The Neural Basis of Bias in Decision Making

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Introduction

The speed and accuracy of perceptual decisions are sensitive to expectations about their outcome[1-4]; when choosing between two alternatives, our choice is biased toward the alternative that is most profitable (*reward amplitude*) and most likely to be correct (*prior probability*). Little is known about how and where in the brain these bias effects alter choice behavior.

The drift-diffusion model (DDM) can be used to investigate the effects of bias on the dynamics of the decision processes. By fitting this model to both reaction time (RT) and accuracy data, we are able to measure the effects of bias in either the *starting point* or the rate of evidence accumulation (*drift rate*) to a decision bound (see Fig. 1).

In the present study, we used model-based functional MRI to investigate:

1. **Do different types of prior knowledge bias choice behavior similarly?**
2. **Is there a common neural substrate underlying these effects?**

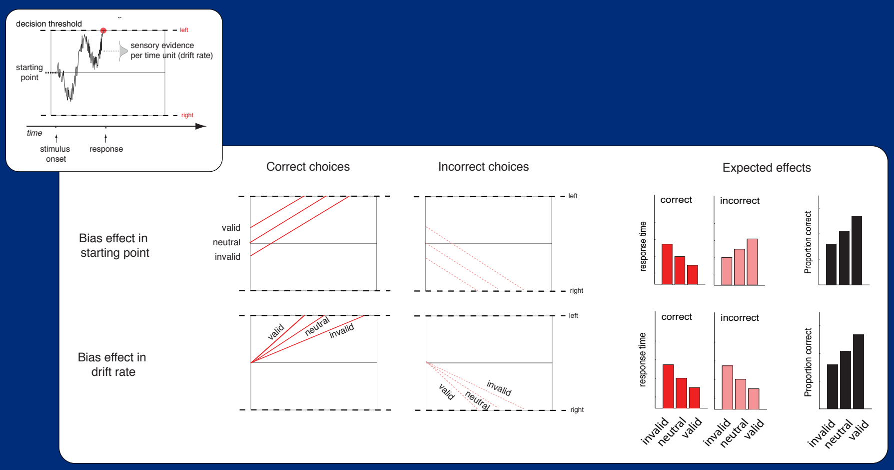

Fig. 1. Effects of bias in choice behavior, explained by the drift-diffusion model. When prior information is *valid* for the choice at hand, subjects will have faster and more correct choices, whereas *invalid* information results in slower and less correct choices, compared to choices where no information is provided (*neutral*). These effects can be explained by chances in the starting point or the drift rate of the accumulation process. Note that effects on each of these parameters will result in different RTs for incorrect choices.

Methods

Paradigm. We used 2 versions of the random dot motion (RDM) paradigm, where we manipulated choice behavior by providing cued prior knowledge about:

1. the likelihood of the direction of the motion stimulus (*prior probability*)
2. the amount of reward associated with the direction (*reward amplitude*)

(see Fig. 2)

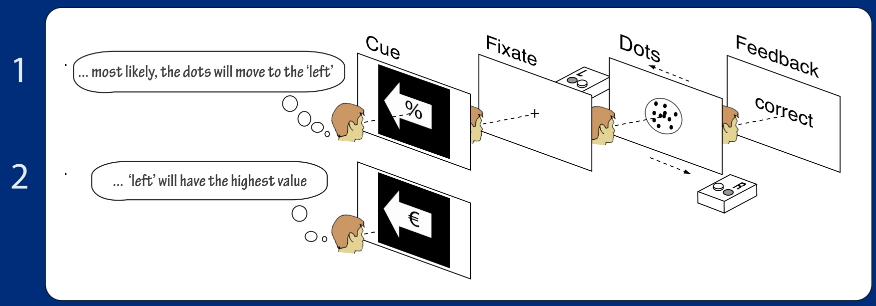

Fig. 2. Two versions of the random-dots motion task, where choice bias was manipulated by providing information about 1) the likelihood of the direction of the stimulus (prior probability) or 2) the value associated with the direction of the stimulus (reward amplitude).

Inside scanner. Five sessions of ~12 minutes each in a 3T MRI scanner: one session to normalize performance on the motion stimulus across subjects and two sessions for each condition (counterbalanced and interleaved).
Outside scanner. Nine sessions of ~6 minutes, again with one session to normalize performance on the motion stimulus across subjects, and 4 sessions for each condition (counterbalanced and interleaved).

Analyses. We fitted the DDM to the individual data to determine the effects of prior knowledge on the starting point or drift rate (Fig. 4A). We then added the bias terms for these parameters as covariates to the GLM in the fMRI analyses to investigate brain regions associated with these bias effects.

Behavioral Results

Descriptives. Overall, subjects make more and faster choices for valid, but less and slower choices for invalid prior information. The linear trend in most of the group averages of median RTs for incorrect choices suggest that adjustments of the starting point underly these effects (Fig 3 & Fig 1).

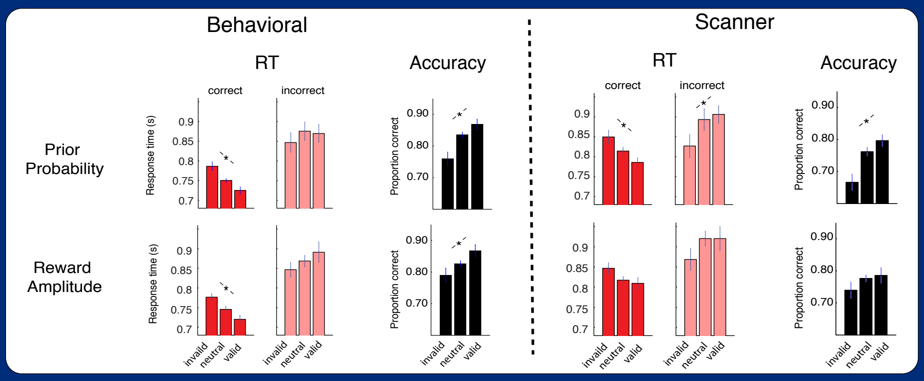

Fig. 3. Effects of bias in RTs and accuracy for choices with valid, neutral or invalid prior information. Asterisks indicate a significant linear trend across trial-types.

Effects of Bias in ddm parameters. Fitting the DDM to the data shows that choice bias is primarily reflected in changing the starting point of the decision process (Fig. 4B).

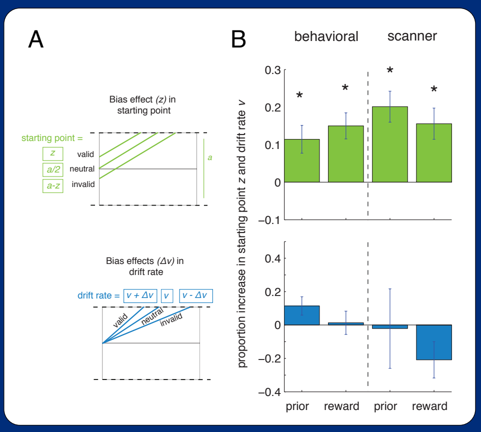

Fig. 4. Effects of bias in ddm parameters.
A) Bias is measured in starting point *z*, which is assumed to be half-way threshold when information is neutral (*a*/2), closer to the correct bound when valid, and further from the correct bound when invalid (*a-z*). Similarly a bias-term (Δv) is used to measure effects of bias in drift rate. Drift rate will increase for valid (v + Δv) but decrease for invalid (v - Δv) prior information.
B) Average (proportional) bias effects for starting point and drift rate across prior and reward conditions, in and outside the scanner environment. Results show significant effects for chances in starting point, but not for chances in drift rate.

Imaging Results

Effects of starting point shifts in BOLD response. To identify regions associated with bias in perceptual decision making, we added for each condition the individual proportional increase in starting point as a covariate to the fMRI GLM design (see Fig. 5).

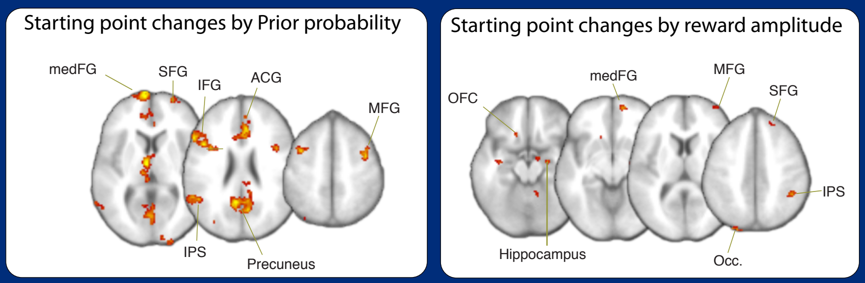

Fig. 5. BOLD responses for prior probability (cluster corrected, z > 2.6, p < 0.05) and reward amplitude (uncorrected, z > 2.6 with cluster extent > 20 voxels)

A common bias network. Regions that were active in both conditions were identified by a conjunction analyses over the two different conditions (see Fig. 6).

Conclusion. Overall, subjects implement bias into the decision process by adjusting starting point values. Brain areas involved in probability and reward processing are in accordance with previous studies[2,3], and a conjunction analysis suggest that there is a common network for processing prior knowledge in decision making.

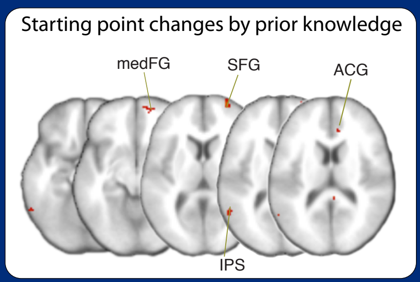

Fig. 6. BOLD responses for prior knowledge (conjunction, uncorrected, z > 2.3, with cluster extent > 5 voxels)

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