Neural signals in primate amygdala discriminate among gradations of value

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We have recently discovered that the primate amygdala contains two populations of neurons that encode the positive and negative values, respectively, of conditioned visual stimuli [1]. For neurons encoding positive value, responses to an image associated with reward were stronger than responses to the same image when it was associated with a punishment; neurons encoding negative value had the opposite response profile. We have now investigated how the amygdala encodes gradations of values assigned to visual stimuli. We recorded single units in the amygdala while monkeys performed a trace-conditioning task in which 3 novel abstract visual stimuli were paired with either large reward (2 large drops of water), small reward (one smaller drop of water) or an aversive air-puff directed at the monkey’s face. The reinforcements were delivered on 80% of trials and were omitted on 20% of trials. After the initial associations were learned, we reversed the assignments without warning, delivering air-puffs instead of large rewards after the image that was initially paired with large reward and vice-versa for the image initially associated with air-puff. The image paired initially with small reward was never reversed. We monitored two behavioral parameters, anticipatory licking and eye closure, that demonstrated monkeys’ leaning. Monkeys typically closed their eyes, in anticipation of aversive air-puff, and licked a reward delivery tube in anticipation of rewards, with licking durations correlated with the size of rewards.

We recorded neural activity from 85 cells in 2 monkeys. About 50% of these cells encoded either positive or negative value of the conditioned images during either the visual stimulus or trace intervals. The majority of these value-coding cells also differentially encoded value gradations of visual stimuli. We defined the trials with large reward as having a strong positive value. Trials with smaller rewards were defined as having a weak positive value, and the trials with air-puffs were defined as having a negative value. Monkeys’ behavior, over the population, reflected that they had learned the association and gradations of value. They licked most on large reward trials, less on small reward trials and almost not at all on negative trials. Blinking behavior reflected learning about negative association, as monkeys closed their eyes anticipating air-puff, but not on either of the two positive trial types.

Across the population of neurons, responses to the image associated with a small reward (weak positive trials) were intermediate to the responses to images associated with strong rewards or aversive air-puffs, especially during the trace interval immediately preceding reinforcement. This finding held whether neurons fired most strongly to images associated with aversive air-puffs (negative value-coding neurons) or to images associated with large rewards (positive value-coding neurons). These data suggest that neurons in the amygdala provide a graded representation of the learned values of visual stimuli. Moreover, the differential responses to images associated with strong and weak rewards demonstrate that the changes in response properties of amygdala neurons during reinforcement learning do not reflect the formation of an association between images and the sensory properties of rewards. The sensory properties of the rewards were identical in the two trial types, and the rewards only differed in quantity. Across the population the graded representation of value is a sustained signal that extends from shortly after the presentation of an image predicting reinforcement and is temporally extended until reinforcement.

References: