

Is your gaze your aim?

Eye position in reward gambling and the role of orbito-frontal cortex in encoding the value of visually cued offers.

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Introduction

Neural cells in frontal brain areas have been widely shown to be involved in high level cognitive control functions. Crucial to the understanding of their function is the investigation of how the neural spiking relates to the processing of sensory features of external stimuli bound in abstract entities of goal-directed relevance. This is often achieved through working memory mechanisms, largely supposed to be functional to the integration of cognitive variables for the selection and achievement of alternative goals, as it is the case for decision making. For decision making tasks with reward gambling and sequential reward offer cues presentation, neurons in the orbito-frontal cortex (OFC) have been associated with the coding and maintenance of the estimated value of a firstly presented offer expected value (EV) so that it could be compared with the estimated value of a later presented one [1-4]. Importantly, it is yet to be assessed what is the role of sensory offer cues and their features, such as the spatial location and temporal order of offer cues presentation in neural firing. Our research aim is to combine the analyses of the role of task variables such as gambling probability and reward sizes with eye movement behavior and neural spiking activity simultaneously recorded in OFC during the execution of a two-alternative gambling task with sequential visual offer cues presentation.

Methods

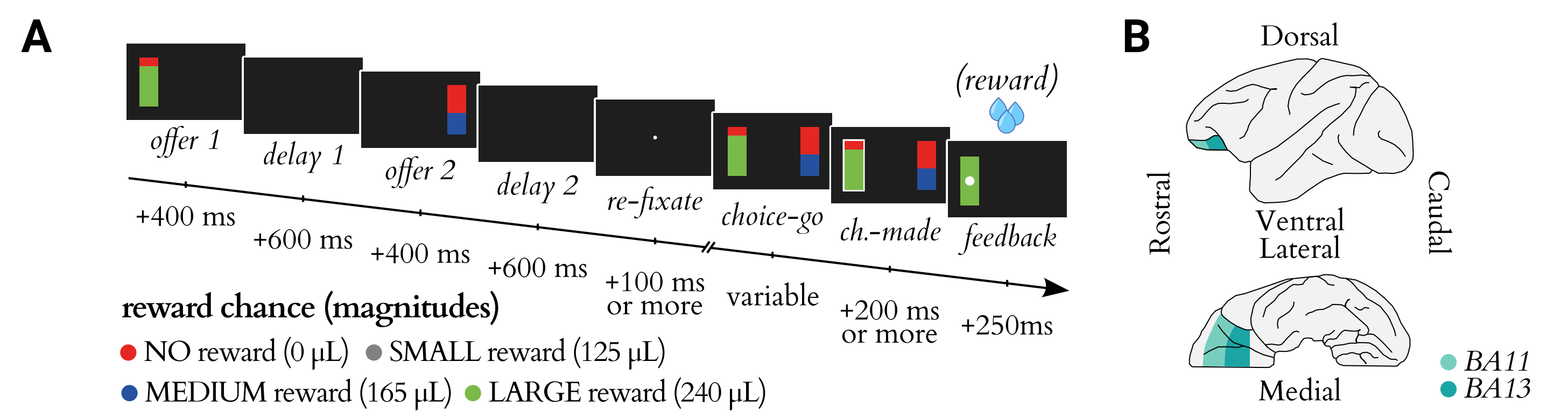


Figure 1. Behavioral Task and recorded brain areas. **A)** Timeline of the two-alternative gambling task for a sample configuration. Reward offers were sequentially cued by visual presentation of vertical bar stimuli on the two opposite sides of the screen. Stimuli colors could either cue to a safe, small fluid reward (gray) or to risky rewards with size medium (blue) or large (green). Risky reward magnitudes were pseudo-randomized across trials. Risky reward probabilities were continuous random variables drawn from uniform probability distributions. The height of bars indicated the probability of achieving rewards with given size. Miss probability was indicated by complementing risky offer bars with red color bars of height matching the probability of no reward. **B)** Recorded areas covered Brodmann Areas 11 (BA11) and 13 (BA13), shown in the above anatomical sketch redrawn from Mansouri et al., 2014^[5]. Two adult male rhesus macaques (*Macaca mulatta*) served as subjects. All procedures were approved by the University Committee on Animal Resources at the University of Rochester or at the University of Minnesota, designed and conducted by T.C.-P., M.W.Z. and B.H. in compliance with the Public Health Service's Guide for the Care and Use of the Animals.

Results

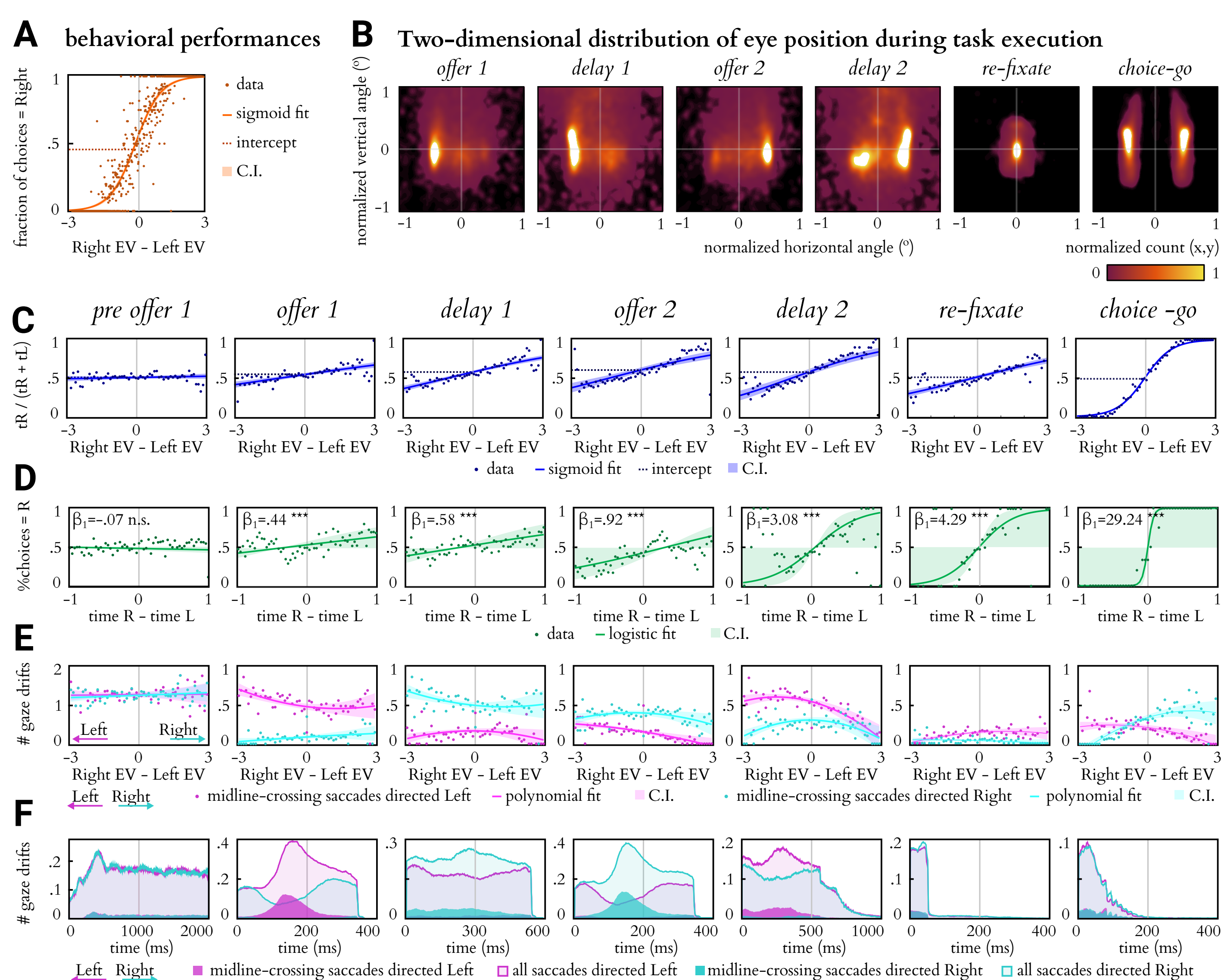


Figure 3. Behavioral data analyses. **A)** Behavioral execution performances: chosen offer vs EV difference. **B)** Two-dimensional distribution of eye position during task execution. Results were smoothed with Gaussian filter with sigma = 5 visual angle bins. **C)** Fraction of time looking at Right screen side vs EV difference (EV resolution used is 0.05 nominal units: 1=small, 2=medium, 3=large reward). Solid lines: sigmoid functions fits; shaded areas: 95% Confidence Interval (CI). **D)** Chosen offer vs difference in time spent at either screen side. Solid lines: logistic regression fits ($\logit(\text{fraction of choices} = \text{Right}) = \beta_0 + (\text{time on the Right side} - \text{time on the Left side}) \beta_1$; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$); **E)** Screen midline crossing saccades labelled by direction. Solid lines: second order polynomial fit; shaded areas: 95% CI. **F)** Time histograms of saccades occurrence labelled by direction. Panels show results for midline-crossing saccades only and including saccades within-hemifields. **A-F** Data include 5971 trials correctly performed (2643 from subject 1, 3328 from subject 2). Pooling is made with reference to the first offer side: eye data in trials with Left offer first are combined with horizontally mirrored eye data in trials with Right offer first.

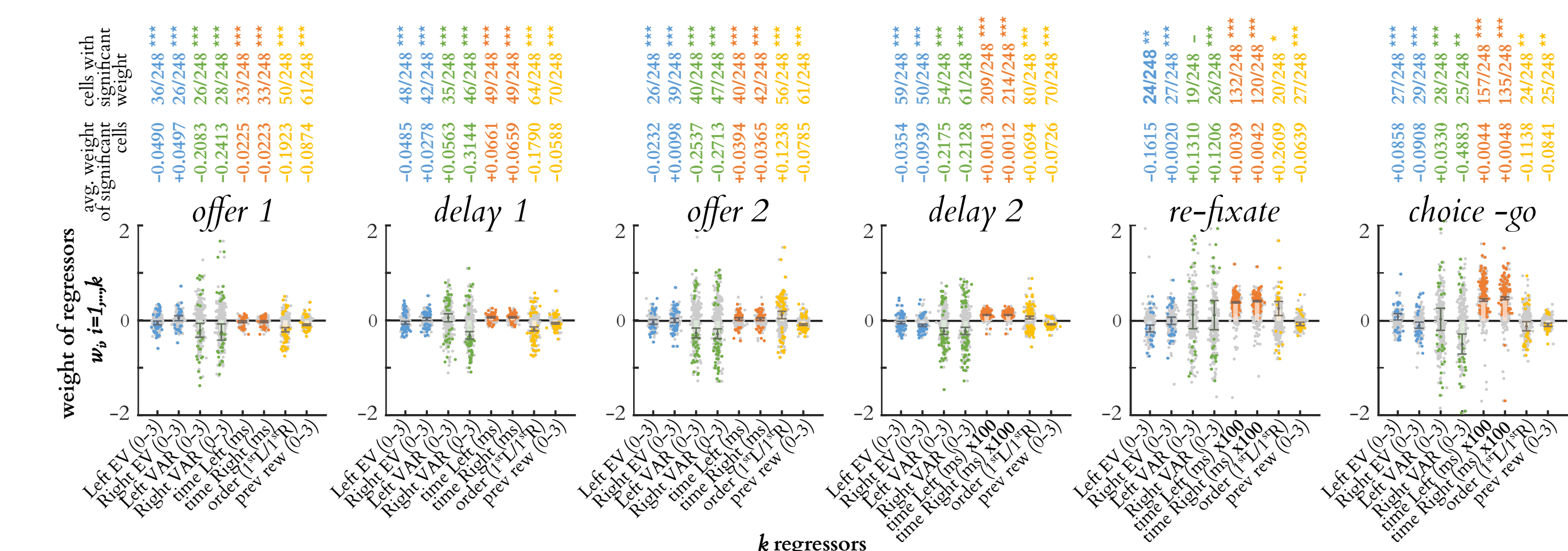


Figure 4. Neural data analyses. **A)** Results of the GLM of neural spike counts. Data include activity from 248 cells (163 from subject 1; 85 from subject 2). Grey dots: weight of regressors for each cell and in each time window. Colored dots: weights for cells with significant regression p-values ($p < 0.05$). To improve visualization, weights for time Left and time R are $\times 100$ in task windows following offer 2. Text reports the portion of significant cells and their average weight. Significance of fraction of cells is assessed via binomial tests with threshold 0.05 (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$).

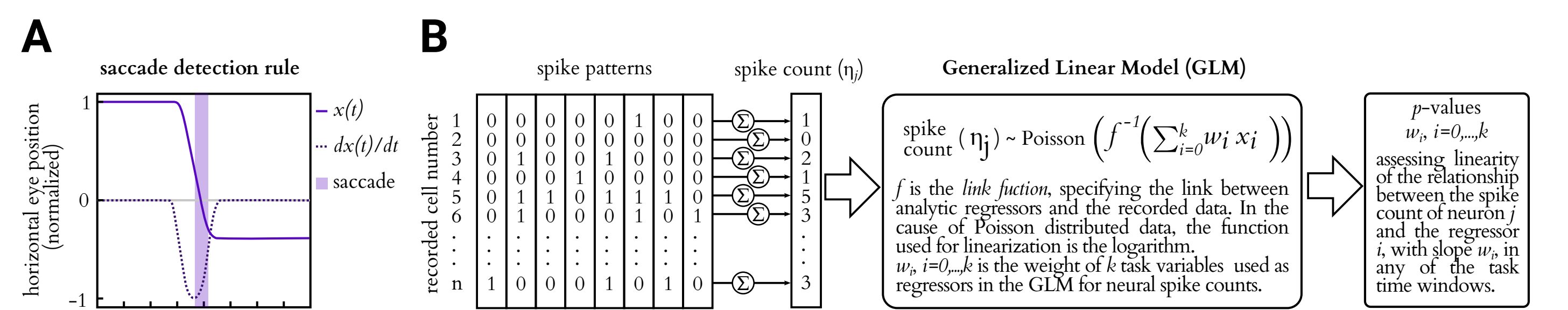


Figure 2. Saccade detection rule and Generalized linear model of OFC neural activity. **A)** Graphical scheme of the saccade detection rule applied in the analysis of eye data. Eye position drifts were detected as saccades when the drift was monotonic and when it persisted for at least 25 ms. Different duration values did not affect qualitative results. **B)** Graphical scheme of the computational tool used to assess the relationship between spike count and analytic regressors such as offer features or behavioral task variables.

Conclusions

Our work first focused on the role of eye position during decision making tasks, revealing how successful behavioral choices coincided with the subject's ability to direct their gaze to the screen side with best offer expected value during task execution. This result motivated us to analyse eye position as a marker of a readout mechanism possibly allowing to aim for the actual best guess. Interestingly, this result becomes more evident and robust after the second offer presentation. We argue this to be a central result as once both offers were presented, the subjects most frequently reached the side of best offer, despite they were left with blank screen and free to move at their will. This crucial result is consistently reported both when considering the fraction of time spent looking at best offer and when considering how looking at either side impacts the choice. Among our results, we show how the subjects systematically moved their gaze following a robust task execution pattern, providing further insight in how eye movements play a crucial role in the decision process. Lastly, we applied Generalized Linear Models to identify cells whose firing rate showed significant linear relationship with offers features and behavioral task variables. In particular, a significant portion of cells showed selectivity to the EV of offers, to the order of offer presentation, and to immediate previous trial rewards. Interestingly, combining eye and neural data analyses, we also reported that the firing rate of a large proportion of the OFC cells recorded was tightly linked with the fraction time spent on either screen side.

References

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