The role of gaze for value encoding and recollection in orbitofrontal cortex

Demetrio Ferro (demetrio.ferro@upf.edu)
Center for Brain and Cognition (CBC), Universitat Pompeu Fabra (UPF)
C. Ramon Trias Fargas, 25-27, Barcelona, 08005 Spain

Anna Rifé Mata (annarife99@gmail.com)
Center for Brain and Cognition (CBC), Universitat Pompeu Fabra (UPF)
C. Ramon Trias Fargas, 25-27, Barcelona, 08005 Spain

Tyler Cash-Padgett (tcashpadgett@gmail.com)
Department of Neuroscience, University of Minnesota (UMN)
Minneapolis, Minnesota MN55455 USA

Maya Zhe-Wang (mwang@mail.bcs.rochester.edu)
Department of Neuroscience, University of Minnesota (UMN)
Minneapolis, Minnesota MN55455 USA

Benjamin Hayden (hayde138@umn.edu)
Department of Neuroscience, University of Minnesota (UMN)
Minneapolis, Minnesota MN55455 USA

Rubén Moreno Bote (ruben.moreno@upf.edu)
Center for Brain and Cognition (CBC), Universitat Pompeu Fabra (UPF)
C. Ramon Trias Fargas, 25-27, Barcelona, 08005 Spain

Abstract:

In value-based decision-making tasks, we tend to perform overt visual search for visually displayed offers during the sampling of options, followed by alternation between them, until a choice is committed. For this kind of tasks, neurons in orbitofrontal cortex (OFC) have been reported to encode offer value, bringing up questions about the dynamics of value-based computation. However, the neural basis of how gaze aids at value-based decisions is unknown. We recorded simultaneous gaze and OFC activity of two macaque monkeys performing a two-alternative reward gambling task. The offers were sequentially presented at opposite sides of the screen, each followed by a blank screen delay time. Interestingly, we found that the looking time of either offer was predictive of the final choice during the whole task time, including delay times. We found that cells encode expected value (EV) of the offers, predominantly during their respective presentation and at subsequent delay time. We found that fixation gates the encoding of ipsilateral EV, even when the offer is not visible. In addition, looking back to the first offer side during second delay re-activated the encoding of first offer EV, even if the subjects looked to opposite side during second offer presentation.

Keywords: value-based decision making; orbitofrontal cortex; encoding of value.

Introduction

The behavioral selection of targets among multiple options typically entails visual search during sampling and comparison before commitment is reached (Russo & Rosen, 1975). In value-based decisions, longer looking time to offers have been linked to a higher probability of being chosen (Chandon et al., 2009). Besides supporting a sensory attentional focus, the sequential nature of offers evaluation roots into the computational benefits of narrowing the evaluation to fewer options at a time (Hayden & Moreno-Bote, 2018; Mastrogiuseppe & Moreno-Bote, 2022).

For value-based decisions, the activity of cells in orbitofrontal cortex (OFC) and ventromedial prefrontal cortex (vmPFC) encode value (Murray et al., 2007; Padoa-Schioppa, 2007, 2011; Strait et al., 2014). However, whether encoding and evaluation happens in parallel by competing neural populations (Padoa-Schioppa, 2007, 2011) or sequentially by a single evaluating population (Hayden & Moreno-Bote, 2018) is under dispute. Studying gaze patterns when offers are not visible could help to discern between the two types of models, as in this condition evaluation can be distinguished from stimulus encoding.

Methods

Behavioral Task

In the adopted reward gambling task (Fig. 1), two reward offers are presented in sequence at opposite screen sides for 400 ms (offer1/2), followed by 600 ms blank screen time (delay1/2). After fixation at the center of the screen, both stimuli are shown, instructing subjects to report their choice by saccade to either target (choice-hold). The stimuli colours cued to either safe, small fluid reward (grey) or risky rewards of medium (blue) or large (green) size. The height of blue/green bars cued success probability, complemented by red bars indicating miss probability. Magnitude m was pseudorandomized and success probability p was drawn from a uniform distribution. The expected value of the offers was defined as EV = mp. The order of presentation was randomized, but data are pooled referencing first offer on the left screen side (data where first offer was on right side are mirrored prior to pooling). We used n = 5971 trials from 4 sessions, 2 per subject.

Behavioural data analysis

We used a logistic regression model to predict the choice as a function of the following regressors: the EV and std. ($\sigma = mp(1-p)$) of the two offers, and the fraction of time spent on right screen time (f_R).

Neural encoding of value

We applied linear regression to assess the fraction of n=248 cells showing significant modulation of their activity by the EV of the two offers (Fig. 2). The spikes are counted in 200 ms time windows starting each 10 ms. We consider trials to be LookL (LookR) if average eye position is negative (positive) for the first 10 ms at the start of the spike count window. Empirical results are assessed via permutation tests, building the null distribution via trial-order shuffled data.

Results

Subjects directed their gaze to offers during their presentation, and shifted if most recent offer was less valuable, mainly fixating the most valuable offers. By factoring out value-related variables, we found that more time was devoted to the chosen offer, suggesting that gaze allocation plays a role in decision making, beyond value-based contingencies ($p < 0.001$, F-test of regression weight for f_R). Almost surprisingly, this also holds during delay times, despite the screen was blank.

We find that EV encoding mainly occurred during offer presentation, or at delay times, before and during choice report ($p < 0.05$, F-test of EV regression weights, Fig. 2). By studying EV encoding in opposite inspection sides (LookL, LookR), we find that the respective offer is significantly encoded in OFC if and only if the subject directs gaze to ipsilateral screen side (Fig. 2). For offer1/offer2 times this tendency is an expected result of overt visual search for sensory sampling. Strikingly, we also find that if subjects looked back at first offer location (LookL) during delay2: the encoding of the first offer EV is significantly stronger (Fig. 2B, top), implying that overt search possibly plays a role in reactivation the value for that offer, even when looking at opposite side (LookR) during offer2 time.

All in all, we provide evidence that eye position reflects and internal deliberation process possibly modulating the encoding of currently (re-)evaluated content, providing a new window to study the hidden dynamics of decision making.

Figures

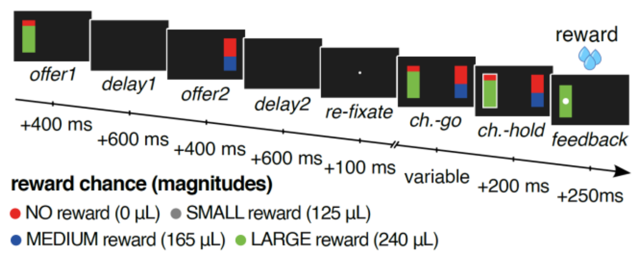

Figure 1: Reward gambling task (Strait et al., 2014).

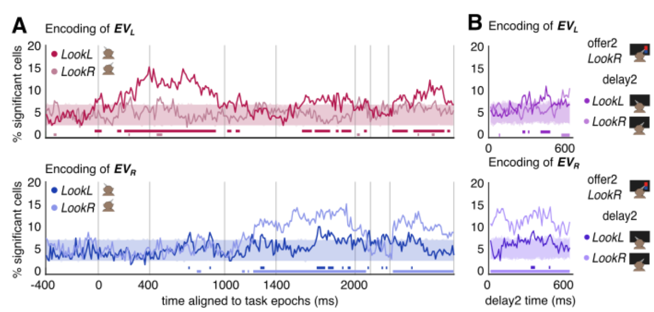

Figure 2: A. Fraction of cells encoding EV_L (top) and EV_R (bottom) for the two sides (LookL, LookR). Fractions of neurons (solid lines) are significant (bottom lines) if larger than 95th percentile of same results for trial-order shuffled data (shaded areas show 5th-to-95th percentile). B. Same as A, focusing on delay2, only including trials for LookR during offer2.

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