Brain and Cognition 77 (2011) 128–134

Contents lists available at ScienceDirect

Brain and Cognition

journal homepage: www.elsevier.com/locate/b&c

Medial frontal event-related potentials and reward prediction: Do responses matter?

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ARTICLE INFO

Article history:
Accepted 6 April 2011
Available online 31 May 2011

Keywords:
MFN
Reward prediction error
ERP

ABSTRACT

Medial frontal event-related potentials (ERPs) following rewarding feedback index outcome evaluation. The majority of studies examining the feedback related medial frontal negativity (MFN) employ active tasks during which participants' responses impact their feedback, however, the MFN has been elicited during passive tasks. Many of the studies examining the MFN show enhanced effects when an error in reward prediction occurs (i.e. expected rewards are not delivered). To clarify the roles of reward prediction error and active responding in producing the MFN, the current study employed a reward prediction design with active and passive task blocks. Following the presentation of a reward predictor, participants (active task) or the computer (passive task) indicated whether participants would receive the outcome associated with a stimulus presented on the left or right of the reward predictor. The MFN was largest when the trial outcome was worse than predicted and this effect was enhanced when the participant, rather than the computer, made the choice. These results show that both reward prediction error and active choice impact the neural system of outcome monitoring with the largest MFN when the individual's decision led to the negative outcome.

1. Introduction

Evaluating the potential positive and negative outcomes associated with individual choices is a critical aspect of the decision-making process. The neural reward system assesses, updates, and maintains reward values based on current and prior decisions and outcomes. Medial frontal event-related potentials (ERPs), including the error related negativity (ERN) and the feedback related negativity (FRN) components index reward-related neural activity associated with task performance and outcome monitoring. Known generically as the medial frontal negativity (MFN), these ERP components index how "good" or "bad" an action or outcome is within a given context (Hajcak, Moser, Holroyd, & Simons, 2006; Nieuwenhuis, Holroyd, Mol, & Coles, 2004). If sufficient information is present for evaluation at the time of the behavioral response, then an ERN occurs to that response, but if performance feedback is required to evaluate the action outcome, then an FRN occurs to the feedback stimulus (Nieuwenhuis, Holroyd, Mol, & Coles, 2004).

A prominent theory of the MFN proposes that these components reflect neural activity associated with reinforcement learning (Holroyd & Coles, 2002; Nieuwenhuis, Holroyd, et al., 2004) and outcome evaluation (Gehring & Willoughby, 2002). The reinforcement learning theory posits that the dopaminergic neurons of the ventral tegmental area, which show enhanced firing to unpredicted rewards and suppressed firing when a predicted reward is not delivered (Schultz, Dayan, & Montague, 1997), deliver a 'learning signal' to the anterior cingulate cortex (ACC) when the outcome of a choice or action is worse than expected (Holroyd & Coles, 2002). The feedback related MFN has a medial frontal scalp distribution, above the ACC, and has been localized to ventral areas of the ACC using source analysis (Nieuwenhuis, Slagter, Alting von Geusau, Heslenfeld, & Holroyd, 2005; Taylor et al., 2006).

Unlike the response related MFN, behavioral errors and active responses are not necessary to elicit a feedback related MFN (Gehring & Willoughby, 2002). Gehring and Willoughby (2002) demonstrated that negative outcomes in a choice alternative task elicited an MFN even when that choice was not an explicit error. 'Slot machine'-like tasks also elicit an MFN that is largest when unfavorable outcomes occur, especially when those outcomes are unexpected, even in the absence of a choice or action by the participant (Donkers, Nieuwenhuis, & van Boxtel, 2005; Martin & Potts, 2004; Potts, Martin, Burton, & Montague, 2006). Although passive tasks can elicit an MFN, the MFN is generally larger during active tasks, implying that the outcome monitoring system is differentially engaged by the individual's actions. Yeung, Holroyd, and Cohen (2005) used a four-choice forced alternative design in which either the participant or the computer made the choice that

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doi:10.1016/j.bandc.2011.04.001

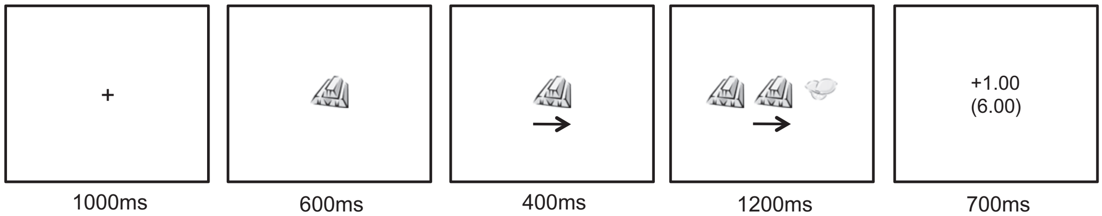

Fig. 1. An example trial illustrating when an unpredicted no reward trial (i.e. the expected reward was not delivered).

resulted in a monetary gain or loss. An MFN was elicited to choices that resulted in loss whether the choice was made by the participant or by the computer, but the MFN was larger when the participant made the choice. However, unlike the passive 'slot-machine' tasks (Donkers et al., 2005; Martin & Potts, 2004; Potts et al., 2006), the design used by Yeung et al. (2005) did not manipulate reward prediction probability; the reward probability associated with each choice was the same, thus the relative impact of reward prediction error and active choice on the outcome monitoring system could not be assessed. Given that the MFN is amplified when outcomes are worse than predicted (Holroyd & Coles, 2002) and during active compared to passive tasks (Yeung et al., 2005), the current study sought to investigate the impact of both reward prediction violation and active choice on the neural system of outcome monitoring using the MFN.

In the current study, reward predicting and outcome delivering stimuli were presented in active and passive choice blocks to determine if reward prediction violation would fully determine MFN amplitude or if active choice in a probabilistic reward context would modulate the MFN. A main effect of reward prediction (expected vs. unexpected outcome) but not task (active vs. passive task) on the MFN would indicate that reward prediction error drives the neural outcome monitoring system to a greater degree than the impact of the participant's choice on that outcome. On the other hand, a main effect of task but not reward prediction violation would indicate that the outcome monitoring system is more devoted to evaluating the individual's actions than to reward prediction error. However, if reward prediction and task interact on the MFN then the results would indicate that the relationship between reward prediction error and choice outcome evaluation is complex and both aspects should be taken into account when developing models of behavior monitoring in the brain.

2. Materials and methods

2.1. Participants

Twenty (five female) Rice University undergraduate psychology students (ages 18–22) participated for course credit. Five participants (one female) were excluded from the ERP analysis due to excessive eye movement and eye blink artifact. Excessive artifact was defined as fewer than 20 artifact-free trials per condition. All participants provided informed consent prior to participation.

2.2. Task and stimuli

A reward prediction S1/S2 paradigm based on Martin and Potts (2004) and Potts et al. (2006) was modified to incorporate both active and passive responses. Stimuli were images of lemons (associated with no reward value) and gold bars (associated with rewards of $0.25). Each trial consisted of a lemon or gold bar (S1) presented at the center of the screen, a choice (left or right) made by the participant's keypress (active blocks) or by the computer (passive blocks), followed by two stimuli (S2) presented to the left and right of S1. The participant received the outcome associated with the selected S2.

S1 predicted reward delivery with 75% accuracy. For example, if S1 was a lemon 75% of the time the selected S2 was also a lemon and, as predicted, no reward was delivered. If S1 was a gold bar then 75% of the time the selected S2 was also a gold bar and, as predicted, a reward was delivered. However, on 25% of the trials S1 did not match the selected S2 and unpredicted outcomes occurred. When S1 was a lemon and the selected S2 was a gold bar, an unpredicted reward was delivered. On the other hand, when S1 was a gold bar and S2 was a lemon, the predicted reward was not delivered. Two-thirds of the trials on which predicted outcomes were delivered consisted of congruent S2 stimuli, i.e. the S2 stimuli on the left and right of S1 both matched S1. The remaining predicted outcome trials and all the unpredicted outcome trials consisted of incongruent S2 stimuli on which only one of the S2 stimuli matched S1. Incongruent stimuli were used to increase participants' levels of engagement on the task by showing that the alternative choice would have resulted in the opposite outcome.

The experiment consisted of eight blocks with 100 trials per block. Four of the blocks were participant choice (active blocks) and four were computer choice (passive blocks). The experiment alternated between active and passive blocks with the order counterbalanced such that half the participants began with an active block followed by a passive block and the other half began with a passive block followed by an active block. Participants began

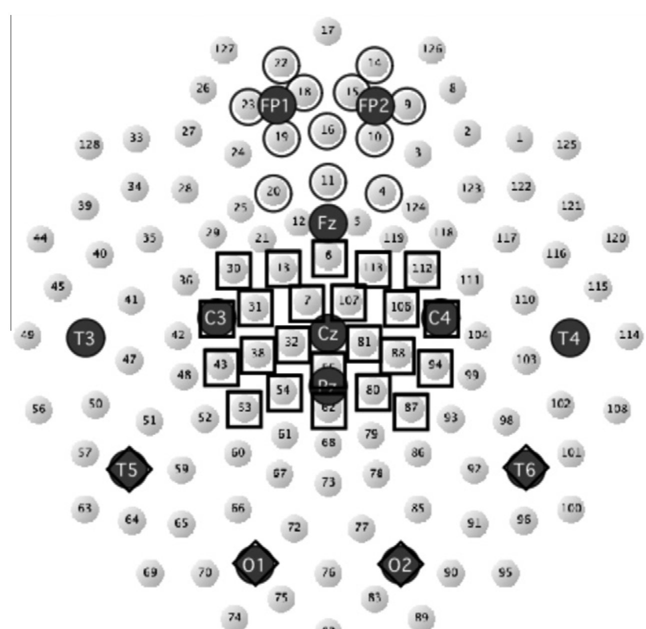

Fig. 2. Map of the 128 channel electrode net with the 10/20 system locations marked. Electrodes included in the Frontal (MFN) ROI are marked with circles, the centro-parietal (P3) ROI with squares.