

# Reward Association Affects Neuronal Responses to Visual Stimuli in Macaque TE and Perirhinal Cortices

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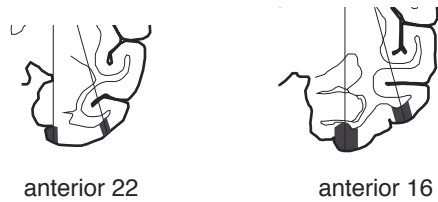
J. Neurosci, 26 (2006) 6761

## Introduction

Predicting reward value of an object from its visual images is essential for visual animals such as monkeys and humans. Liu and Richmond (2000) showed that perirhinal (PRh) cortex shows activity related to reward schedule. However, they examined the effect of reward schedule but not of reward itself. To study the role of PRh and TE in the stimulus-reward associations, we recorded spike activities from cells of PRh and TEad in two monkeys performing a visual discrimination task after stimulus-reward associations were learned.

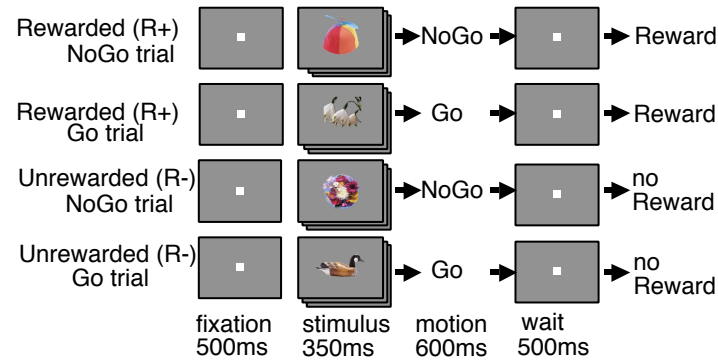
## Recording Sites

The recorded areas ranged from anterior 17 to anterior 23 in Monkey1 and from 16 to 22 in Monkey2. Locations of PRh and TEad cortex were determined by reference to MR images.



All the units that were stable and well separated were recorded and included in the analysis (no sampling bias).

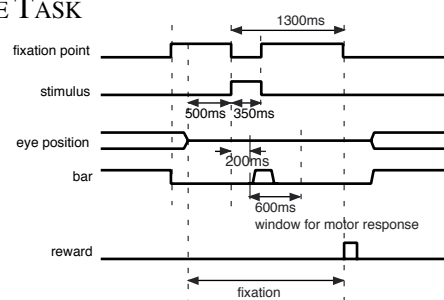
## Behavioral Task



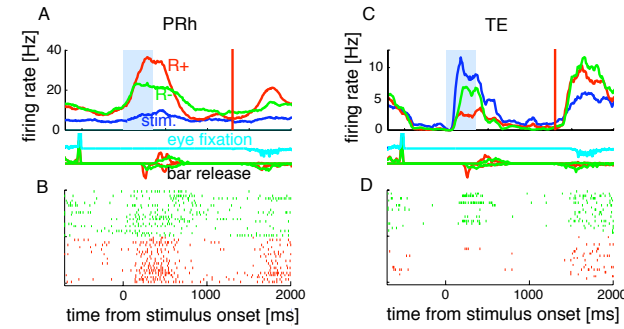
The task was a visually cued go/no-go task. Trial started with a lever press. The Go response is a lever release followed by a press within 600ms. Eye fixation was required until reward delivery. Correction trials were provided after all erroneous trials.

A fixed set of 80 object images was used as the cue pool. This set was divided into 4 quarters: go R+, no-go R+, go R-, or no-go R-.

## TIMECOURSE OF THE TASK

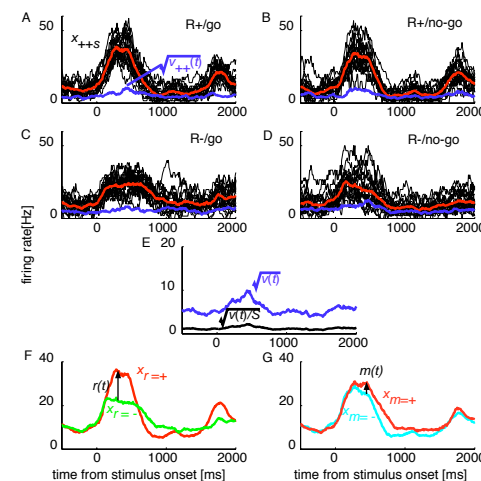


## PRh cells was reward selective and so were TE cells :Examples



Two examples of cells that showed significant dependence on the reward condition. A and C, The red and green lines indicate averaged responses in the rewarded and unrewarded conditions, respectively. The blue line indicates the magnitude of the stimulus selectivity. The cyan line at the bottom indicates the histograms of the times of start (upward) and end (downward) of the eye fixation. The red and green lines at the bottom indicate the histograms of the times of bar release (downward) and re-press (upward) in rewarded (red) and unrewarded (green) trials. The period of visual cue presentation is indicated by the light blue shading, and the time of reward delivery by the red vertical lines. B and D, rastergrams of spike occurrence in individual trials of unrewarded (green) and rewarded (red) conditions for the cell shown in A and C respectively. A vertical short line segment indicates a spike, and a horizontal line represents a trial. The trials shown here were consecutive trials in each condition with different stimuli. Cell shown in A and B was recorded from PRh, and that in C and D from TE.

## Detail about How to Analyze



Responses of a PRh cell. A-D, Individual mean responses (black) to 20 rewarded go stimuli (A), 20 rewarded no-go stimuli (B), 20 unrewarded go stimuli (C), and 20 unrewarded no-go stimuli (D), together with the mean (red) and the standard deviation (blue) within each motor-reward condition. The number of trials included in producing the plots of each type were 116, 111, 102, and 111, respectively. E, Root of the variance (blue), which represents the magnitude of stimulus selectivity, which was used to normalize  $r(t)$  and  $m(t)$  for t-test.  $S=20$ . F, The averaged responses in the rewarded conditions (red) and unrewarded conditions (green).  $r(t)$  is the difference between the two lines. G, The averaged responses in the go conditions (red) and no-go conditions (cyan).  $m(t)$  is the difference between the two lines.

## PRh cells are more reward selective than TE cells are Population data

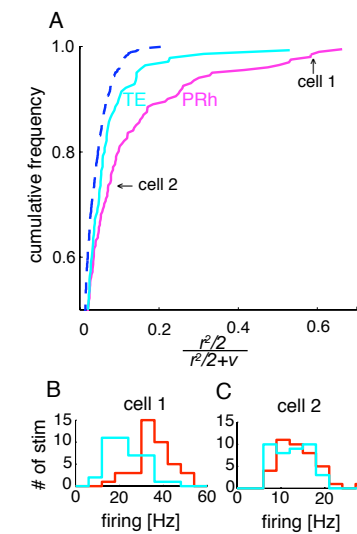
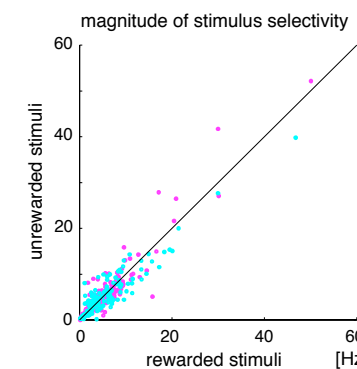


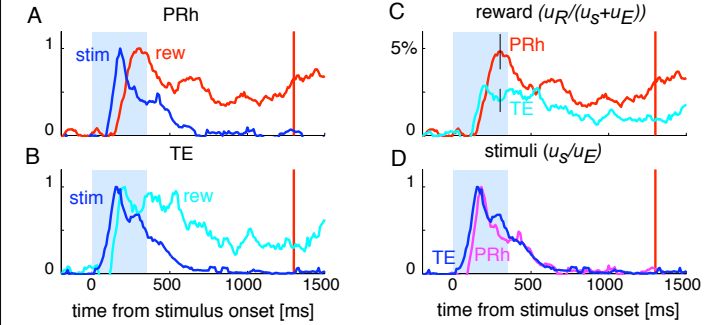
fig.5 Comparison of the magnitude of reward dependence with that of stimulus selectivity. A, The ratio of the variance due to reward conditions to the sum of the variance due to stimulus selectivity and that due to reward dependence are displayed as a cumulative frequency histogram. The number of cell was cumulated and normalized by the total number of cells in each area. The half of the cells with smaller ratios in each area is not shown, because the distribution among these cells was very close to the theoretical distribution of pseudo dependence expected from visual stimulus selectivity in both areas. The variances of responses shown here were calculated for the mean firing rate in a window 250-350 ms from the stimulus onset. The broken line indicates the theoretical distribution of false reward-dependence originating in visual stimulus selectivity. About a tenth of PRh cells showed reward dependence comparable to stimulus selectivity (that is,  $r > 0.7v$ ). TE cells showed smaller reward dependence than PRh cells. B, An example of a PRh cell with strong dependence on the reward condition. The cell is indicated as 'cell 1' in panel A. The magnitudes of responses to rewarded stimuli (red line) largely segregated from those of responses to unrewarded stimuli (blue line). C, An example of a PRh cell with non-significant reward dependence. The cell is indicated as 'cell 2' in panel B.

## Reward doesn't facilitate Visual Discrimination



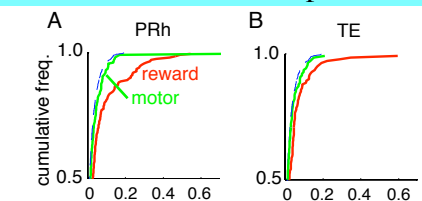
Comparison of the visual stimulus selectivity between rewarded and unrewarded stimuli.

## Reward selectivity appears slightly later in PRh than TE, which suggest forward information flow



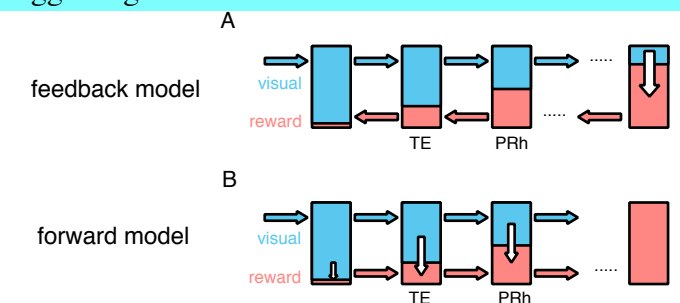
Time courses of reward dependence and visual stimulus selectivity. A and B, The blue lines indicate the time course of averaged normalized stimulus selectivity in PRh cells (A) and in TE cells (B). All the cells (201 PRh cells and 139 TE cells) were included. The peak value of the reward dependence was 4.8% and that of stimulus selectivity was 73% in A, and they are 2.9% and 114% in B, respectively. The stimulus selectivity preceded the reward dependency in both areas. C, The time courses of reward dependence in PRh cells (cyan) and TE cells (magenta). D, The time courses of stimulus selectivity in PRh cells (purple) and TE cells (blue). The two lines are scaled by the peak value of each line. Both the stimulus selectivity and reward dependence appeared and developed earlier in TE.

## PRh and TE is not Motor dependent at all



Comparison of the strength of motor dependence with that of reward dependence in PRh (A) and TE (B). The green lines show the cumulative frequency of the cell in terms of the strength of motor dependence, calculated by the ratio of the variance due to motor conditions to the total variance but excluding the trial variance. The red lines show the cumulative frequency of the cell in terms of the strength of reward dependence. This suggests two facts. One is that our method of 40-40 comparison works well. The second is that our reward dependence is not categorization in IT, but reward information itself.

## Suggesting forward model



## Conclusion

These results suggest the involvement of PRh and TE in associating visual stimuli with reward outcomes.