



## Waves of regret: A meg study of emotion and decision-making

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### ABSTRACT

Recent fMRI studies have investigated brain activity involved in the feeling of regret and disappointment by manipulating the feedback participants saw after making a decision to play certain gambles: full-feedback (regret: participant sees the outcomes from both the chosen and unchosen gamble) vs. partial-feedback (disappointment: participant only sees the outcome from chosen gamble). However, regret and disappointment are also characterized by differential agency attribution: personal agency for regret, external agency for disappointment. In this study, we investigate the neural correlates of these two characterizations of regret and disappointment using magnetoencephalography (MEG). To do this, we experimentally induced each emotion by manipulating feedback (chosen gamble vs. unchosen gamble), agency (human vs. computer choice) and outcomes (win vs. loss) in a fully randomized design. At the behavioral level the emotional experience of regret and disappointment were indeed affected by both feedback and agency manipulations. These emotions also differentially affect subsequent choices, with regret leading to riskier behavior. At the neural level both feedback and agency affected the brain responses associated with regret and disappointment, demonstrating differential localization in the brain for each. Notably, feedback regret showed greater brain activity in the right anterior and posterior regions, with agency regret producing greater activity in the left anterior region. These findings extend the evidence for neural activity in processing both regret and disappointment by highlighting for the first time the respective importance of feedback and agency, as well as outlining the temporal dynamics of these emotions.

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### 1. Introduction

Anyone who has ever made an important decision, such as whether to enter a profession, have children, buy a house, or move abroad, knows that emotions play an important role in decision-making. Indeed, even simple choices, such as how and where to spend the weekend or which university course to take, evoke emotional reactions which depend not only on the outcome itself, but also on how this outcome is achieved. Most decisions involve uncertainty about the consequences of our choice, and therefore before making a decision we often try to think through all possible outcomes, with one of the most important goals of our daily decision-making to choose options that will avoid negative emotional consequences (e.g., Bell, 1982). In the last several decades, the study of how emotions influence decisions has become widespread across

several domains, particularly in psychology (e.g., Kahneman & Tversky, 1982; Mellers, Schwartz & Ritov, 1999; Ritov & Baron, 1990; Zeelenberg, Beattie, van der Pligt & de Vries, 1996) and economics (Bell, 1982; Loomes & Sugden, 1982), but also in other fields such as marketing (Inman, Dyer & Jia, 1997; Simonson, 1992), cross-cultural psychology (Gilovich, Wang, Regan & Nishina, 2003) and, more recently, cognitive neuroscience (Camille et al., 2004; Chandrasekhar, Capra, Moore, Noussair, & Berns, 2008; Chiu, Lohrenz & Montague, 2008; Chua, Gonzalez, Taylor, Welsh & Liberzon, 2009; Coricelli et al., 2005; Liu et al., 2007; Lohrenz, McCabe, Camerer & Montague, 2007; Nicolle, Bach, Driver & Dolan, 2011a; Nicolle, Bach, Frith & Dolan, 2011b; Shiv, Loewenstein, Bechara, Damasio & Damasio, 2005).

#### 1.1. The role of regret and disappointment in decision making

A class of negative emotions that seem particularly aversive are those that create the experienced affective state of “if only I had chosen differently”, more commonly known as regret. Thus,

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before making a decision, people often attempt to anticipate whether they may feel future regret as a consequence of their choice (Bell, 1982; Loomes & Sugden, 1982). In addition to regret, the emotion of disappointment has also been studied extensively across both behavioral science (e.g., Mellers et al., 1999; Zeelenberg & Pieters, 2006) and neuroscience (e.g., Camille et al., 2004; Chua et al., 2009; Coricelli et al., 2005). Disappointment occurs when the actual outcome of a decision is worse than our expectations, and a better outcome would have been possible with a different state of the world (e.g., Bell, 1985; Loomes & Sugden, 1986). Focusing on specific emotions is useful, as research has shown that different emotions have idiosyncratic behavioral tendencies (e.g., Frijda, Kuipers & ter Schure, 1989; Roseman, Wiest & Swartz, 1994). With regard to decision-making, Zeelenberg and Pieters (1999) demonstrated that regret and disappointment are two important emotions which arise in the context of decisions and their associated outcomes, and that are dissociable. While it is certainly true that other emotions can arise after a negative outcome, such as, for example, guilt or shame, regret and disappointment are the two complex emotions that have been studied in most detail with regard to decision-making, likely because both affective states are highly related to the hedonic value of the decision outcomes (e.g., Zeelenberg, van Dijk & Manstead, 1998). Further, emotions such as guilt and shame are more often related to the transgression of a moral or social norm, whereas regret and disappointment are more involved with the 'pure' decision outcome itself. Thus, in this study we focused on regret and disappointment to better understand and differentiate the behavioral and neural dynamics associated with each, in order to gain insight into how these emotions can potentially affect our decision strategies.

### 1.2. How regret and disappointment differ

Regret and disappointment are similar to a certain extent, in that both can arise as a reaction to an unsatisfactory outcome, both is related to decisions taken, and both can even occur simultaneously. Indeed, it is difficult to experience regret without also experiencing disappointment, as both arise when outcomes deviate from one's expectations (e.g., Zeelenberg & Pieters, 2006) and both stem from counterfactual thinking (e.g., Zeelenberg et al., 1998a). Nevertheless, they differ in several important aspects. Regret and disappointment arise from two different counterfactual thoughts: "behavior-focused counterfactuals" for regret and "situation-focused counterfactuals" for disappointment (e.g., van Dijk, Zeelenberg & van der Pligt, 2003), and these two states emerge from a comparison between "what is" and "what might have been", for example if we had made a different choice (regret), or if another state of the world had occurred (disappointment) (Zeelenberg, van Dijk, Manstead & van der Pligt, 1998b). An example of the two emotions is well captured by the following: "The child is disappointed when the Tooth Fairy forgets his third lost tooth. The child's parents regret the lapse" (Landman, 1993, p. 47). Importantly, there are differences in terms of the responsibility that determine each state. Whereas regret is typically related to self-agency (the agent is responsible for the suboptimal decision outcome) and internal attribution (e.g., Gilovich & Medvec, 1994), disappointment is related to other-agency (some external factor is responsible for the outcome) and external attribution (e.g., Frijda et al., 1989).

### 1.3. Behavioral research on regret and disappointment

Behavioral studies have typically investigated the differences between regret and disappointment by using standard decision scenarios, for example a choice between different sections of the same college class, and then by using manipulation of responsibility: a choice made by the participant themselves to induce personal

responsibility and thus potential regret, and a choice made by a computer to induce external responsibility and thus potential disappointment (e.g., Giorgetta, Zeelenberg, Ferlazzo & D'Olimpio 2012; Ordóñez & Connolly, 2000; Zeelenberg et al., 1998; Zeelenberg, van Dijk & Manstead, 2000). Moreover, regret is also said to exist when the decision-maker receives no feedback about the rejected option (e.g., Bar-Hillel & Neter, 1995; Connolly & Zeelenberg, 2002; Zeelenberg et al., 1998; Zeelenberg, 1999). Indeed, according to the "Decision Justification Theory", developed by Connolly and Zeelenberg (2002), there are two different type of regret: comparative (outcome-based) and/or causal (responsibility-based). One (*comparative*) is associated with the comparison between the outcome deriving from the chosen option and some standard, such as the outcome of the rejected option. The other one (*causal*) is associated with the feeling of self-blame, responsibility, subjective evaluation of the quality of the decision made, without knowing the outcome of the rejected option.

### 1.4. Neuroscientific research on regret and disappointment

Neuroscientific studies (e.g., Camille et al., 2004; Chua et al., 2009; Coricelli et al., 2005) have used an alternate method to agency to discriminate between regret and disappointment, namely manipulation of the decision feedback. In these fMRI studies, participants made repeated choices between two gambles. Disappointment was induced by showing participants only the negative outcome of the chosen gamble (partial feedback trials), while regret was created by showing both a bad outcome on the chosen gamble, as well as a good outcome on the unchosen gamble (full feedback trials). These studies showed that the feeling of regret is associated with dorsal anterior cingulate cortex, medial OFC and anterior hippocampus, while disappointment activates middle temporal gyrus and dorsal brainstem (Coricelli et al., 2005). They also showed that both emotional states activate anterior insula, part of dorsomedial prefrontal cortex (BA8 region) and lateral orbitofrontal cortex (Chua et al., 2009), with this activity being stronger for regret. Though neuroscience studies have largely ignored investigating the role of agency on regret and disappointment, Coricelli et al. (2005) and, more recently, Nicolle et al. (2011a) did employ trials where a computer made the choice, but these were only used as a control condition. Specifically, Nicolle et al. (2011a), in a study aimed at investigating how regret affects choice repetition, did not find any behavioral or neural effects associated with computer choices, but did with human choices. Importantly, the crucial role of self-blame and responsibility in the experience of regret, and its role on the subsequent choices has also been recently shown (Nicolle et al., 2011b). However, in this study computer choice and feedback manipulation were not taken into consideration.

### 1.5. Behavioral research vs. neuroscientific research

Overall therefore, findings from both behavioral science and neuroscience suggest that regret exerts a more substantial influence on choice than disappointment, and also that the emotional impact of regret is stronger than that of disappointment (e.g., Chua et al., 2009; Mellers et al., 1999). However, as both behavioral and neuroscientific approaches have used different means of inducing these emotions (agency-based and feedback-based respectively), an important contribution to the investigation of emotions and how they impact decision-making is to use neuroimaging methods to assess whether both agency and feedback explanations for regret and disappointment emanate from the same underlying psychological and neural process.

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