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Neural mechanisms underlying context-dependent shifts in risk preferences

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ABSTRACT

Studies of risky decision-making have demonstrated that humans typically prefer risky options after incurring a financial loss, while generally preferring safer options after a monetary gain. Here, we examined the neural processes underlying these inconsistent risk preferences by investigating the evaluation of gains and losses, and demonstrating how these responses can impact subsequent preference for either risky or safe choice options. Participants performed a task while undergoing fMRI in which they experienced both gains and losses. Immediately following a gain or loss, participants decided to either play or pass on a "double-or-quits" gamble. The outcome of the gamble could either double or eliminate their initial gain (from the time-estimation task) or redeem or double their initial loss. If they chose not to play this gamble, they retained the initial gain or loss. We demonstrate a shift in risk-taking preferences for identical sets of gambles as a function of previous gains or losses, with participants showing a greater preference towards riskier decisions in the context of a prior loss. An interaction between evaluating gain/loss contexts and subsequent behavioral risk pattern revealed an increased BOLD response in the ventromedial prefrontal cortex (vmPFC), with stronger responses for both gambling in a loss context and safety in a gain context. This suggests that the vmPFC is responsible for integrating these contextual effects, with these processes impacting on subsequent risky choice.

Introduction

In daily life, people are typically faced with numerous risky decisions, for instance choosing whether or not to buy insurance on an expensive smartphone, or whether to invest money in stocks or save it for retirement. When deciding what to choose in a risky, uncertain environment, people generally exhibit risk averse tendencies, that is, they generally shy away from options with increased risk, even when the so-called expected value of the choice options is equal (Tversky and Kahneman, 1981, 1992). That is, if given a choice between €10 for sure and a gamble with a 50% chance of €20 and a 50% chance of €0, people overwhelmingly favor the certain €10, and in fact the 'winning' outcome of the gamble usually needs to be considerably higher to induce players to choose the risky option. Classical models of economic decision-making (e.g. utility theory and its variants) also assume that these individual choice preferences should be consistent over situations in which the same choice set is offered. For example, the decision to purchase a €5 lottery ticket should not be affected if you had previously either just found €5 on the street, or if alternately you had unfortunately just lost €5 from your wallet — the choice to spend the money to buy the lottery ticket should in theory be independent of these two events. However, several decades of behavioral work (e.g. Kahneman and Tversky, 1979) have convincingly demonstrated that outcomes unrelated to the decision at hand (e.g., recent financial gains or losses) do in fact play an important role in determining our choices. For example, Xue et al. (2011) had participants play a task where they decided to play or pass on a gamble consisting of one cup with a large gain and multiple cups with small losses, varying in expected value. They showed that participants decided to play the gamble more often after they lost the gamble on the previous trial, whereas when they won the gamble on the previous trial they were more reluctant to play the gamble.

In fact, when deciding between relatively risky and a relatively safe options, individuals typically have higher preferences for riskier options when the choice is made immediately after experiencing a financial loss (which we term here a *loss context*), while they generally prefer safer options when the choice takes place after experiencing a financial gain (i.e. *gain context*) (Tversky and Kahneman, 1992). This phenomenon can occur even when faced with a choice set presented as either gains or losses (Tversky and Kahneman, 1981; De Martino et al., 2006; Porcelli and Delgado, 2009).

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In the current study, we are interested in exploring the neural processes underlying these inconsistent risk preferences following gains and losses respectively. Specifically, we aim to gain greater insight into the mechanisms underlying risk assessment and preference, by investigating the neural substrate during the evaluation of gains and losses prior to a risky decision situation and demonstrating how these responses can predict and influence subsequent preference for either risky or safe choice options.

Vitally important for decision-making is an adequate evaluation of gains and losses, as these outcomes usefully inform us whether or not to continue a particular behavioral strategy (Barto and Sutton, 1997). Brain areas associated with the evaluation of gains/losses and with value-guided decision-making are, among others, ventromedial prefrontal cortex (vmPFC), striatum, and insula (Breiter et al., 2001; Delgado et al., 2003; Tom et al., 2007; Rangel and Hare, 2010; Basten et al., 2010; Boorman et al., 2013). For instance, Tom et al. (2007) observed that when participants were presented with a mixed gamble offering an equal chance of a monetary gain or loss, BOLD responses in striatum and mPFC increased with the size of the monetary gain; in contrast, BOLD responses in the insula increased with gambles containing greater losses. Similar effects were found when gain and loss outcomes were anticipated (Breiter et al., 2001; Knutson et al., 2001; Kuhnen and Knutson, 2005), or when the gain and loss were not monetary but instead delivered in the form of primary incentives, such as tasty versus nontasty liquids (see also Bartra et al., 2013). Different decision parameters (e.g. outcome evaluation, choice riskiness, magnitude) are believed to be integrated via a common network in the assessment of choice preference and guiding subsequent behavior. Interestingly, this network, in particular the vmPFC may play an important role in integrating the gain/loss outcomes and in light of choice options to assess their subsequent preference.

Moreover, studies have shown that the vmPFC is also involved in the prediction of choice. Studies found that while viewing different goods the vmPFC response correlated with the actual preference for those goods, even in the absence of choice, suggesting that the vmPFC also reflects a choice preference signal prior to making a choice (Lebreton et al., 2009; Levy et al., 2011). Specifically with regard to value-based decision-making, the medial orbitofrontal cortex (mOFC) and vmPFC, including striatum and insula, exhibit a significant increase in signal for options yielding higher expected value, and a significantly reduced signal for options yielding lower or negative expected value (e.g. loss) (Platt and Huettel, 2008; Rangel et al., 2008; Rangel and Hare, 2010; Tom et al., 2007). Options that have ultimately been chosen, with respect to those that have not been chosen, also correlate with the value response of the vmPFC (Boorman et al., 2009).

In particular, the vmPFC has been suggested as a general "hub" for value-guided decisions. This area has strong connections with other reward- and control-related areas (Grabenhorst and Rolls, 2011). It has been suggested that vmPFC guides the valuation process (Plassmann et al., 2010; Rangel et al., 2008), taking into account the decision-makers goals and the current context, by integrating information signals related to the valuation of rewarding and aversive outcomes, choice signals, and signals from regions involved in cognitive control (e.g. IFG, lateral PFC; Hare et al., 2009; Weller et al., 2007; Rosenbloom et al., 2012). The aforementioned studies imply that the vmPFC may be a key region that operates in shaping preference for which choice option to pursue. However, a relevant question is how different values related to each phase of the decision are integrated and updated, and subsequently impact the decision process. More specifically, it is important to understand how appraisals of the context (i.e. gain and loss) of choice guide subsequent decision-making.

We hypothesize here that in the light of different gain and loss contexts prior to making a risky choice, engagement of the vmPFC may mediate risk preferences in line with the behavior described by previous studies, that is, a stronger involvement for risk avoidance in the gain context and for risk seeking in the loss context.

To investigate this, in the present study we varied the delivery of monetary gains and losses preceding a risky choice. We expected that this contextual change would in turn alter risk preferences, even though the actual choice facing the participant was the same in each event. We expected that the engagement of the vmPFC reflected a combined value of the appraisal of the current gain or loss by the subsequent anticipated choice and outcome, and that this relative engagement would be potentially predictive of the degree of riskiness of subsequent decisions in the context of gains or losses.

Materials and methods

Participants

Thirty undergraduate students participated in the study. All provided written informed consent and were financially compensated via a flat fee (25 Euro) for completion of the task. In addition, they also had the opportunity to win a bonus on top of this participation fee, a maximum amount of 10 Euro. Exclusion criteria were self-reported claustrophobia, neurological or cardiovascular diseases, psychiatric disorders, regular use of marijuana, use of psychotropic drugs, or metal parts in the body. Four participants were excluded due to technical problems during scanning. Data is therefore reported from twenty-six participants (14 men and 12 women, $M = 22$ years, $SD = 2.68$, range = 19 to 27 years, all right-handed). The study was approved by the local ethics committee.

Task design and procedure

We developed a novel paradigm in order to study risk-taking behavior in the context of prior gains and losses. Each trial began with a simple time-estimation task in which participants either won or lost money depending on their performance (Boksem et al., 2011). The purpose of this task was to induce either a gain or a loss context. Directly after the gain or loss feedback from the time-estimation task, participants received a mixed (50/50 chance, gain/loss) gamble (see Fig. 1), which they could decide to either pass or play. If they decided to pass on the gamble they would simply retain their gain or loss from the preceding time-estimation trial, which would then be added to the total balance of the money won so far. However, if they decided to play the gamble, the gamble was resolved for them and the corresponding win or loss amount was added to their total experimental balance. The mixed gamble contained either a positive expected value ('+ EV'), a negative expected value ('− EV'), or an equal expected value ('0 EV') by varying the gain or loss outcome from €1.00, €1.20, to €1.40 as compared to the 'pass' option (i.e. choosing to keep the €1.20 gain or loss) (Table 1). We created these three different gamble types to assess whether participants were attending and sensitive to the expected value of the gamble.

This study differs in important ways from previous efforts to assess contextual influences on risky decision-making (such as the 'framing effect'; Kahneman and Tversky, 1979; Tversky and Kahneman, 1981; De Martino et al., 2006). The current task design allowed us to disentangle the context from the decision itself. In other words, the current task design enables us to test how a gain/loss context influences risk preferences for identical choice sets. Other tasks (Porcelli and Delgado, 2009) have not been able to purely disentangle the choice from the context, as the gambles were not of comparable value, but contained either only losses or only gains. Other studies (De Martino et al., 2006) have manipulated the decision options by phrasing them either as a gain or a loss, even though the outcome of the options always had a positive expected value (i.e. contained an expected gain). To avoid this confound, we implemented a task design where we can always compare the decision play or pass on a gamble using the same gambles across both gain and loss contexts. Other studies (Xue et al., 2010, 2011) have used mixed gambles too, however not by separating them from the respective