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Pre-existing brain states predict risky choices

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ABSTRACT

Rational decision-making models assume that people resolve an economic problem based on its properties and the underlying utility. Here we challenge this view by examining whether pre-stimulus endogenous neuronal fluctuations can bias economic decisions. We recorded subjects' pre-stimulus neural activation patterns with fMRI before presentation and choice between pairs of certain outcomes and risky gambles. Our results indicate that activities in the left nucleus accumbens and medial frontal gyrus can bias subsequent risky decision making, showing that neuronal activities in regions associated with uncertainty and reward processing are involved in biasing subsequent choice selection. This finding challenges theories which propose that choices merely reveal stable underlying distributions of hedonic utility. Endogenous brain states of this sort might originate from a systematic cause or a stochastic type of neural noise, which can be construed as contextual factors that shape people's decision making.

Introduction

How does brain activity associate with subjective preferences and value-based decisions? Choice behavior is thought to reflect decision makers' underlying utility (Stigler, 1950; Varian, 1992) after they have integrated important and relevant factors. However, recent findings show that brain states occurring *before* the appearance of decision-related stimuli can bias or predict perceptual and motor inclination (Bode et al., 2012; Hesselmann et al., 2008). These findings suggest that pre-existing brain states in themselves can generate perceptual or motor biases, and might challenge the view that people resolve economic problems based solely on their properties and the underlying utility.

Pre-existing brain states have been shown to predict upcoming percept, including those made during binocular rivalry while resolving perceptual ambiguity to form a conscious percept (Hsieh et al., 2012), perceptual performance (Boly et al., 2007; Hesselmann et al., 2010; van Dijk et al., 2008; Wyart and Tallon-Baudry, 2009), and aesthetic judgments (Colas and Hsieh, 2014). Self-initiated free motor decisions can also be biased by neural activity before one becomes consciously aware of intending to act (Haggard, 2005; Libet, 1985; Soon et al., 2008). However, while these can be described as "decisions," they are generally low-level processes involving only arbitrary perceptual or motor tasks without a utility component (but see Soon et al., 2013). The extent to which pre-existing neural processes can bias high-level abstract decisions, involving the meaningful integration of decision-relevant information and one's reaction to that information, remains unclear. Here, we investigated whether pre-existing brain states can affect value-based decisions and their means of exerting an influence if present. We hypothesized that endogenous biases might also exist for high-level value-based decisions and manifest themselves neurally before the information relevant to a decision is presented.

To assess whether prior brain activity can bias subsequent risky decision making, 14 subjects performed a simple economic decision task of choosing between two options: a risky gamble (e.g., 50/50 chance of getting $0 or $13) versus a certain outcome (e.g., getting $5 for sure) (Fig. 1). Individual risk-preferences were first assessed outside the scanner by determining each subject's indifference point — the ratio of the gamble option's expected value to the certain outcome's fixed value at which a subject chose either option with equal probability. Each subject then performed a similar task while undergoing fMRI, with the option pairs of every trial close to the subject's indifference point. For the scanner gamble task (Fig. 1), we used a slow event-related design with 20 s between gamble trials to avoid contamination of the pre-stimulus signal by responses to previous trials. Furthermore, to keep subjects from ruminating on upcoming trials we maintained cognitive engagement with a cognitively demanding distractor task. During the 16 s before each gamble trial, the subject counted the number of times a red square appeared by covertly reciting letters of the alphabet in sequence. We then used searchlight based multi-voxel

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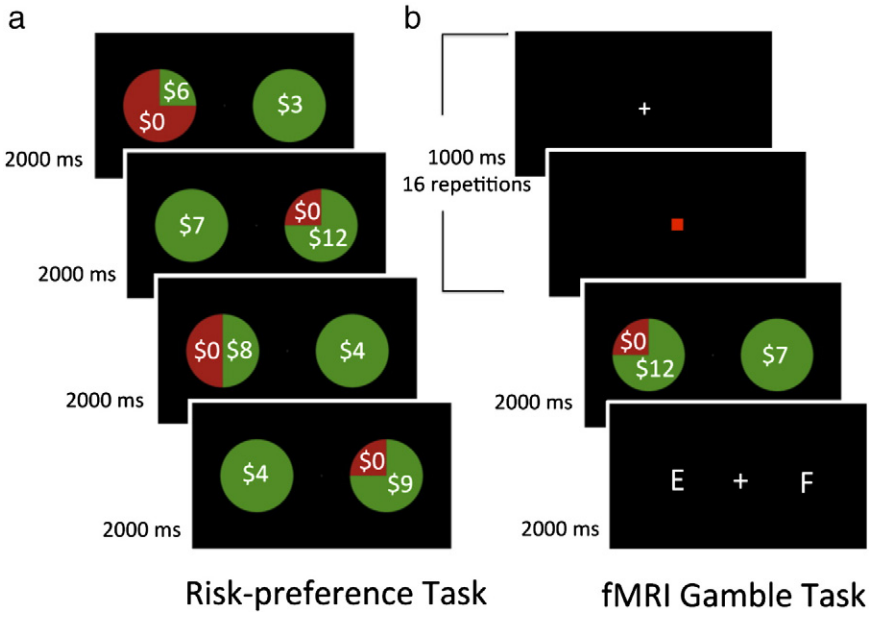

Fig. 1. Stimuli and Procedures. (a) Behavioral risk-preference task: In each trial the choice stimuli were presented for 2000 ms. Each stimulus was composed of a certain option and a risky gamble option, randomly assigned to the two hemifields. Subjects selected the preferred option by pressing one of two buttons, using the corresponding hand. (b) fMRI gamble task: Each trial consisted of three parts. A distractor task was performed before each gamble task to prevent premeditation on the upcoming decision. Subjects covertly counted the number of times a red square appeared by incrementally reciting letters of the alphabet. Next, the gamble stimulus appeared, showing a certain outcome and a risky gamble. Again, subjects indicated their preference by pressing two corresponding buttons within the 2000 ms that the stimulus was shown. The response for the counting task was only given after the gambling task, when two options were provided: the correct letter corresponding to the number of times the red square appeared (e.g., letter E if there were 5 red squares that appeared), and a wrong letter immediately before or after (e.g., letter G or F).

pattern analysis (MVPA) of blood-oxygen-level-dependent (BOLD) signals to investigate the extent to which neural signals existing before stimulus onset could predict whether they would make a risky decision.

Materials and methods

Participants

14 adult volunteers (10 males) between 20 and 34 years old (mean = 26.20) participated in the study. An advertisement was posted on a school-wide bulletin to recruit subjects. All subjects were healthy, right-handed, and had normal or corrected-to-normal visual acuity. All subjects provided informed written consent within a protocol approved by the Duke-NUS Graduate Medical School Committee on the Use of Humans as Experimental Subjects and were compensated 50 Singapore Dollars for their participation.

Behavioral paradigm

All subjects performed a behavioral risk-preference calibration task outside the scanner, and a gambling task (with a secondary distractor task) within the scanner (Fig. 1). We first determined each subject's risk preference with a behavioral task outside the scanner. Each trial involved selecting between a certain option and risky gamble option, randomly presented in the left and right visual hemifields to dissociate brain activity related to risk decision from those related to motor response (Stanton et al., 2011). A certain outcome is a definite reward, while a risky gamble contained a known probability and its associated reward, (e.g., $5 for sure vs. 50/50 chance of winning $0 or $13). The gamble stimulus was presented for 2000 ms and subjects pressed one of two corresponding keys to indicate their choice between the risky gamble and the certain outcome. Subjects performed 120 trials that consisted of a full combination of three parameters: 1) reward value of a certain outcome, 2) probability of winning the gamble option, and 3) the ratio between the expected values of gambles and certain outcomes. The full combination of trials was composed of the following sets: the value of the certain outcome was [$3, $4, $5, $6, $7]; the probability of winning the gamble was [0.25, 0.50, 0.75]; the set of examined ratios of the expected value of the gamble to the value of the certain option was [0.5, 1.0, 1.3, 1.6, 1.9, 2.2, 2.5, 3.0]. For each subject, their indifference point (ratio of the expected value of the gamble to the value of the certain option at which they have equal probability of choosing the gamble versus certain outcome) was determined and used to tailor the fMRI stimuli to their specific risk preferences.

fMRI scanning protocol

Each participant was scanned for approximately 2 h. Scanning was performed at Duke-NUS Graduate Medical School, Singapore, with the Cognitive Neuroscience Laboratory's 3T Siemens Trio scanner (Siemens, Erlangen, Germany). Functional MRI runs were acquired using a gradient echo-planar imaging sequence (TR = 2 s, TE 30 ms, FA 75°, FOV 192 × 192 mm, 64 × 64 matrix, 3 × 3 mm in-plane resolution). Thirty-six slices were collected with a 12-channel head coil (3 mm thick with a 0.3 mm inter-slice gap). Slices were oriented roughly parallel to the AC-PC and covered the whole brain. An anatomical image was acquired using an MPRAGE sequence (TR = 2.3 s, TI 900 ms, flip angle 9°, BW 240 Hz/pixel, FOV 256 × 240 mm, 256 × 256 matrix, 192 slices, 1 × 1 × 1 mm).

fMRI gamble task

The quantified risk preference of each subject was used to generate their stimuli for the gamble task in the scanner, such that the profile of presented trials was around each subject's indifference point. We used a slow event-related design with 20 s between gamble trials (stimulus onset asynchrony) to avoid contamination of the pre-stimulus signal by responses to previous trials. Subjects chose between a certain outcome and a risky gamble by pressing one of two buttons using the left or right index finger (two-alternative forced choice) within 2000 ms.