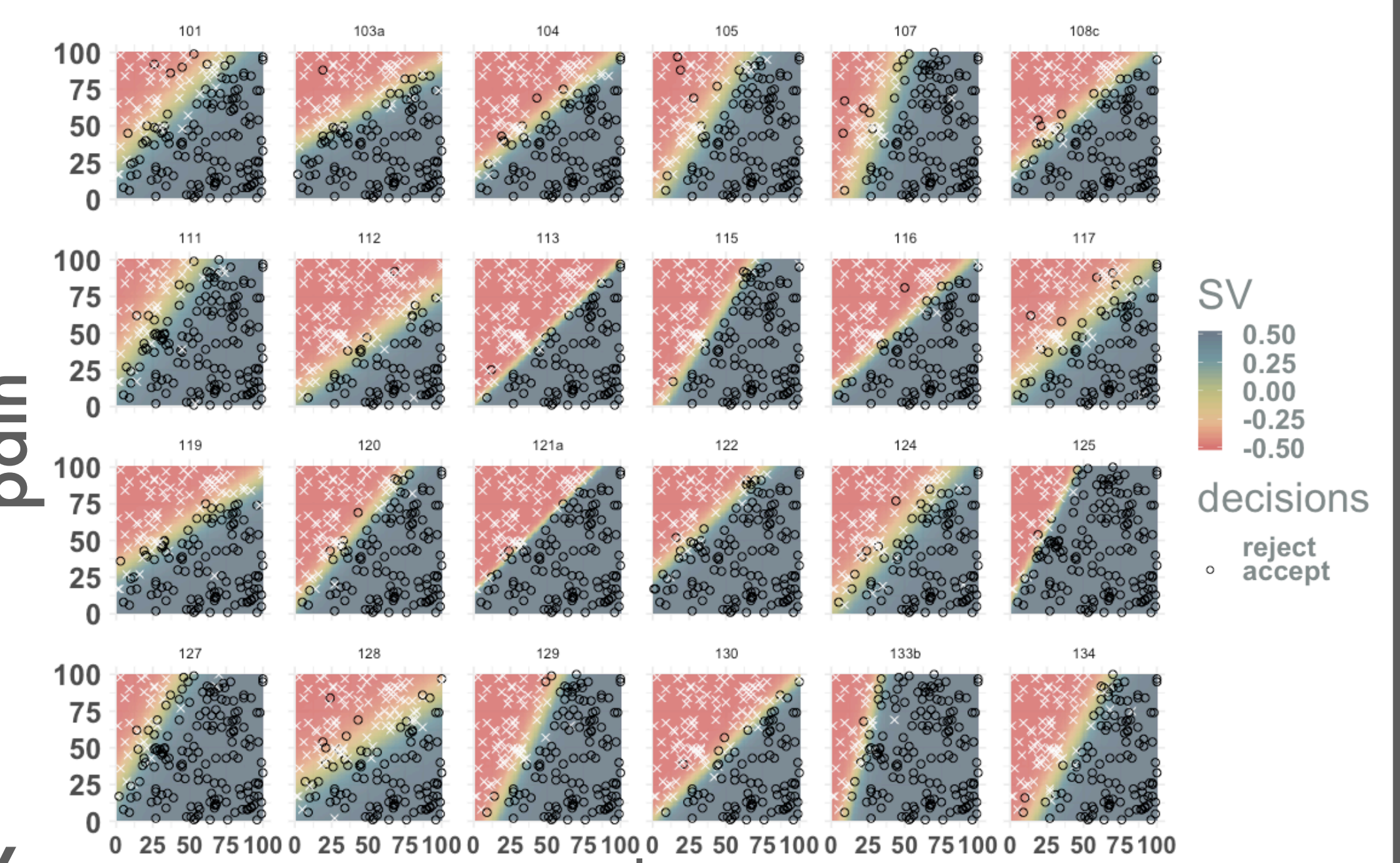
METHODS

- 24 healthy participants (18-25 years old, 15 women)
- Shock stimuli:**
 - PowerLab 26T, intensities depended on individual's measured pain threshold with maxima ranging 5mv-31mv
- Anatomical ROI selection:** Harvard-Oxford Atlas
 - anterior/posterior insula ROIs were formed by masking the Harvard-Oxford atlas with anterior and posterior insula divisions from the Brainnetome atlas
- Imaging:** Siemens 3T Magnetom Prisma Fit (64-channel phased-array head coil).
 - Structural: high-res. 0.94 mm isotropic T1 and T2*-weighted
 - Functional: multiband T2*-weighted echo planar gradient-echo imaging sequence (TR=910 ms, multiband factor 8, coronal slices, 2 mm thick; 2x2 mm in-plane resolution).

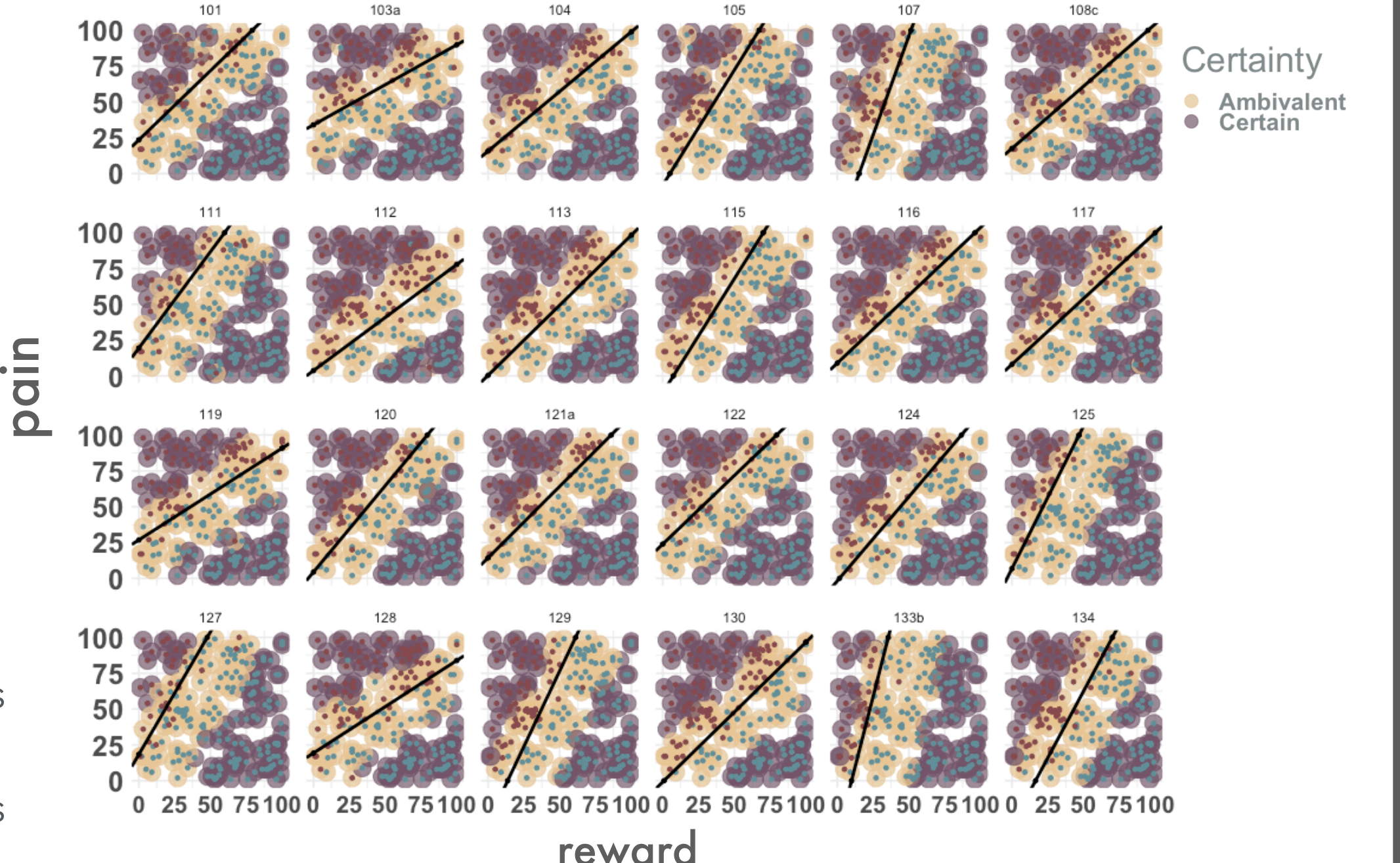
RESULTS: DECISION BEHAVIOR

Choice Outcomes

- Logistic regression fit individuals' choice outcomes and predicted SV of the reward/pain offer presented on each trial
- Substantial individual differences in SV for objectively equal cost/benefit offers
- Substantial individual difference in variability in choice decision behavior
 - Not explained by changing preferences within the task
 - For some, pain costs may not be costly enough.
 - Additive SV model and interactive SV model fit choice outcomes equally well



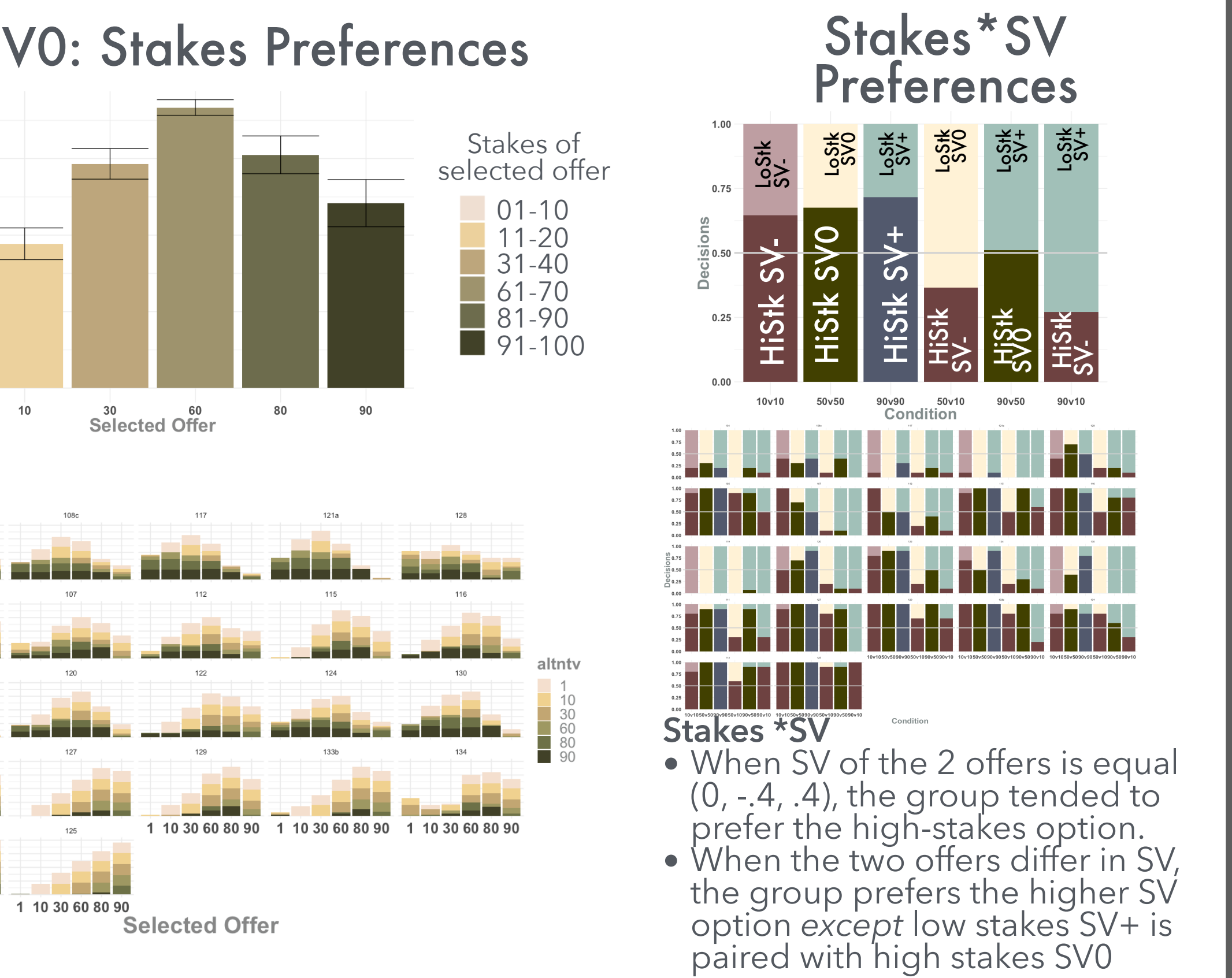
Modeled Certainty



- Estimated SV x observed choice outcome on each trial = choice certainty
- Accept Certain** = upper 50th percentile SV of all accepted offers (SV+, high certainty)
- Accept Ambivalent** = lower 50th percentile SV of all accepted offers (SV+, low certainty)
- Reject Certain** = lower 50th percentile SV of all rejected offers (SV-, high certainty)
- Reject Conflict** = upper 50th percentile of all rejected offers (SV-, low certainty)
- Individual differences in choice x certainty bin for identical stimuli

Task 2: Stakes Preferences

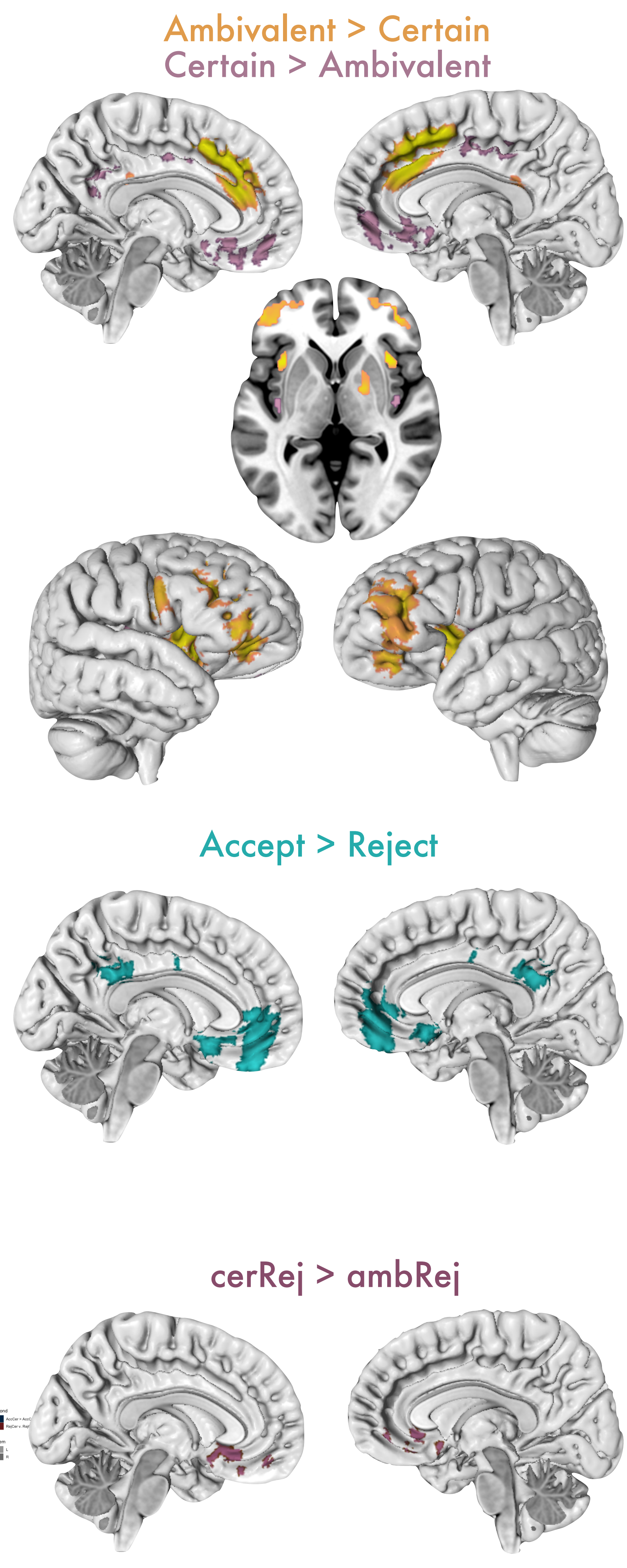
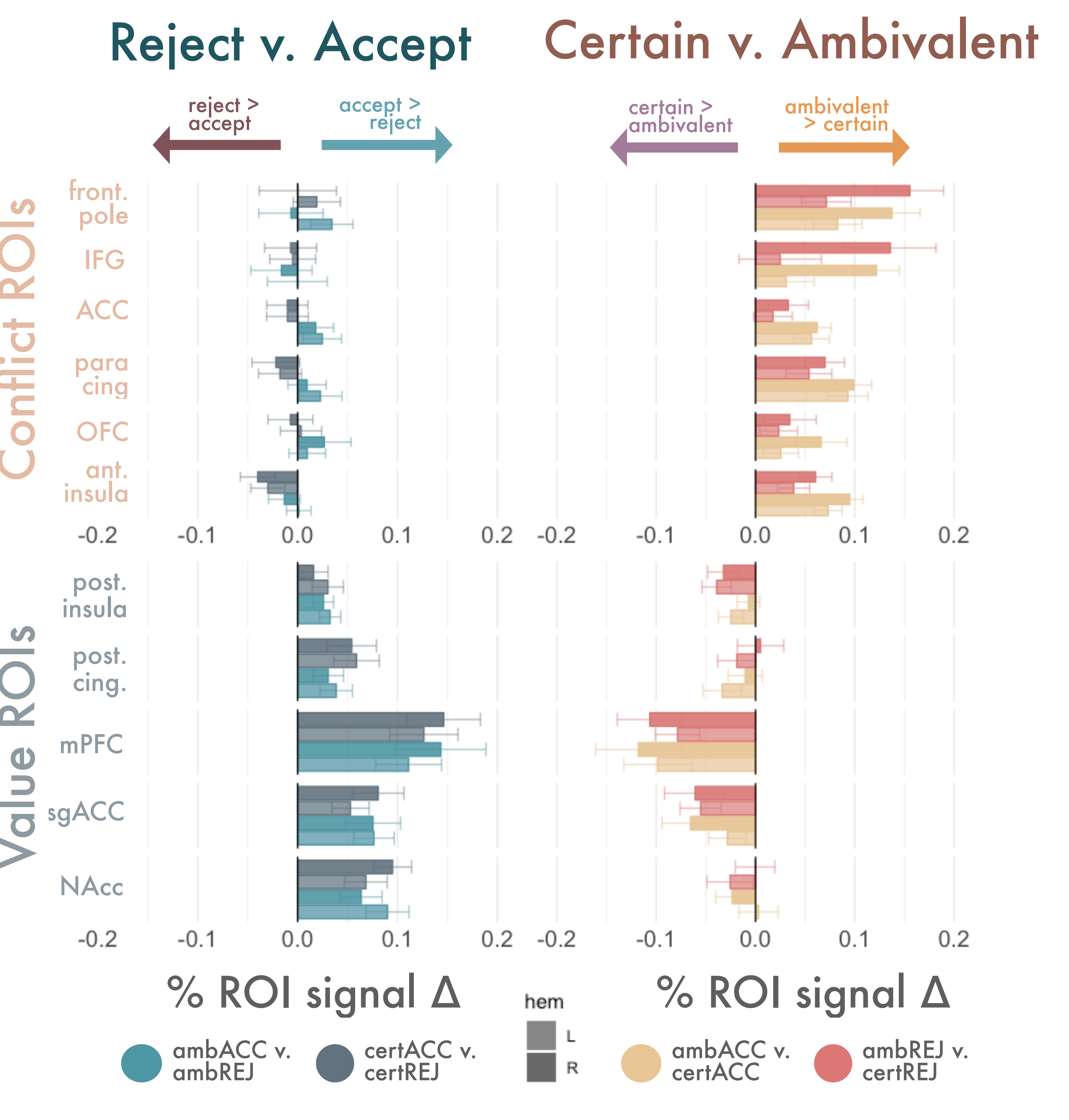
- Boundary Offers:**
 - on each trial both offers taken from decision boundary but vary in stakes (magnitude)
- Systematic preferences for values with same estimated SV from task 1
- Large individual differences in preference structure
- Most individuals demonstrate tuning-shaped preference structure with a peak-preference (most frequently selected magnitude), with similar magnitudes having similar choice frequencies.
- The group preferred 60% magnitude offers, however large individual differences in most preferred magnitude



RESULTS: fMRI

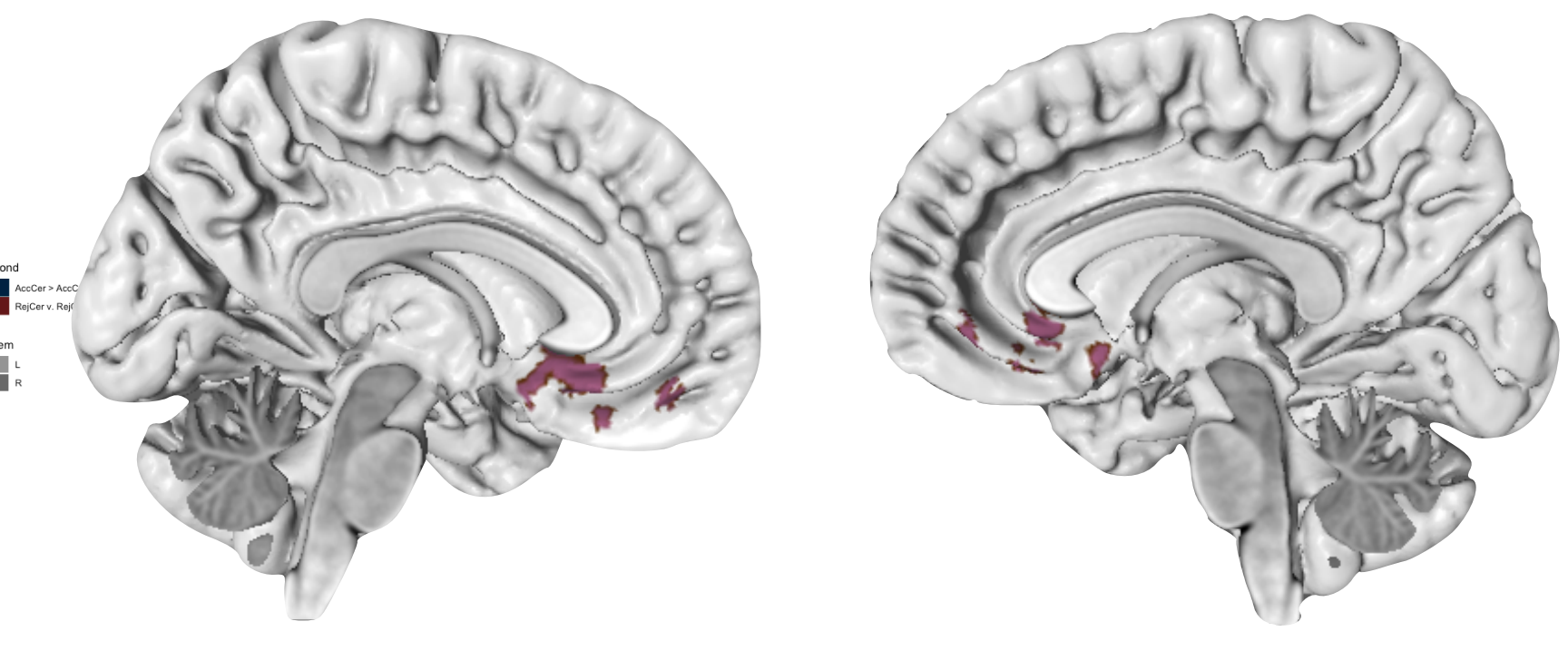
Value & Conflict ROIs

- Lateral PFC, ACC, OFC, and anterior insula engage when there is choice conflict (ambivalence). Activity in these regions does not correspond to choice outcome (except anterior insula).
- vmPFC, NAcc, posterior cingulate, and posterior insula engage when offers are accepted. NAcc and posterior cingulate signals are insensitive to choice conflict, whereas activity in vmPFC and posterior insula correlates with both choice outcome and choice certainty.



vmPFC ROI

- Small-volume FDR correction in anatomical vmPFC ROI (comprising sgACC and mPFC) reveals choice certainty significantly predicts activity.
- This is the case for certain accept > ambivalent accept, when high certainty also indicates high value. Notably, this is also the case for certain rejects > ambivalent rejects, when high certainty indicates low value.



CONCLUSIONS

- SV in deterministic choices with mixed outcomes of money and pain best predicted by additive model, however there are large individual differences in SV attributed to offers of identical objective value.
- Choice certainty can be estimated as distance from decision boundary with near-boundary offers = low certainty.
- Brain regions associated with conflict resolution and response competition are active during low-certainty choices, but their activity does not seem to correlate with the outcome of the choice.
- Brain regions associated with value, pain, and emotion are more active for accept choices (SV+) than reject choices (SV-)
- vmPFC response is *not* value-specific, but rather depends on both value and certainty, with stronger responses during high-certainty choices than low-certainty choices
- In the context of free choice between 2 available offers with equal SV_{task1}, participants are not equally likely to choose either offer, but rather form new systematic biases in choice behavior based on the relative magnitudes (stakes) of their options.