NeuroImage xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

NeuroImage

journal homepage: www.elsevier.com/locate/ynimg

Sunk costs in the human brain

Ariane Haller [a], Lars Schwabe [a,b,*]

[a] Institute of Experimental Psychology, Department of Biological Psychology, Heinrich-Heine University Düsseldorf, 40225 Düsseldorf, Germany
[b] Institute of Cognitive Neuroscience, Department of Cognitive Psychology, Ruhr-University Bochum, 44780 Bochum, Germany

ARTICLE INFO

Article history:
Accepted 7 April 2014
Available online xxxx

Keywords:
Decision-making
Sunk costs
Prefrontal cortex
vmPFC
dlPFC
Norms

ABSTRACT

Rational decision-making should not be influenced by irrecoverable past costs. Human beings, however, often violate this basic rule of economics and take 'sunk' costs into account when making decisions about current or future investments, thus exhibiting a so-called 'sunk cost effect'. Although the sunk cost effect may have serious political, financial or personal consequences, its neural basis is largely unknown. Using functional magnetic resonance imaging (fMRI) and a novel financial decision-making task, we show here that previous investments reduced the contribution of the ventromedial prefrontal cortex (vmPFC) to current decision-making and that this reduction in vmPFC activity correlated with the sunk cost effect. Moreover, activity in the dorsolateral prefrontal cortex (dlPFC) was associated with the norm not to waste resources and negatively correlated with vmPFC activity. The present findings show how past investments may bias decision-making in the human brain, suggesting that the interaction of vmPFC and dlPFC may promote a tendency to throw good money after bad.

Introduction

According to traditional economic theory, rational decision-making should be based on current and future costs and benefits associated with the available alternatives (Bernoulli, 1954; Frank and Bernanke, 2006). Past costs that have already been incurred and cannot be recovered, however, should be ignored when making decisions about present investments. Nevertheless, people are frequently influenced by previous investments in their decision-making, succumbing to a cognitive bias known as the 'sunk cost' effect (Arkes and Ayton, 1999; Arkes and Blumer, 1985). Although the sunk cost effect often leads to adverse financial (McNamara et al., 2002), political (Staw, 1976), or personal consequences (Strube, 1988), its neurobiological underpinnings are largely unknown.

Recent years have seen rapid advances in understanding how decision processes are implemented in the brain (Blakemore and Robbins, 2012; Grabenhorst and Rolls, 2011; Kable and Glimcher, 2009; Rangel et al., 2008). Neurophysiological and neuroimaging studies identified a large network of brain areas relevant for decision-making, including the ventral striatum, the amygdala, the anterior cingulate cortex (ACC), and the parietal cortex (de Martino et al., 2006; Hare et al., 2008; Hunt et al., 2012; Platt and Glimcher, 1999). However, in particular the orbitofrontal cortex (OFC) and the ventromedial prefrontal cortex (vmPFC) are thought to integrate the various dimensions of an option and to compute expected value or utility (Grabenhorst and Rolls, 2011; Kable and Glimcher, 2009; Padoa-Schioppa and Assad, 2006; Schwabe et al., 2012; Valentin et al., 2007) that is central in economic and psychological decision theories (Kahneman and Tversky, 1979; von Neumann and Morgenstern, 1944). Here, we set out to examine how past investments change the contribution of these areas to decision-making and, thus, to characterize the brain mechanisms underlying the sunk cost effect.

To this end, we collected functional magnetic resonance images (fMRI) while participants performed a novel financial decision-making task in which they first had to decide whether to invest a certain amount of money in a project and were then asked whether they wanted to make additional investments that would be required to continue the project. According to economic theory, the initial investment decision and the decision to make further investments should be independent. Furthermore, the decision whether to continue a project or not should be unaffected by the amount of previous investments but only be influenced by the expected value of the current decision alternatives. We predicted, however, that current decision-making would be biased by past investment decisions and that this bias would be dependent on the amount that has already been invested. We further predicted that this sunk cost effect would be mediated by reduced activity in prefrontal areas that are implicated in expected value representation. Moreover, based on previous behavioral data (Arkes and Ayton, 1999), we expected that the tendency to consider sunk costs in current decision-making would be related to the individual norm not to waste resources and that this norm would be represented by brain areas that

* Corresponding author at: Ruhr-University Bochum, Department of Cognitive Psychology, 44780 Bochum, Germany. Fax: +49 234 3214308.
E-mail address: Lars.Schwabe@ruhr-uni-bochum.de (L. Schwabe).

http://dx.doi.org/10.1016/j.neuroimage.2014.04.036
1053-8119/

have been implicated in rule based control before, such as the dorsolateral prefrontal cortex (dlPFC; Koechlin and Summerfield, 2007).

Methods

Behavioral pilot studies

The task described below was first tested in two consecutive behavioral pilot studies. In the first pilot study, 12 healthy, young participants (6 men, 6 women; age range: 18 to 32 years) completed a task version that differed from the task that was finally used in the fMRI study in the probabilities of success (low probability of 25% vs. high probability of 75%) Because these parameters resulted only in limited behavioral variability, we ran a second pilot study, in which 15 healthy participants (7 men, 8 women; age range: 18 to 32 years) were tested and in which the investment task was used with exactly the same parameters as described below ("Investment task").

fMRI study

Participants

Twenty-eight healthy, right-handed volunteers with normal or corrected-to-normal vision and without a history of any psychiatric or neurologic disorders participated in this experiment (15 women; mean age = 24.8 years, age range: 20–31 years). All participants gave written informed consent and were paid for their participation. The study was approved by the Institutional Review Board of the Ruhr-University Bochum.

Investment task

During fMRI scanning, participants performed 324 trials of an investment task. On each trial, they were presented a project that was characterized by its costs and probability of success (Fig. 1). The project costs were 0.20 Euros (low) or 0.55 Euros (high) and the probability of success was 40% (low), 50% (medium), or 60% (high). These stated probabilities of success corresponded exactly to those success probabilities that were actually implemented in the trials. Behavioral pilot studies (see "Behavioral pilot studies") showed that these parameters resulted in sufficient variability in investment decisions. Participants had 5 s to decide whether they wanted to invest the requested amount in the given project or not by pressing the corresponding button on a response box; the location of the "invest" and "do not invest" responses on the screen varied randomly across participants. If they did not respond within 5 s or decided not to invest in the project, the trial was aborted. However, if participants decided to invest in the project, they received either the immediate feedback that the project was successful or not (according to the given probability of success) or they were informed that further investments would be required. In this latter case, participants were next shown the additional costs that would be required and the current probability of success. The additional costs could again be 0.20 Euros or 0.55 Euros and the probability of success could again be 40, 50, or 60%, thus the only difference between the decision scenarios for the initial investment and the follow-up investment was whether or not participants had already invested in the project. Again, participants had 5 s to decide whether to invest the additional costs or whether to stop the project. If participants invested the additional costs, they received immediate feedback on the success of the project, i.e., there was at maximum one follow-up investment. If the participants decided not to invest the additional costs, the trial was aborted.

Each of the six trial types that resulted from the different combinations of project costs (low vs. high) and probability of success (low vs. medium vs. high) was presented 54 times. In order to make sure that there was a sufficient number of trials in which the influence of prior investments on current investment decisions could be tested (i.e., in which participants had decided to invest), two-thirds of all trials were 'follow-up trials'. In these trials, participants were informed that follow-up investments would be required after they had decided to make the initial investment. These follow-up trials were further subdivided into those in which a low initial investment (0.20 Euros) had been made and those in which participants had already invested a high amount of money (0.50 Euros). Apart from the previous investment, 'no prior investment trials', 'low prior investment trials', and 'high prior investment trials' were identical; all possible costs × probability combinations were presented equally often in these trials. The inclusion of low- and high-prior investment trials has the advantage that possible effects of the amount of prior investment on decision-making

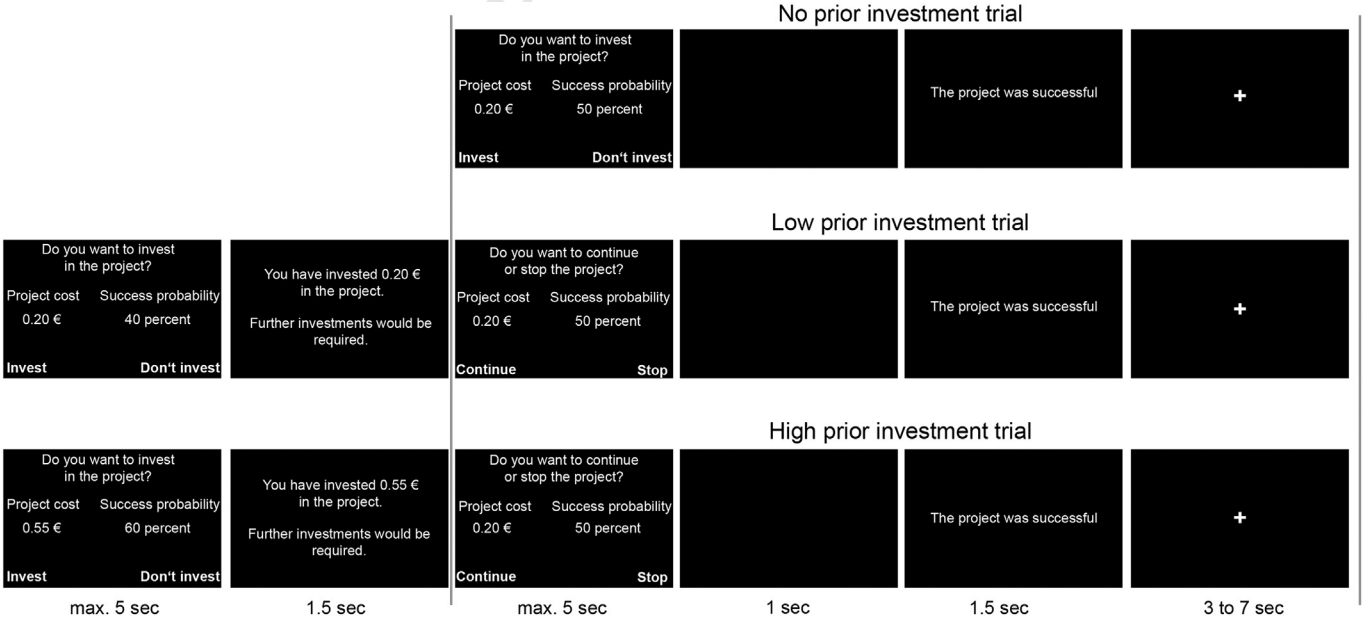

Fig. 1. The investment task. In each trial, participants were presented a project that was characterized by its costs (low vs. high) and probability of success (low vs. medium vs. high). Subjects should decide whether they wanted to invest the requested amount of money in the project or not. If they made the investment, they received either immediate feedback about the project's success (no prior investment trial) or were told that further investments would be required and had to decide whether to invest the additional costs or not (low- and high prior investment trials). The no-, low-, and high prior investment trials differed only in whether and how much participants had already invested in the project.

Please cite this article as: Haller, A., Schwabe, L., Sunk costs in the human brain, NeuroImage (2014), http://dx.doi.org/10.1016/j.neuroimage.2014.04.036