Human EEG Responses to a Conditioned Stimulus Reward Delay

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Introduction

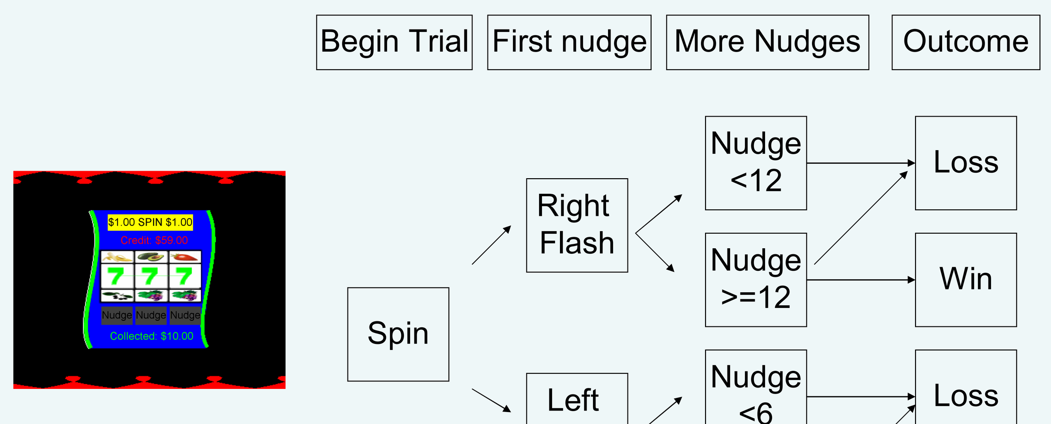
Shuler & Bear (2006) found that evoked responses in rat primary visual cortex (V1) to a flash of light changed with conditioning to a delayed reward. Our aim was to adapt the methods of this study for use in humans. In humans, evoked potentials must be extracted using non-invasive means. A naturally rewarding human behavior has to replace the water tube used to condition the rats.

Methods

A Las Vegas style "fruit machine" (see picture below) was used to simulate the water tube used by the rats. Rewards were conditioned on the appearance of a hemi-field flash. After spinning the dials, like on a slot-machine, the fruit machine had a 'nudge' option appear, to nudge the central dial further in order to try and obtain a reward. A flash appeared on the first nudge. The participant was encouraged to maximize her profits in the game.

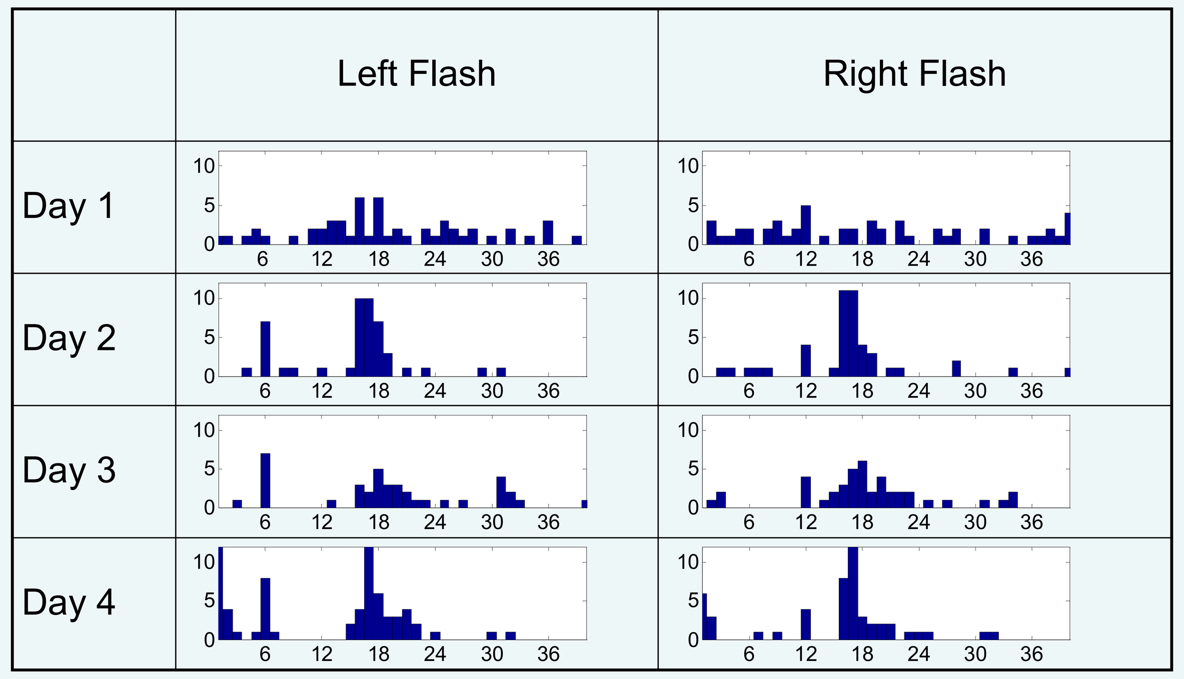
	Shuler & Bear	Our methods
Trial initiation	Approach nose poke	Spin
Reward time cue	Flash in head-mounted goggles	Hemifield flash
Continue trial	Lick nose poke	Nudge
Reward	Drop of water	Virtual money coupled with auditory reward
Data processing	Normalization of trials over licks	Partitioning and aligning trials by nudges

- Button presses were performed bimanually
- The first nudge coincided with on screen hemifield flash
- Right flash=win after 12 nudges 50% of the time
- Left flash=win after 6 nudges 50% of the time
- Trial ended with a win or the participant stopped nudging
- All data were collected using an Active Two EEG system
  - 128 channel cap plus 2 grounds worn on participant's zygomatic bones
- All data was processed using Matlab and the EEGlab toolbox



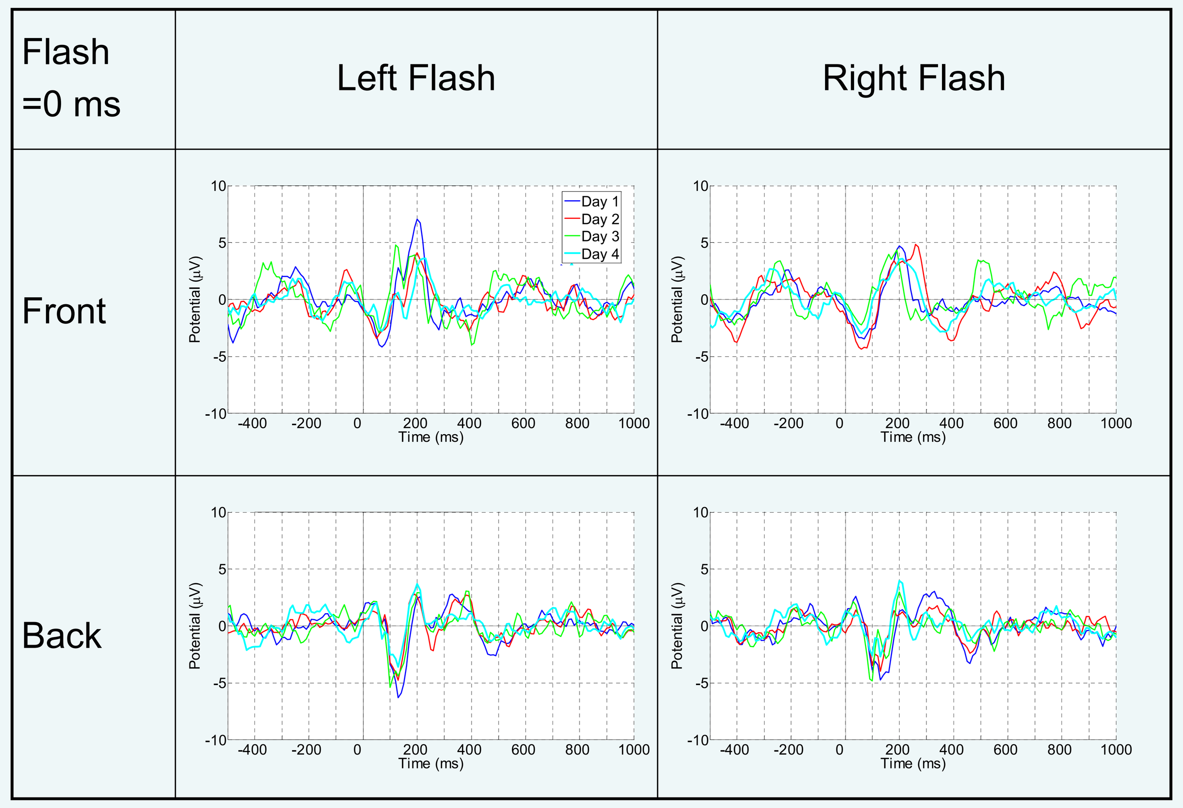
Fruit Machine

Results



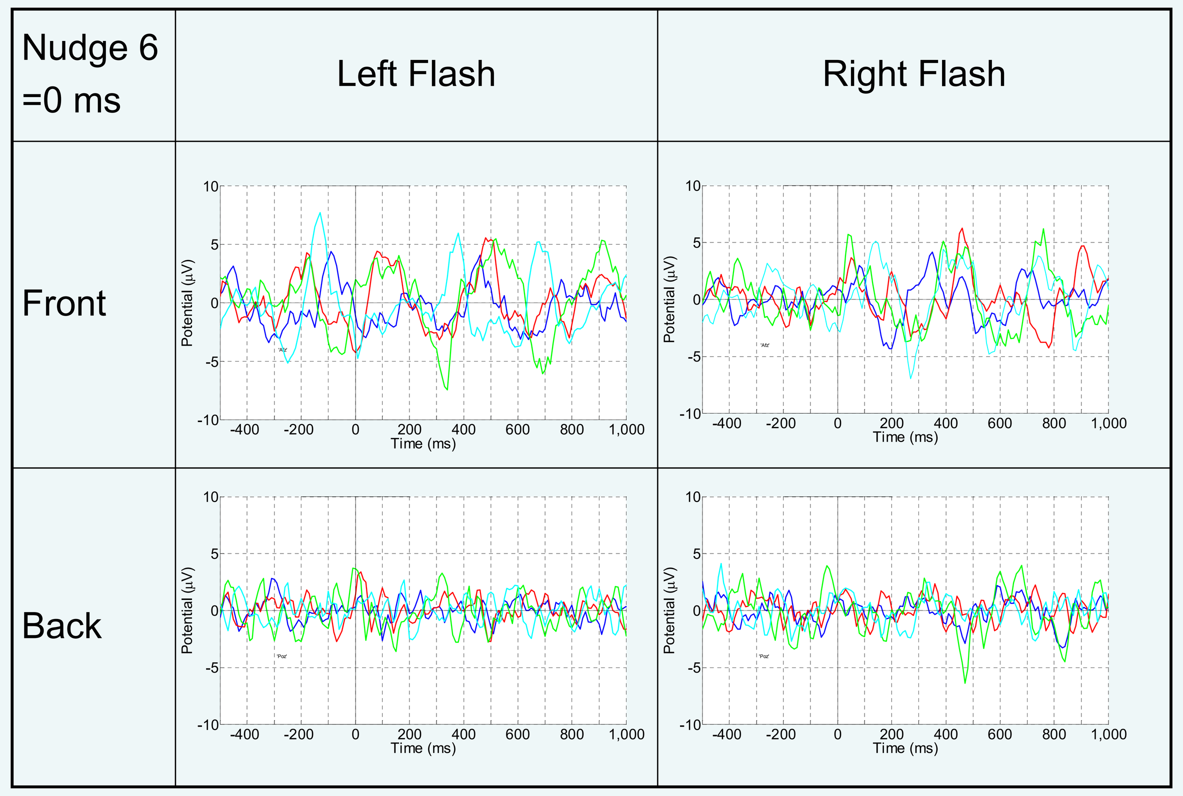
This figure shows a histogram of the number of nudges made by the participant on non-reward trials, on the four testing days.

- On Day 1, trials were broadly distributed across a wide range of different numbers of nudges.
- On subsequent days the participant made 15-20 nudges on many trials.
- There was also a peak at 6 nudges for left-flash trials, and 12 nudges for right-flash trials, corresponding to reward learning.



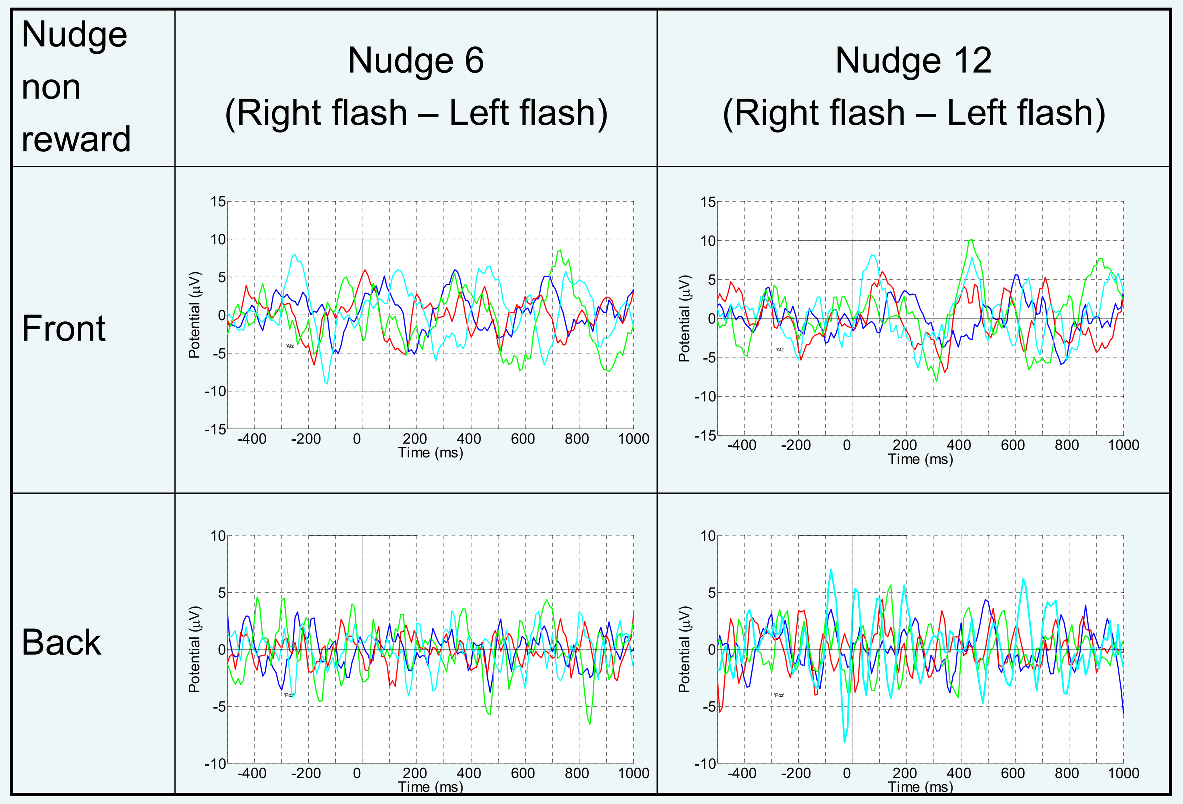
This figure shows the evoked responses to Left and Right flashes over the four days (as separate lines), averaged across 19 active electrodes in the front and back (occipital) regions of the scalp. The flashes coincided with nudges, explaining the frontal response.

- Note the decreasing amplitude of the response over days, particularly around the P300 peak in the back of the scalp.
- This might reflect habituation, corresponding to the participant's subjective report that she learned to ignore the flash.



The previous figure showed the flash response, overlying a nudge response. Here is the nudge response alone, centered around the 6th nudge on non-reward trials, with the flash on the left or right.

- The phase, frequency and amplitude of the nudge response varied across days.
- It seems likely the participant was using different nudging strategies.



The responses on the 6th nudge shown above were subtracted (Left from Right flash) to determine whether the participant learned to expect a reward on the 6th nudge when the flash was on the left. Similarly, responses on the 12th nudge were subtracted. Only non-reward trials were used in these subtractions.

- There was no indication of learning in this evoked response, to suggest a different reward expectation after 6 and 12 nudges, depending on whether the flash was on the left or on the right.

Evoked responses are plotted around the time of the nudge preceding the reward (this is the 6th nudges for a Left flash, or the 12th nudge for a Right flash). Averaged across electrodes.

- Responses at the front of the scalp increased in amplitude over the four days, between 100 and 500 ms after the nudge on reward.

Discussion

Like the rats in the study of Shuler & Bear (2006), our participant showed behavioral learning of the reward delay. She learned to make fewer nudges when the flash was on the left, and this learning was unconscious although she reported that she learned to ignore the flash. The evoked response to the flash lessened in amplitude over the four days of training, whereas the evoked response to the reward increased in amplitude. However, unlike in the rats, we saw no indication of a change in evoked potentials around the time of the rewarded nudges on non-reward trials, either in occipital regions at the back of the scalp, or in more frontal regions, as reported by others (e.g. Fuster & Jervey, 1981).

It is possible that such learning might occur with a greater number of training sessions, more participants, real monetary rewards, and a more sensitive measurement of the evoked response.

Acknowledgements

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