# Reward associative learning does not automatically alter cortical responses measured by steady-state visual evoked potentials

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## Introduction

- Objects associated with **rewards** tend to grab our attention. Yet, how reward associative learning may automatically alter cortical responses remains unclear.
- A training plus test design was used:

1. **training**: visual search with eye tracking for reward training (colors were associated with rewards);
2. **test**: EEG fast period visual stimulation (FPVS) to test cortical responses to reward colors;
3. **re-test**: repetition of the FPVS session 7 days apart to test the endurance of potential learning effects and test–retest reliability

Fig. 1


**Figure 1**. **Overall procedure**: two sessions, one week apart.

Fig. 2

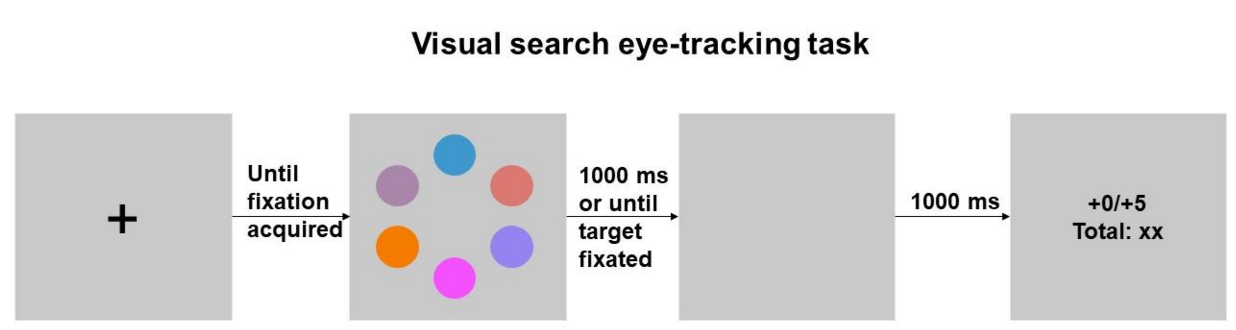


**Figure 2**. **Training** with eye-tracking and a visual search task: target colors (red and green) were associated with high and low rewards.

## Methods

- **Participants**: 37 participants took part in the first session including an eye-tracking task and an EEG task. To evaluate test-retest reliability, 33 of them participated in the second EEG session after approximately a week (**Fig. 1**).
- **Session 1: training.** during training, participants completed a visual search eye-tracking task. They were randomly divided into two groups: one group with reward associative learning; the other, associative learning without rewards. For the reward learning group, participants made eye movements toward a target circle (either red or green) among distractor circles (other colors) in a visual search task. Following a correct response, one target color was associated with high reward (80% chance of receiving 5 points, 20% chance of receiving 0 point), the other color, low reward (the opposite reward schedule). Colors were counterbalanced across participants (**Fig. 2**).
- **Session 1: test.** After training, participants completed an EEG task. A series of task-irrelevant, randomly colored circles appeared at the center at a fixed temporal frequency **(4 Hz)**, among which a circle with a fixed color appeared at a slower frequency **(0.8 Hz).** This oddball could be a high-value color, a low-value color, a distractor color, or there could be no oddball (control). To probe how responses to the oddball stimuli might depend on attention, participants were asked to respond to changes of the fixation cross, either any changes (low load) or specific lengthening and shortening of the vertical and horizontal lines (high load). For the no-reward learning group, the procedure was the same except that no explicit reward was provided (**Fig. 3**).
- **Session 2: test.** Same as the test in Session 1, just one week apart.

Fig. 3

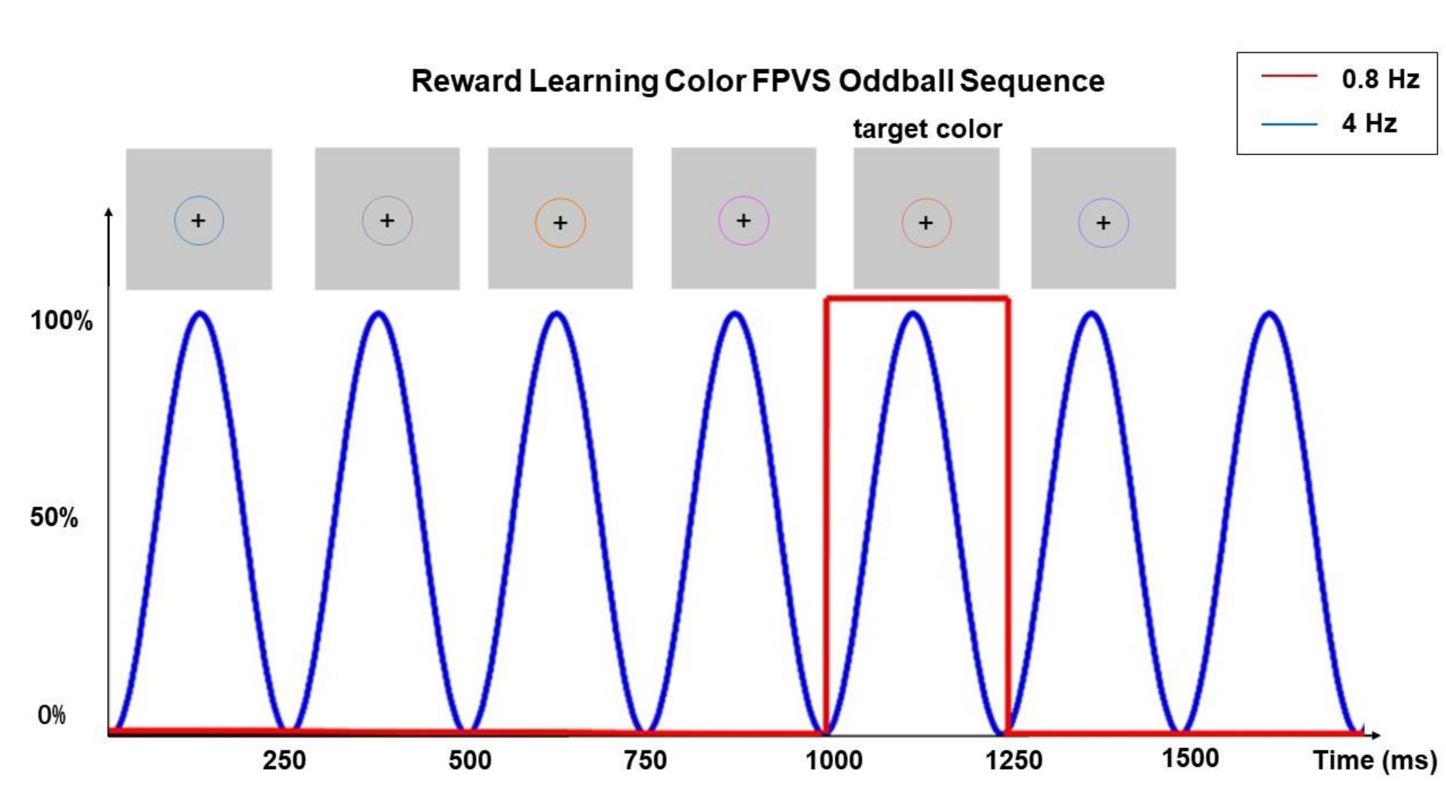


**Fig. 3**. **Test with EEG**. In this FPVS oddball sequence, participants were required to quickly respond to changes of the cross inside the colored circle. **Target** color circles were presented at **0.8 Hz**; **non-target** circles were of random non-target colors presented at **4 Hz**.

## Results

- Oddball frequency had a significantly higher **signal-to-noise ratio (SNR)** than control (without oddball frequency) in both low and high load conditions, but it did not differ between the reward and no-reward groups (**Fig. 4**). There was also no differences between high reward color, low reward color, and distractor color.
- The oddball frequency effect was highly reliable. Test–retest reliability was high **(ICC of 0.86; Fig. 5)**

Fig. 4

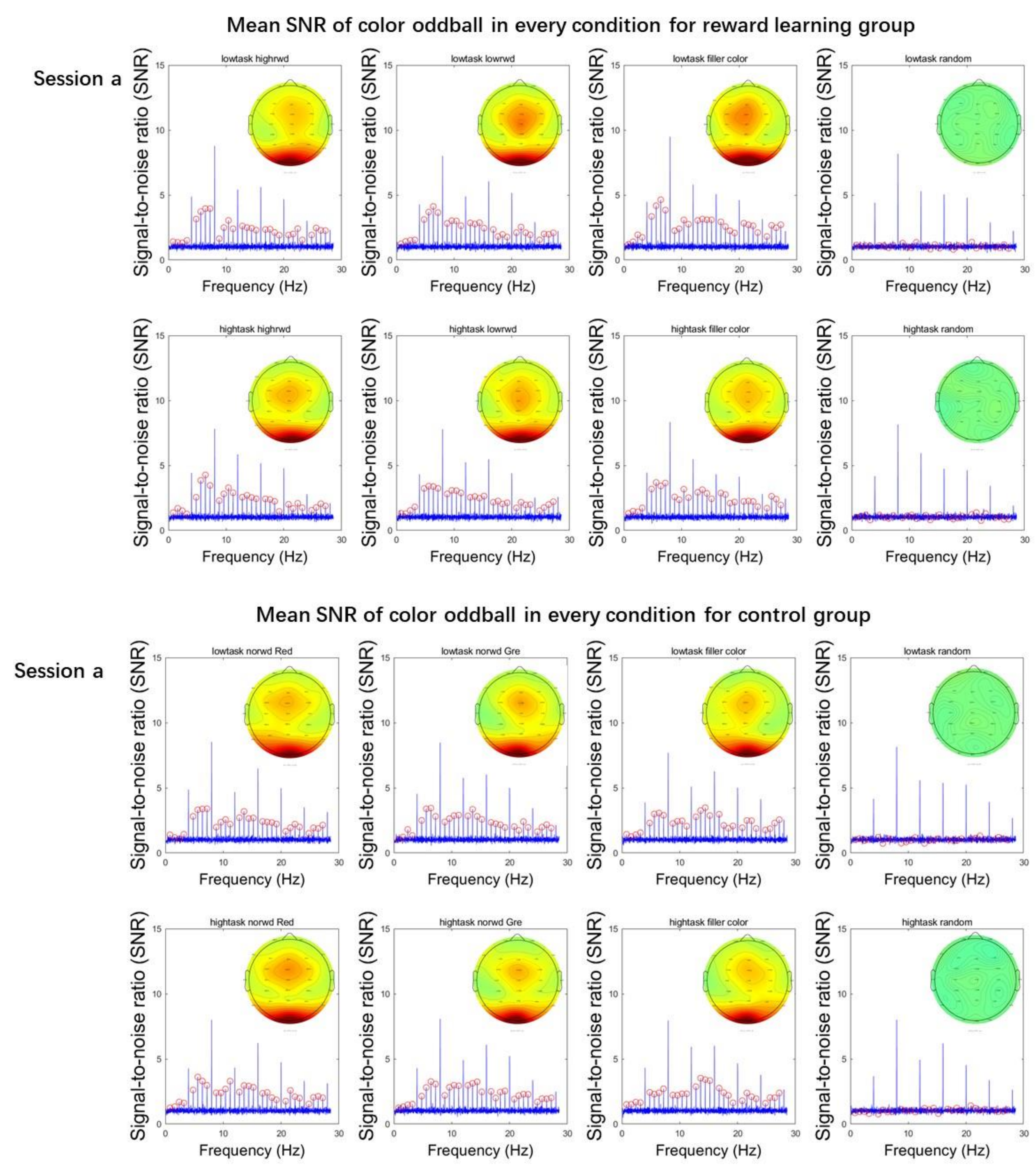


**Figure 4**. **First test results:** The mean SNR of color oddball for the reward and no-reward groups in session 1, each with eight conditions (low/high load x high reward/low reward/non-target color/control). For the frequency-SNR graphs, we illustrate using the Oz electrode, which had the strongest oddball frequency effect. The red circles represented the oddball frequency and its harmonics.

Fig. 5

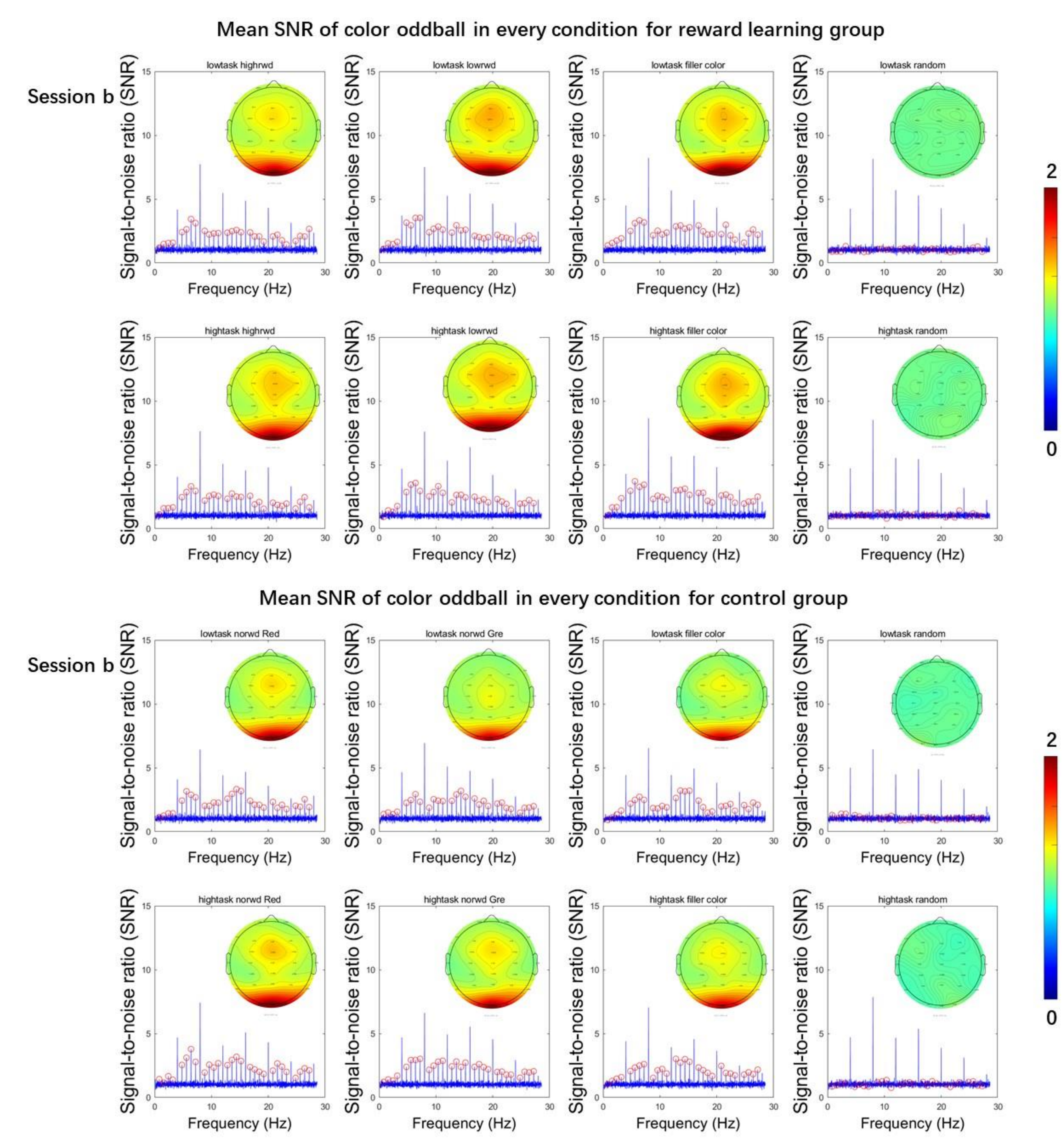


**Figure 5. Second test results:** The mean SNR of color oddball for the reward and no-reward groups in session 2, each with eight conditions (low/high load x high reward/low reward/non-target color/control).

## Discussion

In the visual search task, the stimulus was presented in a circle in groups of six, whereas in the EEG task, the stimulus was presented alone at the center of the screen. Consistent stimulus configuration might be necessary for attention capture of reward association.

## Conclusion

These results demonstrated that reward associative learning does not automatically alter cortical responses as indexed by steady-state visual evoked potentials.

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