Differential effects of ambiguity and risk upon brain systems for decision making

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1 INTRODUCTION

Many decisions are made under limited information about potential outcomes. When two or more outcomes are possible, with knowable probabilities, decisions are made under *risk*. Conversely, decisions made with limited knowledge of outcome probabilities are made under *ambiguity*. The distinction between risk and ambiguity has been long debated within the economics literature (see Knight, 1921). In the current study, we investigated using functional magnetic resonance imaging (fMRI) whether risk and ambiguity evoke distinct patterns of neural activity during decision making.

Subjects participated in two sessions (one behavioral and one fMRI) of choices between pairs of monetary gambles. Each gamble showed one or more probabilistic rewards (displayed as a pie chart or "spinner"). Three gamble types were used: Ambiguous, Certain, and Risky. These gambles could be arranged in four possible pairings: Risky/Certain (RC), Risky/Risky (RR), Ambiguous/Certain (AC), or Ambiguous/Risky (AR).

Experimental Hypotheses

1. That performance of this decision task would evoke activation in anterior dorsolateral prefrontal cortex (dlPFC) and in posterior parietal cortex (pPAR), as reported in numerous other decision-making studies.
2. That activation in dlPFC and PPC would be influenced by the risk or ambiguity associated with those decisions.
3. That ambiguity/risk effects within dlPFC would be found in posterior regions associated with contextual analysis, not in anterior regions associated with behavioral selection.

2 METHODS

Subjects

- Participants were 13 young adults (mean: 22y).

Experimental Task

- Subjects made choices between pairs of monetary gambles (~200/session).
- Each gamble was depicted as a roulette wheel (e.g., pie chart).
- There were three types of gambles:
  - Certain: 100% chance of winning a shown reward
  - Risky: 25%, 50%, or 75% chance of winning large / small rewards
  - Ambiguous: Chance of winning unknown until gamble selected
- After subjects selected one gamble, any ambiguity was revealed and both gambles were resolved via revolving balls on their perimeters.
- At the end of the experiment, subjects were paid off on a proportion of their gambles, randomly selected from all choices.

Behavioral Measures

- For all subjects, we estimated risk and ambiguity preference parameters using *power* and *α-maximin* utility functions, respectively.
- We estimated impulsiveness for 10/13 subjects using the Barratt Impulsiveness Scale (BIS).

Data Acquisition using fMRI at 1.5T

- Images were acquired sensitive to BOLD contrast (i.e., T_2*-weighted).
- We used a spiral-in pulse sequence (TR: 1500ms; TE: 35ms).
- We acquired 34 axial slices (3.75*3.75*3.8mm voxels).
- Preprocessing steps (SPM99) included motion correction, slice timing correction, normalization, and spatial smoothing (8mm).

Data Analysis

- We conducted multiple regression analyses using SPM2.
- Regressors were created for each of the three phases of the trials, and were analyzed by trial type, response, and delivered reward.
- Head motion parameters were included in the design matrix.
- Planned contrasts compared different design phases and gamble types.
- Significance was assessed using second-order random effects analyses.
- Significance indicated by colormap with thresholds (p<.001 to p<.00001).
- Time courses were calculated from the functional regions of interest (ROIs) derived from the random-effects analyses.
- Brain activation was correlated with several behavioral measures: Risk preference, Ambiguity Preference, and BIS scores.

Acknowledgments

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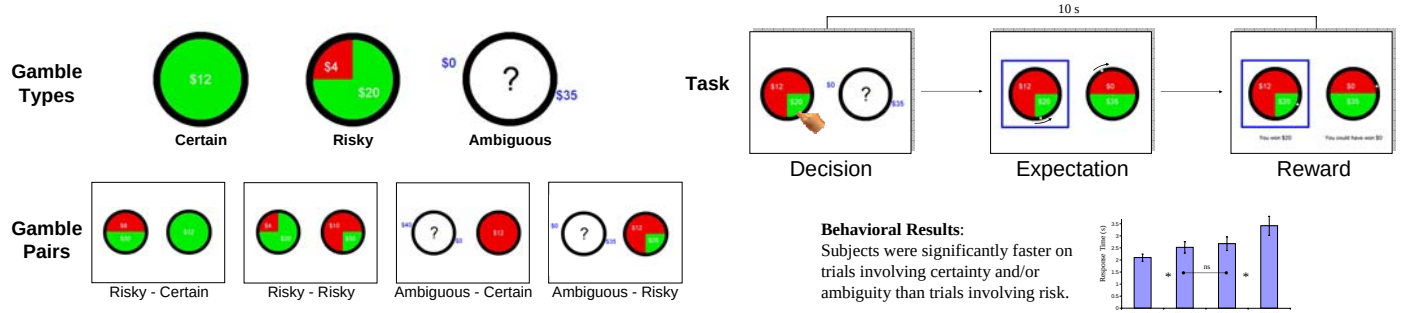
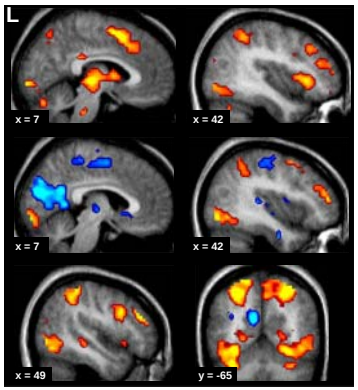
3 EXPERIMENTAL PARADIGM

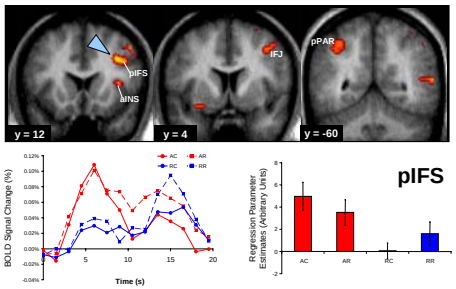


Behavioral Results: Subjects were significantly faster on trials involving certainty and/or ambiguity than trials involving risk.

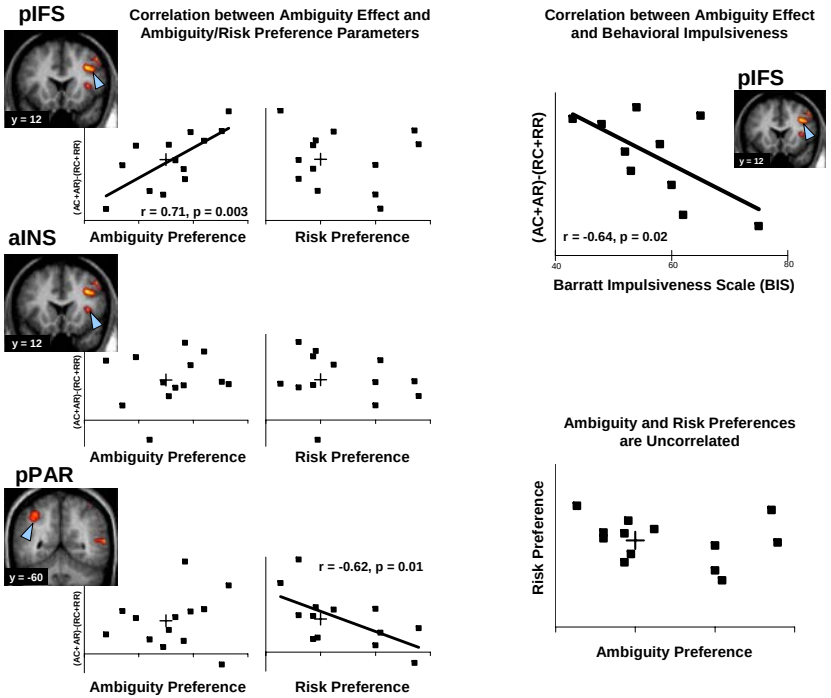
4 TRIAL PHASES



5 AMBIGUITY EFFECTS



6 BEHAVIOR/BRAIN CORRELATIONS



7 CONCLUSIONS

1. **Decisions between monetary gambles evoke activation in prefrontal and parietal cortices, along with motor and visual regions.**
2. **Ambiguity increased activation in the posterior inferior frontal sulcus (pIFS), anterior insula (aINS), and posterior parietal cortex (pPAR).**
3. **The ambiguity effect in pIFS tracked both ambiguity preference (positively) and behavioral impulsiveness (negatively).**
4. **The ambiguity effect in pPAR tracked risk preference (negatively).**
5. **The results suggest that the pIFS implements contextual analysis while inhibiting impulsive responses.**