Encoding of Reward Size and Reward Delay by Individual Neurons in the Ventral Striatum in the Non-human Primate Engaged in an Intertemporal Choice Task

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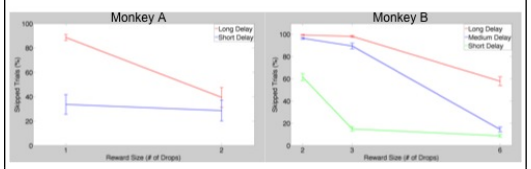
Introduction

The ventral striatum (VS), a deep brain structure involved in the processing of reward, is implicated in neurologic disorders including depression and addiction. Intertemporal choice involves the relative valuation reward size and delay to obtaining it. We are studying the role of the VS in this valuation by recording single unit neuronal activity in non-human primates engaged in a novel intertemporal choice task.

Figure 2: Behavior

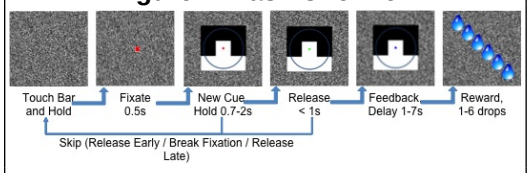


Monkeys predictably accepted high value trials and skipped low value trials

Methods

Two rhesus monkeys were trained to associate visual cues with various combinations of water amount and delay during a bar touch and release task (Figure 1). The monkeys accepted the trials in a predictable and reliable manner (Figure 2).

Figure 1: Task Overview



Visual cues denoted the size and delay of liquid reward to be delivered after successful completion of the task. By releasing early, breaking fixation, or releasing late, animals may skip the trial and view a new cue.

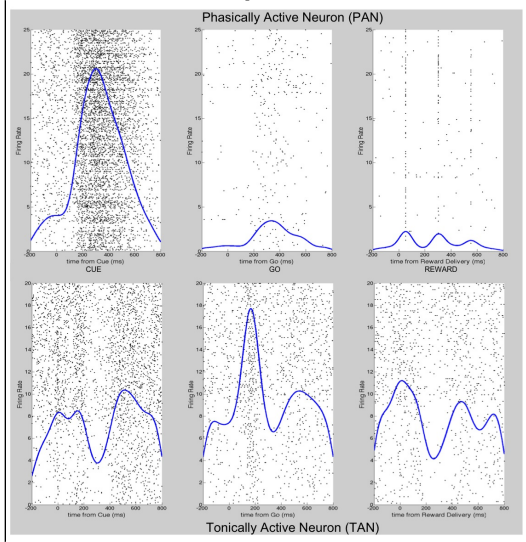
Results

We recorded VS neuronal activity from 131 neurons in two monkeys engaged in this task. A 2x2 design (reward sizes x reward delays) was used for Monkey A and a 3x3 design for Monkey B. Neuronal firing rate following cue presentation was compared between the conditions using a two factor ANOVA. Two patterns of neuronal firing were apparent, corresponding to phasically active neurons (PANs--putative medium spiny GABAergic projection neurons) and tonically active neurons (TANs—putative aspiny cholinergic interneurons). We identified 88 PANs and 43 TANs (see Figure 3 for examples). Overall 66/131 (50%) neurons demonstrated significant main effects ($p<0.05$) of reward size or delay on the firing rate following cue presentation. Significant main effects were seen for size alone in 32 neurons (24%), delay alone in 9 neurons (7%), and both size and delay in 25 neurons (19%). A significant interaction effect of size and delay was seen in 23 neurons (18%). Among PANs, significant main effects for size alone and both size and delay were seen more than for delay alone (24/88 size alone, 3/88 delay alone, 18/88 both size and delay, $p<0.001$ for both comparison). This difference was not found among TANs (8/43 size alone, 6/43 delay alone, 7/43 both size and delay). See Figure 4 for representative examples.

Conclusions

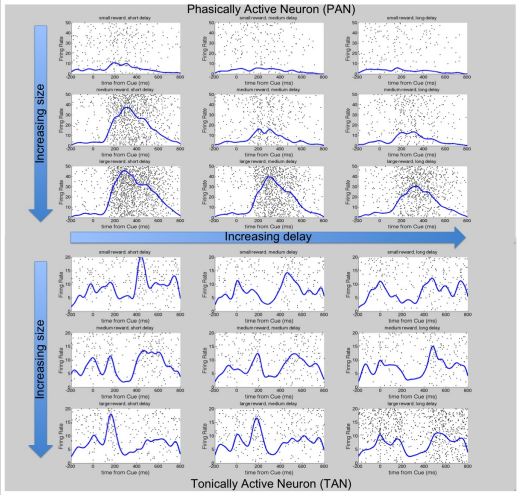
We find evidence for both separate and combined encoding of reward size and delay by both phasically and tonically active neurons in the ventral striatum.

Figure 3: Neuronal Responses to Trial Components



Spike rasters and overlaid spike density plots in representative neurons. The top panel demonstrates a phasically active neuron (PAN) with a low background firing rate and a burst of activity following cue presentation. The bottom panel demonstrates a tonically active neuron (TAN) with characteristic pause and rebound pattern following both cue presentation and reward delivery with a burst/pause pattern following 'Go' symbol. Based on inspection of overall patterns of activity, we subsequently analyzed the effects of reward size and reward delay on the firing rate in the period 100-500 ms following cue presentation.

Figure 4: Effects of reward size and delay on firing rate following cue presentation in representative neurons



Spike rasters and overlaid spike density plots for each of the trial conditions for the same neurons in Figure 3. When comparing the firing rate fusing a 2-factor ANOVA for the period 100-500 ms following the cue presentation in the representative PAN (top panel), both reward size and reward delay demonstrate significant main effects and the two demonstrate an interaction effect (all $p<0.001$). Over the same period in the representative TAN (bottom panel) only reward delay demonstrates a significant main effect ($p<0.001$, reward size and interaction $p>0.1$).

Support

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