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Electrophysiological correlates of anticipating improbable but desired events

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ABSTRACT

Psychological studies have emphasized that motivation is regulated by the anticipation of the emotional impact from the possible occurrence of unexpected rewarding events. Here, we scrutinized the existence of a corresponding neural signal by means of event-related potentials (ERPs) and computational modeling. In the first experiment, we designed a task that manipulated the probability of gaining a monetary reward and measured ERPs during anticipation and at reward delivery. A sustained frontocentral neural activity (i.e., the stimulus preceding negativity, SPN) was evidenced during the anticipation period. Critically, the SPN was found to increase in amplitude as the reward became more unexpected. Changes in the SPN were found to be predictive of individual differences in risk seeking, suggesting that a greater risk attitude involved a greater motivational state for receiving an improbable reward. In the second experiment, SPN results associated with unexpected monetary gains were replicated in a condition in which participants avoided monetary losses and the occurrence of unexpected rewards was also associated with an increase in the amount of self-reported pleasure. These findings support the existence of a neural ERP signature that encodes the process of tuning our motivation to the possibility of receiving a desirable but improbable rewarding outcome.

Introduction

Neuroeconomists and psychologists have largely emphasized that motivation is strongly influenced by the expected hedonic consequences of the outcome of one's choice (Mellers and McGraw, 2001). This is so because humans are endowed with the ability to mentally simulate the emotional consequences that events are likely to engender (Gilbert and Wilson, 2007). For instance, a person often exhibits a high level of excitement while awaiting the result of a lottery ticket, even though our midbrain dopaminergic neural system has anticipated with precision that the probability of gaining is remarkably remote (Knutson et al., 2001; Schultz, 2011; Tobler et al., 2005). One possible explanation for such elevated motivational expectations can be derived from the processing of highly unexpected but desired rewarding events (Mellers et al., 1997, 1999). Indeed, psychologists have highlighted the emotional amplification that occurs when receiving an unforeseen rewarding event and the subsequent elevation of motivational expectation for similar future rewards (Mellers and McGraw, 2001). However, the brain mechanisms responsible for the changes in attentional or motivational state during the anticipation of improbable rewarding events remain unexplored and this constitutes the aim of the present research.

To determine to what extent brain anticipatory responses expressed differences in motivational states, event-related potentials (ERPs) were measured in two separate ERP experiments. We used ERPs here because, unlike other neuroimaging approaches, they allow for the assessment of how neural activity evolves during the time leading up to an event. Additionally, the fine-grained time resolution of ERPs permits the separation of neural state signals in response to different events that occur very close in time, such as the anticipation and impact of a reward.

In the present investigation, we used a sustained frontocentral negative component known as the stimulus preceding negativity (SPN) as an index of the degree of a participant's reward expectation. The SPN is easily observed in the 'waiting period' expressing the motivational/attentional engagement due to possible informative or emotionally relevant feedback (Brunia et al., 2011). The impact of reward delivery was evaluated through the modulation of the amplitude of the feedback-related negativity (FRN) and the P3. The FRN is thought to represent

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the manifestation of a rapidly evaluating motivational system provided by the feedback stimulus that is especially sensitive in expressing the degree by which an outcome is better or worse than expected (Gehring and Willoughby, 2002; Holroyd and Coles, 2002). The P3 has been shown to provide a suitable neural coding response for the degree of unexpectedness or surprise of an event (Duncan-Johnson and Donchin, 1977; Sutton et al., 1965) (see Polich, 2007 for a review).

We tested the prediction that unexpected rewards would induce motivational/attentional states by examining how experimental manipulations and individual differences can modulate neural signals elicited during anticipation and at reward delivery. In the first ERP and computational modeling experiment, we aimed to evaluate the relative contributions of neural signals to anticipation under 5 blocked conditions in which reward was increasingly less likely, with probabilities ranging from 0.9 down to 0.1 in each of the blocks. Because reward magnitude was equated between probability conditions, we hypothesized that (i) differences in motivational/attentional brain states during reward anticipation (measured through the SPN) should vary as a function of reward unexpectedness, (ii) the magnitude of neural responses (measured through the FRN and P3) at reward delivery activity should increase according to the degree of participants' surprise, and (iii) individual differences in SPN magnitude should covary with differences in participants' risk seeking because anticipated pleasure has been related to risk attitude (Mellers and McGraw, 2001). In the second ERP experiment, we aimed to replicate the previous findings regarding SPN and the probability of receiving unexpected monetary gains and we further evaluated the degree that these findings could be extended to an experimental situation in which participants instead of exclusively gaining money were requested to avoid a possible punishment or negative outcome (monetary losses). Finally, we sought to additionally test in the second ERP experiment whether the amount of surprise after a reward was delivered was related to increases in self-reported feelings of pleasure.

Material and methods

Experiment 1

Participants

Sixteen participants were recruited for this study (twelve females; mean age, 23.5; SD, 1.6 years). All participants were healthy, right-handed and reported neither vision problems nor neurological disorders. Informed consent was obtained from participants in accordance with procedures approved by the Ethics Committee of the University of Barcelona.

Task design

The paradigm consisted of a task that required the participants to learn the correct association between a picture and a button press (see Fig. 1A). Participants were instructed that each cue (i.e., pictures) was associated with a single correct response. They were explicitly told that pressing the correct button was sometimes, but not always, followed by a 'gain' outcome (+0.04€). In addition, they were told that trials with an erroneous button press would always be followed by a 'no-gain' outcome (0€). The experiment consisted of 5 identical trial-structure blocks in which the probability to have a rewarded trial, in the case of a correct picture–button association, was parametrically manipulated. The 5 blocks involved a particular probability to obtain a reward: 0.1, 0.3, 0.5, 0.7 and 0.9, which covered the entire probability density. The order of the blocks was pseudorandomized. However, blocks of 0.1 and 0.3 were never presented at the beginning of the experiment. Based on previous pilot studies, this criterion was set to avoid the possibility that participants would not learn any picture–response association during these blocks. Each block contained a set of 6 different familiar black and white pictures (Snodgrass and Vanderwart, 1980) that were randomly assigned to 1 out of 3 possible buttons on a standard PC keyboard ('V'; 'B'; 'N'). Each of the pictures

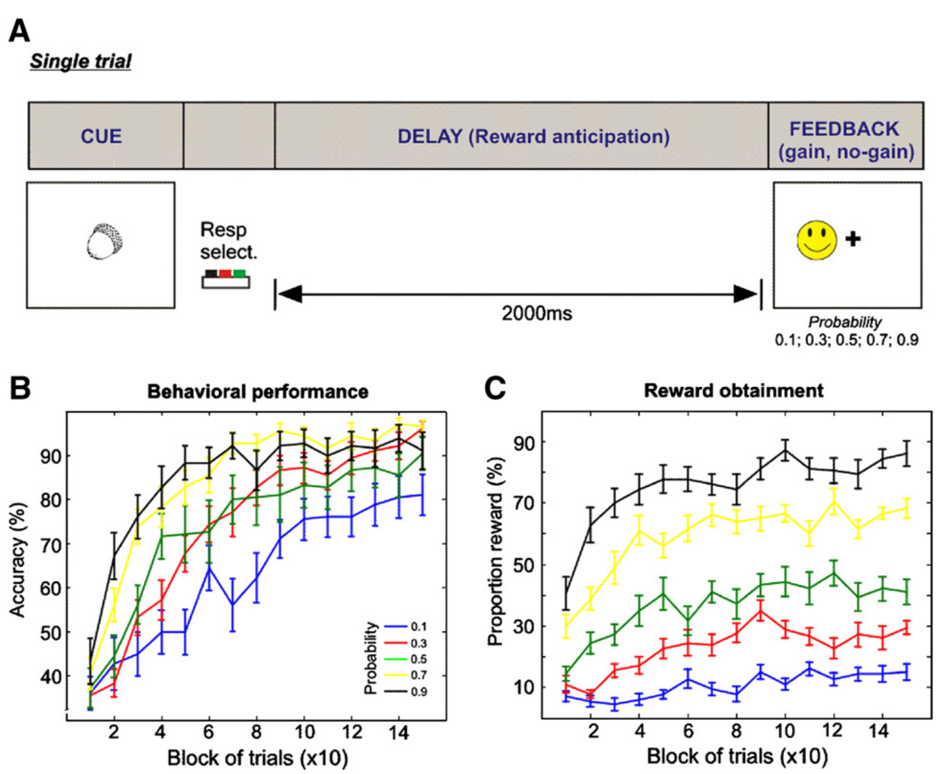

Fig. 1. (A) Schematic representation of a single trial. A cue-picture was presented and participants were instructed to learn which correct button to press so that after a fixed delay of 2 s the correct button press would give them a reward (5 different independent blocks with p = 0.1, 0.3, 0.5, 0.7 and 0.9 to obtain a reward). (B) Percentage of trials in which a correct response was given. Error bars denote the standard error of the mean. (C) Percentage of rewards (gain trial) obtained across participants throughout each experimental block.