Biological Psychology 126 (2017) 30–40

Contents lists available at ScienceDirect

Biological Psychology

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

Effects of loss aversion on neural responses to loss outcomes: An event-related potential study

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ARTICLE INFO

Keywords:
Decision making
Loss aversion
Reward and punishment
Orbitofrontal cortex
Feedback-related negativity

ABSTRACT

Loss aversion is the tendency to prefer avoiding losses over acquiring gains of the same amount. To shed light on the spatio-temporal processes underlying loss aversion, we analysed the associations between individual loss aversion and electrophysiological responses to loss and gain outcomes in a monetary gamble task.

Electroencephalographic feedback-related negativity (FRN) was computed in 29 healthy participants as the difference in electrical potentials between losses and gains. Loss aversion was evaluated using non-linear parametric fitting of choices in a separate gamble task.

Loss aversion correlated positively with FRN amplitude (233–263 ms) at electrodes covering the lower face. Feedback related potentials were modelled by five equivalent source dipoles. From these dipoles, stronger activity in a source located in the orbitofrontal cortex was associated with loss aversion.

The results suggest that loss aversion implemented during risky decision making is related to a valuation process in the orbitofrontal cortex, which manifests during learning choice outcomes.

1. Introduction

Loss aversion is the tendency to prefer avoiding losses over acquiring gains of the same amount (Kahneman & Tversky, 1979). Loss aversion affects a large range of economic behaviours, such as willingness to part with an object in one's possession (Kahneman, Knetsch, & Thaler, 1990), relative sensitivity to price changes (Hardie, Johnson, & Fader, 1993; Putler, 1992), decision making in a monetary gamble task (Sokol-Hessner et al., 2009; Takahashi et al., 2012; Tom, Fox, Trepel, & Poldrack, 2007), or the style of playing golf (Pope & Schweitzer, 2011).

In prospect theory of decision making (Kahneman & Tversky, 1979), individual decisions are modelled by two functions, the probability weighting function and the utility function. Loss aversion, typically evaluated in tasks involving decision making under risk (Barkley-Levenson, Van Leijenhorst, & Galván, 2013; Canessa et al., 2013; Tom et al., 2007; Wright et al., 2012), is defined as a utility function that is steeper for losses than for gains of equal size. Similarly, losses are associated with greater autonomic (Sokol-Hessner et al., 2009; Stancak et al., 2015) and cerebral (Sokol-Hessner, Camerer, & Phelps, 2013; Tom et al., 2007) responses in people with strong loss aversion compared to people with small loss aversion. Individual levels of loss aversion have been shown to negatively correlate with the presence of norepinephrine transporters in the thalamus (Takahashi et al., 2012). Further, a recent structural magnetic resonance imaging (MRI) study revealed a positive correlation between loss aversion and grey matter volume in amygdala, thalamus and striatum (Canessa et al., 2013). Together, the above results suggest that loss aversion may operate as a relatively stable feature during decision making (Glöckner & Pachur, 2012), although loss aversion can also be modulated by the task or context (Schulreich, Gerhardt, & Heekeren, 2016; Sokol-Hessner et al., 2013; Stancak et al., 2015).

A loss in a monetary gamble task is a negative feedback. A wealth of electrophysiological data suggests that presenting information about losses compared to gains is associated with a negative deflection in the electrocortical potential, which is superimposed on the subsequent, typically large positive P300 component (Nieuwenhuis, Yeung, Holroyd, Schurger, & Cohen, 2004; Yeung, Holroyd, & Cohen, 2005).

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http://dx.doi.org/10.1016/j.biopsycho.2017.04.005
Received 20 September 2016; Received in revised form 4 April 2017; Accepted 4 April 2017
Available online 08 April 2017
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This negative electrical potential, known as feedback-related negativity (FRN), occurs between 200 and 350 ms (Gehring & Willoughby, 2002; Miltner, Braun, & Coles, 1997; Nieuwenhuis, Holroyd, Mol, & Coles, 2004; Walsh & Anderson, 2012) and shows a characteristic scalp potential map with a spatial maximum in the fronto-central midline region of the scalp (Gehring & Willoughby, 2002; Hajcak, Moser, Holroyd, & Simons, 2006; Nieuwenhuis, Yeung et al., 2004; Walsh & Anderson, 2012; Yeung & Sanfey, 2004). The cortical source of FRN has been located near or in the anterior cingulate cortex (Bellebaum & Daum, 2008; Gehring & Willoughby, 2002; Hewig et al., 2007; Miltner et al., 1997; Potts, Martin, Burton, & Montague, 2006; Ruchsow, Grothe, Spitzer, & Kiefer, 2002). However, the potential fields during the period of FRN appear to have a more complex topography with positive components occupying the bilateral temporal regions of the scalp, suggesting the possibility that multiple cortical sources might be involved (Gehring & Willoughby, 2002). Indeed, several studies have identified additional brain regions contributing to the generation of FRN (for reviews see Hauser et al., 2014; Walsh & Anderson, 2012), such as the posterior cingulate cortex (Badgaiyan & Posner, 1998; Cohen & Ranganath, 2007; Müller, Möller, Rodriguez-Fornells, & Münte, 2005; Nieuwenhuis et al., 2005) and the striatum (Martin, Potts, Burton, & Montague, 2009; Nieuwenhuis et al., 2005).

In the context of the present study, punishment sensitivity has been shown to be related to the amplitude of FRN (Santesso, Dzyundzyak, & Segalowitz, 2011; Unger, Heintz, & Kray, 2012). In studies exploring effects of framing, stronger FRN amplitudes were found in prospects framed negatively compared to those framed positively (Ma, Feng, Xu, Bian, & Tang, 2012; Yu & Zhang, 2014). Further, a recent ERP study showed that loss aversion attenuated amplitudes of a posterior positive slow wave during decisions involving low conflict between competing options (Heeren, Markett, Montag, Gibbons, & Reuter, 2016). These studies suggest the possibility of an association between FRN and loss aversion.

The purpose of the present study was to identify the cortical regions and time period when loss aversion modulates the cortical response to losses during the evaluation of choice outcomes. Although loss aversion affects decision making during the period of evaluation of expected utilities of individual prospects, previous studies also found processing of loss outcomes related to loss aversion (Sokol-Hessner et al., 2009, 2013; Stancak et al., 2015). Neural responses to expected (Knutson, Adams, Fong, & Hommer, 2001) and actually perceived (Delgado, Nystrom, Fissell, Noll, & Fiez, 2000; May et al., 2004) losses or gains are processed in an overlapping set of regions. Meta-analyses of fMRI studies typically point to ventral striatum, orbitofrontal and ventromedial prefrontal cortex as playing a central role in value-based decision making (Bartra, McGuire, & Kable, 2013; Clithero & Rangel, 2014). Therefore, we postulated that loss aversion will be associated with the electrophysiological responses to choice outcomes in one or more regions belonging to the brain valuation system (Bartra et al., 2013; Clithero & Rangel, 2014; Lebreton, Jorge, Michel, Thirion, & Pessiglione, 2009). To identify the brain regions involved in mediating the relationship between loss aversion and FRN, we applied source dipole analysis and analysed the associations between source dipole waveforms and loss aversion using correlation analysis. To differentiate the effects of sensitivity to losses from sensitivity to risk, a non-linear parametric method was applied to model the individual choices using three parameters: loss aversion, curvature of the value function and choice sensitivity (Sokol-Hessner et al., 2009, 2013; Stancak et al., 2015). Although the primary focus of the present study was on loss aversion, the curvature of the value function was evaluated as well to check the potentially overlapping effects of these two preference parameters. Finally, choice sensitivity served as an estimation of participants' response consistency throughout the experiment.

2. Methods

2.1. Participants

A total of 31 participants (16 females) completed the study. Two participants were removed from subsequent analyses due to technical issues encountered during EEG recordings. Thus, the final sample included 29 participants (14 females), aged 22.5 ± 3.6 years (mean ± SD), 4 left-handed. The experimental procedures were approved by the Research Ethics Committee of the University of Liverpool. All participants gave written informed consent in accordance with the Declaration of Helsinki.

2.2. Procedure

The experiment involved two different tasks. The first one was a monetary gamble task comprising 100 trials. Participants had to select between two prospects with one of them offering a sure zero outcome or sure non-zero gain and the other an uncertain gain or loss of variable amounts. This task was used to assess individual loss aversion levels. Next, participants completed an EEG experiment involving only uncertain monetary gambles followed by presentation of the outcome. The event-related potential analysis of the outcome period served to evaluate the individual FRN potentials. The purpose of the experiment was explained to participants, who were given instructions for the tasks at the beginning of the session.

2.3. Loss aversion task

The initial monetary gamble task was adapted from previous studies (Sokol-Hessner et al., 2009, 2013; Tom et al., 2007), and in particular from Stancak et al. (2015). Participants received an initial endowment of £20 and were instructed to use it for gambling during the experiment. They were informed that 10% of the difference between their total gains and losses would be added to or subtracted from this £20 endowment and they would receive the remaining amount as a reimbursement for their participation.

The task consisted of a total of 100 trials. In 80 of those trials, participants decided between a gamble and an alternative sure zero outcome. Each gamble consisted of 8 possible gain amounts (£1.0, £2.0, £3.0, £3.5, £4.5, £5.0, £5.5, £6.0) in combination with 10 possible losses. The losses were computed by multiplying each particular gain value with a coefficient from 0.2 to 2.0 in 0.2 steps in all possible permutations (8 gains × 10 losses). Potential gains and losses were associated with equal probabilities (i.e., 50%). In additional 20 trials, participants decided between a gain-only gamble and a sure non-zero outcome. Here, the gain-only gambles offered a 50% chance to win a certain gain amount or zero otherwise, whereas the sure alternative was a smaller gain. These 20 gambles were identical with those listed in Table 1 in our previous study (Stancak et al., 2015). Trials were presented in random order for each participant.

Participants were seated in front of a 19-inch CRT monitor, and rested their right hand on a computer mouse. The stimuli were presented using Cogent software 2000 (UCL, London, United Kingdom) for Matlab (Mathworks, Inc., USA). The trial structure is shown in Fig. 1A. Each trial began with a fixation cross that stayed on the screen for 1 s. Subsequently, two possible choices were displayed on the screen for 4 s. Half of the screen presented a gamble option (e.g., "you win £3.0, you lose £3.0") in yellow text on black background. Participants were informed that the outcome was always random (i.e., with 50% probability). The other half of the screen showed the value of a sure outcome (e.g., £0). They were instructed to choose between the two prospects by pressing the left or right mouse button according to the part of the screen they preferred. If the participant selected the risky gamble option, feedback about the outcome was shown for 1 s ("you won" or "you lost"). The duration of this initial gamble task was

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