Reward positivity is elicited by monetary reward in the absence of response choice

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The neural response to positive and negative feedback differs in their event-related potentials. Most often this difference is interpreted as the result of a negative voltage deflection after negative feedback. This deflection has been referred to as the feedback-related negativity component. The reinforcement learning model of the feedback-related negativity establishes that this component reflects an error monitoring process aimed to increase behavior adjustment progressively. However, a recent proposal suggests that the difference observed is actually due to a positivity reflecting the rewarding value of positive feedbacks – that is, the reward positivity component (RewP). From this it follows that RewP could be found even in the absence of any action-monitoring processes. We tested this prediction by means of an experiment in which visual target stimuli were intermixed with nontarget stimuli. Three types of targets signaled money gains, money losses, or the absence of either money gain or money loss, respectively. No motor response was required. Event-related potential analyses showed a central positivity in a 270–370 ms time window that was elicited by target stimuli signaling money gains, as compared with both stimuli signaling losses and no-gain/no-loss neutral stimuli. This is the first evidence to show that RewP is obtained when stimuli with rewarding values are passively perceived. *NeuroReport* 26:152–156

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Introduction

Feedback-related negativity (FRN) is characterized by a negative peak on the event-related potential (ERP) signal that reaches its maximum point at ~250 ms after the onset of negative feedback as compared with positive feedback [1]. Although a growing body of research has been dedicated to the study of FRN, the functional interpretation of this evoked potential remains controversial [2].

According to the reinforcement learning model of the FRN (RL-FRN), the FRN is the neural correlate of an error prediction signal, which is used for response correction [3]. However, recent experiments have shown that FRN can be found in passive tasks in which the participants do not have to execute any instrumental response [4,5]. For instance, Yeung *et al.* [4] recorded ERPs while participants were working on three different tasks: a choice task, a no-response task, and an odd-ball task. In the choice task, participants had to choose one of the four stimuli displayed on the screen. They were instructed that each stimulus selection was associated with winning or losing money. Emoticon images were used as feedback (informing about these monetary consequences): a smiling emoticon indicated a gaining of 4¢, and a sad emoticon indicated that they had lost 2¢. In the no-response task the emoticons were displayed within a stream of nonrelevant images. In this passive task participants did not make any choice; they simply had to attend to the emoticons to keep count of their winnings. Importantly, these had the same monetary consequences as in the choice task. Finally, the odd-ball task was similar to the no-response task, with the difference that emoticons did not entail any monetary consequence. It was counting the right number of relevant emoticons that made participants win money. Analysis of ERP signals locked to the emoticon's onset showed an FRN in the choice task. This component was not observed in the odd-ball task, in which no differences between positive and negative emoticons were observed. Importantly, Yeung and colleagues obtained a moderate but reliable FRN in the no-response task. Similar results have been obtained with different experimental procedures [5].

It is important to note that results indicating that the FRN can be obtained in passive tasks cannot be explained by the RL-FRN theory. According to this model, the FRN would be generated by the anterior cingulate cortex in response to the activation of the mesencephalic dopamine system, which would act as a continuous performance evaluation system. Specifically, when a feedback stimulus indicates that the consequences of an action are worse than expected, motor neurons of the anterior cingulate cortex suffer a phasic decrease in dopamine activity, leading to a large FRN [3]. Thus, in the absence of actions to be monitored, the RL-FRN theory predicts absence of FRN [4].

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Given that FRN has been obtained in passive task contexts, contrary to the prediction of the RL-FRN theory, other authors have proposed that the FRN might reflect the process of evaluating the rewarding value of a stimulus itself, instead of processing related to motor behavior [6]. In this vein, recent results seem to indicate that FRN is caused by the processing of correct feedback stimuli, which would produce a positive deflection – namely, the reward positivity (RewP) [7,8]. According to these authors, the voltage difference observed in FRN is caused by the presence of the RewP following the appearance of a positive feedback, compared with the ERP caused by the appearance of a negative feedback, which would not show a RewP. These authors suggest that the characteristic negative peak found in negative feedback is actually a N2b, produced by the presentation of a relevant stimulus. Thus, according to this theory every presentation would be accompanied by a negative N2b, and only in the positive feedback trials would there be a RewP. An unsolved question is whether the RewP would be observed even in task contexts in which the target stimuli do not provide feedback about the participant's previous action – for instance, the no-response task used in Yeung *et al.* [4].

In the present experiment we assessed whether RewP would be obtained in passive tasks. Thus, experimental stimuli were perceived passively and their presentation was randomly predetermined and out of the participant's control. Participants were instructed to silently count the number of target stimuli – as in the no-response task of Yeung *et al.* [4]. Thus, participants were merely exposed to stimuli of positive (money gain), negative (money loss), and neutral (neither money gain nor loss) valences. Importantly, this is the first study that compares a neutral condition with a positive and a negative condition in a passive task context. By using this neutral condition as a control condition we could test whether the mere emotional valence of target stimuli can produce the RewP.

Methods

Participants

A total of 23 right-handed adults participated in the present study, which was approved by the Ethics Committee of the University of Málaga and met the ethical standards of the Helsinki Declaration. All participants gave their informed consent before the experiment. Two participants were excluded from subsequent analysis because they repeatedly failed to correctly recollect the number of targets at the end of the block (percentage of errors more than two SDs from the sample mean). Therefore, the final sample was composed of 21 participants (10 males) between the ages of 19 and 33 ($M=22.1$, SD = 3.8). Participants received a monetary incentive for completing the experimental session ($M=$ €24.8, SD = €2.8).

Procedure

Participants sat 60 cm from a 19 inch computer screen, on which black-and-white stimuli were shown centered on a gray (RGB: 192, 192, 192) background. These stimuli measured at the most 7 cm wide and 7 cm high, thus subtending a maximum horizontal and vertical visual angle of $\sim 7°$. A total of 195 pictures were used as stimuli. Three of them were emoticons with three different expressions – namely, happy, neutral, and sad. The remaining 192 visual stimuli were drawings that belonged to one of the following 16 categories: sea life, animals (excluding aquatic ones), stationery, hats, clothes (excluding hats), food, iconic drawings of Olympic sports, vehicles, musical instruments, forest life, hieroglyphics, toys, kitchenware, world monuments, toiletries, and abstract symbols.

Participants were told that they had to watch sequences of consecutive pictures on a computer screen. Each sequence constituted a block. They were instructed to count how many times an emoticon appeared in each block. Then, they had to say aloud the number of targets in a block just when that block finished. There were blocks with sad emoticons, with neutral emoticons, and with happy emoticons. In the case of blocks with happy emoticons (hereafter called positive valence condition), participants always won money, specifically €0.08 per emoticon, if the participant said the correct number of emoticons at the end of the block, and €0.04 per target otherwise. In the case of blocks with neutral emoticons (hereafter called neutral valence condition), giving the right answer for the number of emoticons made participants win a fixed amount of €0.75, whereas giving a wrong one made them lose the same amount of €0.75. Finally, in the case of blocks with sad emoticons (hereafter called negative valence condition), participants always lost money, specifically €0.04 per emoticon when they gave the correct answer at the end of the block, and €0.08 per emoticon otherwise. Participants started the task with an initial amount of €5.

The whole experimental session consisted of 48 blocks – 16 blocks per valence condition – intermixed randomly. In each block, a fixed number of 16 target stimuli (i.e. emoticons) appeared among 48 nontargets. However, some stimuli – including target stimuli – were included at the end of each series to randomize the actual number of target stimuli in a block. Thus, the actual range of stimuli in each block was between 17 and 20.

At the beginning of every block, participants were presented with a fixation cross placed in the center of the screen for 900 ms before the presentation of the first picture. Each visual stimulus was shown for 500 ms. The interstimulus interval was random, ranging between 900 and 1100 ms inclusive, with a mean step size of 25 ms. During the interstimulus interval, a fixation cross was shown in the center of the screen.

At the end of each block participants were asked to say aloud how many emoticons had appeared in that block. Then, feedback was provided by the experimenter. Thereafter, the amount of money that the participant had earned up to that point was displayed on the screen. The participant carried on to the next block by pressing the spacebar.

Data recording

An IBM compatible computer was used to collect behavioral data and present stimuli. Responses at the end of the blocks were registered using a PC keyboard below the computer monitor.

ERPs were recorded from the scalp with tin electrodes mounted on an electrocap at 29 standard positions (10–20 system) (Fp1/2, F3/4/7/8, Fc3/4, C3/4, Cp3/4, P3/4, O1/2, T3/4, TP7/8, T5/6, Fpz, Fz, Fcz, Cz, Cpz, Pz, Oz). The data were referenced to the outer canthus of the right eye (on-line) and the average mastoid recording (off-line). The electrooculogram of the vertical eye movements was monitored by an electrode placed on the infraorbital ridge of the right eye. Electrode impedances were kept below 5 kΩ. The electrophysiological signals were digitized at a rate of 250 Hz.

We filtered the electroencephalographic signal (EEG) with a Notch filter centered in 50 Hz and a Butterworth bandpass filter between 0.1 and 40 Hz. The presence of artifacts in the resultant data was corrected by applying the SOBI algorithm [9]. Additional artifacts were eventually rejected, excluding from the analysis those epochs with a base-to-peak EEG amplitude greater than 100 μV. The entire processing stage was carried out using EEGLAB [10]. As a result, the mean percentage of valid epochs extracted for each valence condition was 89.02, 90.06, and 88.68 for the positive, the neutral, and the negative valence condition, respectively.

ERP data analysis

EEG epochs were extracted from the 200 ms previous to the target's onsets to the 600 ms after it. Data were baseline-corrected by subtracting the average activity that occurred during the 200 ms preceding the onset of the time-locking event, and averaged across conditions for each participant.

The FRN/RewP was measured as the mean amplitude of the 100 ms time window occurring for 270–370 ms after the target's onset. This window was centered over the peak with maximum difference between the mean voltages of negative and positive valence target stimuli – within a 200–350 ms time window [11]. We selected for statistical analysis the electrode in which this negative-minus-positive effect was maximum (Cz, Fig. 1). By doing so, we guaranteed that the time window and electrode selection was optimal to detect the presence of differences between positive and negative conditions. It must be noted that the neutral condition was not used for this selection. This criterion maximizes the sensitivity of the measure for detecting the FRN (negative–positive) without increasing the probability of type I error for the critical positive versus neutral comparison. Greenhouse–Geisser correction for degrees of freedom was performed when sphericity was violated in repeated-measures analysis of variance (ANOVA).

Results

Participants' performance in counting targets was equivalent through the three conditions [$\chi^2(2, N=1008)=1.705$, $P=0.426$ (mean value of 93% of correct responses)]. Trials corresponding to blocks in which a wrong answer had been given were excluded from subsequent statistical analyses.

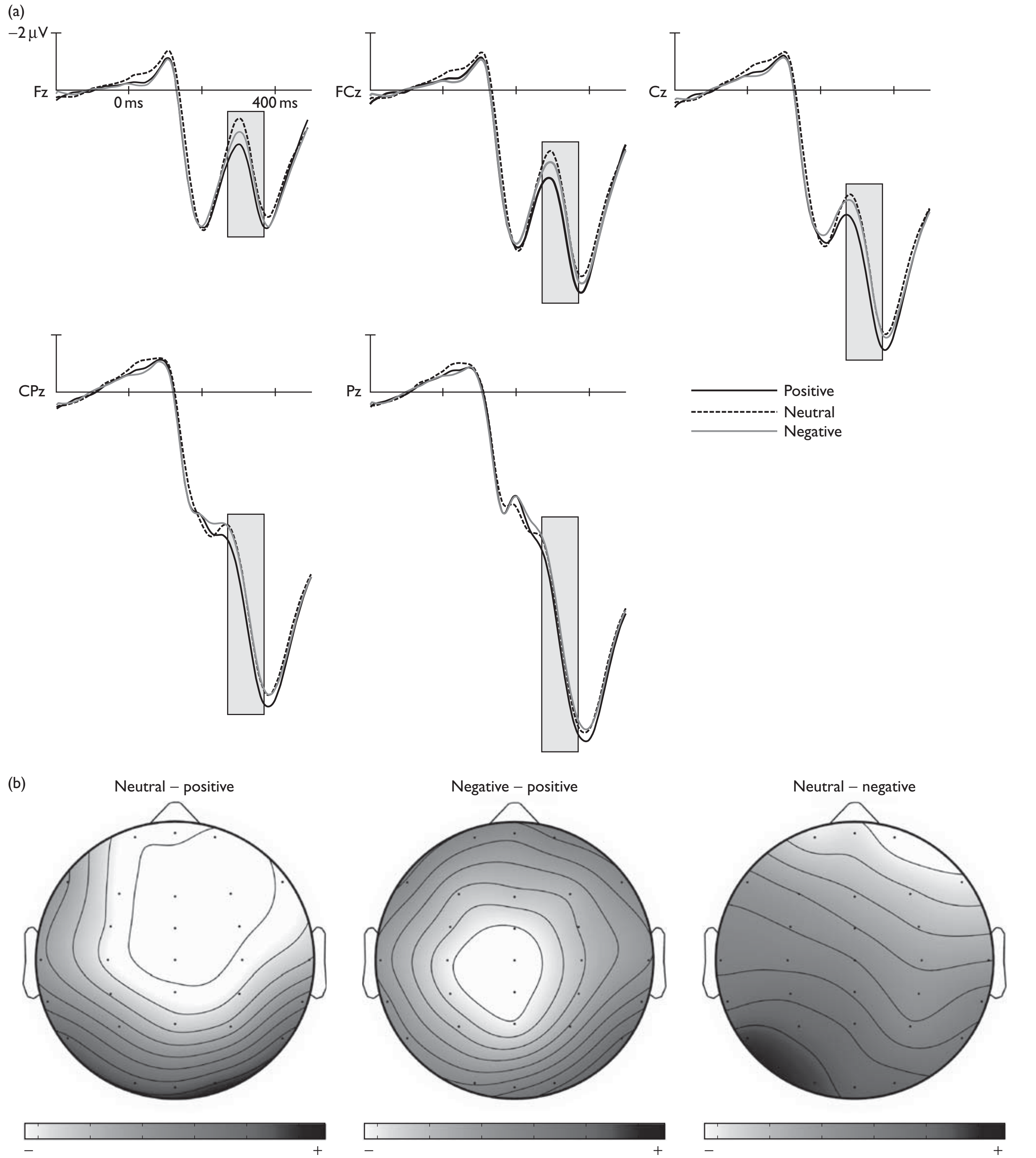
Figure 1 shows the ERPs (lowpass filtered below 10 Hz) for the three different valence conditions of target stimuli in five electrodes of the central line. We conducted a one-way ANOVA to compare the effect of the different valence conditions on the voltage in Cz. The analysis revealed a main effect of valence condition [$F(2, 40)=4.738$, $P=0.014$, $\eta_p^2=0.192$]. Specifically, the amplitude in the positive valence condition was significantly more positive than the amplitude both in the neutral [$t(20)=2.525$; $P=0.020$; $d=0.173$] and in the negative valence condition [$t(20)=2.353$; $P=0.029$; $d=0.137$], whereas the amplitudes in the neutral and negative valence conditions did not differ [$t(20)<1$].

We also controlled for the possibility that the effects reported above were caused by P3 modulations. If our results were caused by P3 modulations, because the P3 component is more parietal than the FRN, we would expect larger effects in Pz than in Cz. Importantly, this was not the case. We performed an additional three (valence: positive, neutral, and negative) × 2 (electrode: Cz and Pz) repeated-measures ANOVA. This analysis revealed a main effect of valence [$F(2, 40)=3.546$, $P=0.038$, $\eta_p^2=0.151$], a main effect of electrode [$F(1, 20)=29.6$, $P<0.001$, $\eta_p^2=0.597$], and a significant valence × electrode interaction [$F(2, 40)=4.503$, $P=0.017$, $\eta_p^2=0.184$]. Pairwise comparisons indicated that in Pz the mean amplitude of the EEG signal did not differ between conditions [positive vs. neutral: $t(20)=1.451$; $P=0.162$; $d=0.137$; positive vs. negative: $t(20)=2.005$; $P=0.059$; $d=0.163$; neutral vs. negative: $t(20)<1$]. Thus, the ERP effect found in Cz was not due to P3 modulations.

Discussion

In the current experiment, the mean voltage during a 270–370 ms window after the target's onset was more positive in the case of positive target stimuli than in the case of negative or neutral target stimuli, which did not differ between them. Thus, our results are consistent with previous experiments in which FRN was observed

Fig. 1



(a) Target stimuli-locked EEG signals for the three experimental conditions in five electrodes of the central line. (b) Topographic distribution of the three resultant difference waveforms between valence conditions within a 100 ms time window between 270 and 370 ms after stimulus onset. The voltage of the three topographic distribution graphs ranges from −0.65 to 0.5 μV. EEG, electroencephalography.

in passive tasks [4,5]. In addition, we have shown for the first time that the processing of motivational positive stimuli produces a RewP in a passive task.

If the RewP index neural activity related to the motivational properties of positive rewards ([8]), it should appear in different related situations. A recent study showed that the RewP is elicited during the presentation of stimuli, which indicated that a large reward could be earned in that trial, as compared with noninformative stimuli and stimuli signaling low reward [12]. In a similar vein, the RewP is reduced when the experimental context emphasizes that no actual money could be won or lost, as compared with tasks in which actual money could be won [13].

However, other aspects of RewP are less understood. For example, there are studies that point to an involvement of the RewP in the neural processes responsible for the integration of actions and their outcomes [14]. Thus, it seems that more research is required for a better characterization of the functional role of the RewP, as well as for the potential interactions with different cognitive and neural systems.

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Conflicts of interest

There are no conflicts of interest.

References

1 Miltner WH, Braun CH, Coles MG. Event-related brain potentials following incorrect feedback in a time-estimation task: evidence for a 'generic' neural system for error detection. *J Cogn Neurosci* 1997; **9**:788–798.
2 Walsh MM, Anderson JR. Learning from experience: event-related potential correlates of reward processing, neural adaptation, and behavioral choice. *Neurosci Biobehav Rev* 2012; **36**:1870–1884.
3 Holroyd CB, Coles MG. The neural basis of human error processing: reinforcement learning, dopamine, and the error-related negativity. *Psychol Rev* 2002; **109**:679–709.
4 Yeung N, Holroyd CB, Cohen JD. ERP correlates of feedback and reward processing in the presence and absence of response choice. *Cereb Cortex* 2005; **15**:535–544.
5 Warren CM, Holroyd CB. The impact of deliberative strategy dissociates ERP components related to conflict processing vs. reinforcement learning. *Front Neurosci* 2012; **6**:43.
6 Gehring WJ, Willoughby AR. The medial frontal cortex and the rapid processing of monetary gains and losses. *Science* 2002; **295**:2279–2282.
7 Holroyd CB, Pakzad-Vaezi KL, Krigolson OE. The feedback correct-related positivity: sensitivity of the event-related brain potential to unexpected positive feedback. *Psychophysiology* 2008; **45**:688–697.
8 Proudfit GH. The reward positivity: from basic research on reward to a biomarker for depression. *Psychophysiology* 2014. doi: 10.1111/psyp.12370.
9 Belouchrani A, Cichocki A. Robust whitening procedure in blind source separation context. *Electron Lett* 2000; **36**:2050–2051.
10 Delorme A, Makeig S. EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *J Neurosci Methods* 2004; **134**:9–21.
11 Marco-Pallares J, Cucurell D, Münte TF, Strien N, Rodriguez-Fornells A. On the number of trials needed for a stable feedback-related negativity. *Psychophysiology* 2011; **48**:852–860.
12 Luque D, Moris J, Rushby JA, Le Pelley ME. Goal-directed EEG activity evoked by discriminative stimuli in reinforcement learning. *Psychophysiology* 2014. doi: 10.1111/psyp.12302.
13 Weinberg A, Riesel A, Proudfit GH. Show me the money: the impact of actual rewards and losses on the feedback negativity. *Brain Cogn* 2014; **87**:134–139.
14 Weinberg A, Luhmann CC, Bress JN, Hajcak G. Better late than never? The effect of feedback delay on ERP indices of reward processing. *Cogn Affect Behav Neurosci* 2012; **12**:671–677.