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

Cinzia Giorgetta [a,b,*], Alessandro Grecucci [a], Nicolao Bonini [a,c], Giorgio Coricelli [d,e,f], Gianpaolo Demarchi [d], Christoph Braun [a,d,g], Alan G. Sanfey [a,h,i,j]

[a] Department of Psychology and Cognitive Science, University of Trento, Italy
[b] Institute of Cognitive Science and Technology, CNR, Trento, Italy
[c] School of Economics and Management, University of Trento, Italy
[d] Center for Mind/Brain Sciences, CIMEC, University of Trento, Italy
[e] Cognitive Neuroscience Centre, CNRS, University of Lyon, France
[f] Department of Economics, University of Southern California, USA
[g] MEG-Center, University of Tübingen, Germany
[h] Donders Institute for Brain, Cognition and Behavior, Radboud University Nijmegen, The Netherlands
[i] Department of Psychology, University of Arizona, USA
[j] Behavioural Science Institute, Radboud University Nijmegen, The Netherlands

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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.

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).

* Correspondence to: Department of Psychology and Cognitive Science, Corso Bettini 31, Rovereto 38068, TN, Italy. Tel.: +39 0464 808645; fax: +39 0464 808602.
E-mail address: cinzia.giorgetta@unitn.it (C. Giorgetta).

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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, 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 are 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; Ordönez & 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

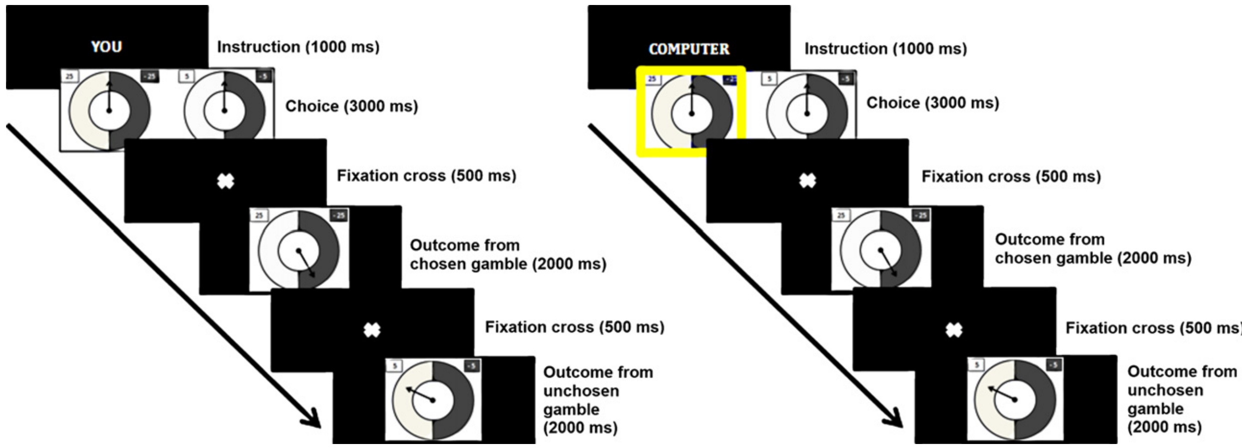

Fig. 1. Gambling task. Two examples of the gambling task. In both, the outcome from chosen gamble was a loss and the outcome from unchosen gamble a win. The left side represents the condition where participants chose by themselves; the right side the condition where the computer made the choice.

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.

1.6. Purpose of the present study

To determine the brain processes specifically related to the emotions that play a pivotal role in decision-making, we used magnetoencephalography (MEG). Use of MEG allowed us to explore the temporal dynamics of their experience. Emotions have early and short-lasting effects on the brain (e.g., D'Hondt et al., 2010; Hung et al., 2010; Peyk, Schupp, Elbert & Junghöfer, 2008), and so the superior temporal resolution of MEG enables more precise quantification. Specifically, we employed a well established gambling task paradigm, previously used in fMRI studies on regret and disappointment (e.g., Camille et al., 2004; Chua et al., 2009; Coricelli et al., 2005; Nicolle et al., 2011a), in which we applied both feedback-based and agency-based manipulations. This design therefore allowed us to carefully separate the various components of regret and disappointment. Additionally, previous studies on regret/disappointment (e.g., Camille et al., 2004; Chua et al., 2009; Mellers et al., 1999) have simply asked participants to rate their emotions on a univariate happy/sad scale. This scale provides relatively weak discriminability between regret/disappointment and a general sad mood, and also does not ensure that regret and disappointment are in fact the two most important components of the participants' experience. To address these points we also asked, during a training phase, about the same happy/sad ratings but also employed a debriefing session where we specifically assessed regret and disappointment in addition to other relevant emotions.

At a behavioral level, we hypothesize that regret and disappointment will be the two primary emotions experienced in our task, with greater differential effect for regret when one is personally responsible for the negative outcome, and for disappointment when one is not. This latter point is of considerable interest in terms of the validity of using gambling tasks when studying regret and disappointment. We also explored the risk-taking behavior and reaction times exhibited by participants and examined the differential effects of experienced emotions on the subsequent choices. We hypothesize that regret, but not disappointment, exerts an important role on subsequent choice behavior. Such a finding would be important in that it can show a converging role for both agency and feedback on choices.

At a neural level, we aim to extend previous findings on regret and disappointment in order to demonstrate that both feedback and agency should be taken into account when investigating the processing of these affective states. We addressed this point by looking separately at the brain's global field activity for the role of feedback and agency respectively. We hypothesize that relatively early after the presentation of the outcome there is separation in their processing. Looking separately at the effect of feedback and agency, using the local field activity level, enabled us to answer another compelling question, whether these two different components (feedback and agency) share the same cortical localization or rather if they are implemented in different brain regions. One possibility is that they are coded in different brain regions. fMRI studies suggest a right brain specialization, based on feedback accounts for regret and disappointment. Thus, one potential hypothesis is that when looking at the feedback effects we will find differential activity, after the full and partial feedback, localized in the right regions of the brain. If shown, this finding will be important as it will strongly support the notion of right hemispheric responses to negative emotions. With regard to agency effects, differential brain activity related to the experience of regret and disappointment would support the idea, stemming from behavioral science, that these two emotions differ based on responsibility attribution. Additionally, different cortical localization between agency and feedback would support the idea of regret as a multi-component process. Though both components (comparative-feedback and causal-agency) have a crucial role in determining the experience of regret (Connolly & Zeelenberg, 2002), to date no study has examined whether these experiences co-occur or are to some degree separable. By assessing the similarities and differences of the neural dynamics of feedback and agency on regret and disappointment, we can significantly contribute to integrating disparate strands of research on these emotions, as well as increasing our understanding of how the brain processes emotions, in particular emotions directly related to decision-making.

2. Material and methods

2.1. Participants

Sixteen right-handed participants (8 Males, mean age: 25.5 ± 3.6 years; mean education: 17.03 ± 2.1 years) participated in the study. Three of these sixteen participants were excluded from the analyses for signal artifacts, and so data is reported from a total of 13 participants. In order to exclude participants with abnormal emotional reactivity, in the assessment phase participants completed the

Positive and Negative Affective scales (PANAS, Watson, Clark & Tellegen, 1988). The mean ratings for the Negative and Positive Affective scale were, respectively of 20.4 (NA) and 34.1 (PA), matching the mean of the Italian population ($M=20.9$ for NA and $M=33$ for PA; Terracciano, McCrae & Costa, 2003). Therefore, none were excluded for abnormal emotional reactivity. All participants had normal or corrected to normal vision, and provided written informed consent as approved by the local ethical committee. Participants were compensated at the rate of €30 for the study, and were also awarded a small financial bonus (average €5). The entire session lasted about 2 h.

2.2. Design

We employed a within-subject experimental design, and utilized a standard gambling paradigm modified from previous tasks in this domain (e.g., Camille et al., 2004; Chua et al., 2009; Coricelli et al., 2005; Mellers et al., 1999). On each trial, participants saw two gambles, one safe and one risky, as defined by their respective variances, and had to choose one of them to play. Following Gehring and Willoughby (2002), the *Risky* option was the one with the larger outcome variance (both positive and negative) and the *Safe* was the one with smaller outcome variance. We used 3 different pairs of gambles: 1) a gain or loss of 5 points (safe option) and a gain or loss of 25 points (risky option); 2) a gain or loss of 10 points (safe option) and a gain or loss of 30 points (risky option); 3) a gain or loss of 15 points (safe option) and a gain or loss of 35 points (risky option). Participants were informed that the probabilities of winning or losing each option was always 0.5, thus, the expected value of both options was actually zero.

As in Fujiwara, Tobler, Taira, Iijima and Tsutsui (2009), on each trial participants were shown the outcome of the chosen option and then that of the unchosen option, presented sequentially. The outcome of each trial was determined pseudorandomly with the constraint that each participant experienced an equal number of losses and of wins. Importantly, participants were not told about these experimental contingencies, and were simply instructed to earn as many points as possible. Since the probability of receiving positive or negative outcome was equal in any given trial, it was not possible for the player to devise any helpful strategy to win in the game. The number of small or large outcomes accrued depended on the participants' safer or riskier choices and thus was not controlled. Whereas participants chose for themselves in half of the trials, in the other half of the trials the computer made the choice. The computer choice was randomized, but with the constraint that half of the time it picked a risky option and the other half a safe option.

The trials used for data analyses were those mixed gambles which consisted of one loss and one gain outcome. The outcomes in these trials were manipulated so that a specific emotion could be induced. Filler trials, where the two gambles offered either both gains or both losses, were also used in order to prevent participants anticipating the outcome of the unselected gamble.

To experimentally induce each emotion, outcomes (win vs. loss) and agency (human vs. computer) was manipulated. Thus, the conditions for regret were those where participants made the choice themselves (human agent), received a loss on the chosen gamble and saw that the unchosen gamble was a win. The conditions for disappointment were those where the computer made the choice (computer agency) and the outcome from chosen gamble was a loss and the outcome from unchosen gamble was a win. Other conditions of interest were where the outcome from the chosen gamble was a win and the outcome from the unchosen gamble was loss in the human agency condition (rejoice) and the same set of outcomes in the computer agency condition (elation). There were 60 trials shown for each of the 4 emotion conditions, plus 96 filler trials. In total therefore participants saw 336 trials, divided in 4 fully randomized blocks.

Whereas in the previous Fujiwara et al. (2009) and Chua et al. (2009) studies only human agency trials occurred, in other studies (Coricelli et al., 2005; Nicolle et al., 2011a) "computer agency" trials did also occur. In Coricelli et al. (2005) these were in separate blocks, and in Nicolle et al. (2011a) these trials were instead randomly intermixed within blocks. In both studies the computer made the choice only in a small number of trials. In the current study we also intermixed trials in order to enhance participant engagement at the choice phase, but we used an equal number of trials in both "computer agency" and "human agency" conditions to enable careful comparison.

2.3. Procedure

Before the MEG session, participants were familiarized with the computerized version of the gambling game (Fig. 1) and emotional ratings were acquired. To do this, participants saw 24 trials, 6 trials for each of the four emotion conditions. After each trial participants were asked an "Emotion" rating and a "Choice" rating, which measured both intensity and valence, adapted from previous studies (Camille et al., 2004; Chua et al., 2009; Mellers et al., 1999). In the "Outcome" rating they were asked how they felt about the outcome on a 9 point-scale, ranging from 1 (sad) to 9 (happy). In the "Choice" rating they rated their desire to change the choice made (by them or by the computer) on a 9-point scale, ranging from 1 (definitely yes) to 9 (not at all). This second question assessed the counterfactual thinking stemming from the knowledge of the feedback on both the chosen gamble outcome and the unchosen gamble outcome. As both regret and disappointment stem from counterfactual thinking (e.g., Zeelenberg et al., 1998), in contrast to previous studies (Chua et al., 2009) we did not expect differences in the "outcome" and in the "choice" questions after experiencing either regret or disappointment. In both conditions the difference is related to who made the choice but not to the outcomes, that is, participants have lost but they would have won with the unchosen gamble.

Next, each participant was seated inside the shielded MEG room with his/her head placed in the helmet-shaped dewar. Electromagnetic brain activity was recorded while performing the gambling task, illustrated in Fig. 1.

During the MEG session, participants were asked to perform the gambling game with the goal of earning as many points as possible. They were informed that they would be paid an additional cash bonus based on their performance in 100 randomly selected trials. In fact, all participants received the same bonus at the conclusion of the study.

During the task (Fig. 1), participants first saw a label that indicated who would make the choice on that trial ("YOU" or "COMPUTER"). Participants were told that when the label was "you" (human agency trials) they had to choose one of the two gambles by pressing the button corresponding to the location of the chosen gamble. When the label was "computer" (computer agency trials) a yellow square appeared behind one of the two gambles and they had to press the corresponding button. The button press was required in order to have equivalent motor responses during both trial types.

After the choice phase, which lasted for 3000 ms, a fixation cross appeared at the center of the screen for 500 ms. Then the outcome of the selected gamble was shown for 2000 ms at the center of the screen, with an arrow indicating the white (for gain) or gray (for loss) side of the circle. After an additional interval of 500 ms during which participants again saw a fixation cross, participants saw what they would have won or lost if the other option had been chosen. Again, this information remained on the center of the screen for 2000 ms. The two feedback stimuli representing the outcome of both the chosen and unchosen gamble were perceptually identical (both appeared in the middle of the screen), but were presented separately in time in order to avoid any confound due to simultaneous presentation when measuring cortical activity. The presentation of both outcomes was necessary for eliciting the emotional experiences of regret and disappointment, as they stem from the comparison between chosen and unchosen options (e.g., Zeelenberg et al., 1998). Each trial was followed by an inter-trial interval of 1000 ms. In total the MEG session lasted about 1 h.

At the end of the MEG session, participants were administered a questionnaire on the perceived responsibility and experienced anger, happiness, regret, and disappointment in the different conditions (excluding the filler trials), using a 9-point scale. Specifically, subjects were asked to read a scenario summarizing what they did during the gambling task. The situations presented were the following: for the regret condition "Imagine that you have chosen between two gambles and you receive a loss and later on you discover that the other gamble would have been a win"; for disappointment condition "Imagine that the computer has chosen between two gambles and you received a loss, and later on you discover that the other gamble would have been a win". Scenarios with both rejoice and elation conditions were also used. After each situation subjects were asked to answer the following questions: "to what extent do you feel responsible?"; "how much regret do you feel?"; "how much disappointment do you feel?"; "how much anger do you feel?"; "how much happiness do you feel?". In this way we were sure each condition was treated in the same way and that the emotional ratings were not biased in any direction.

The whole experiment lasted less than 2 h.

2.4. MEG data acquisition

Neuromagnetic fields were recorded with an Elekta Neuromag MEG system with 306 channels whole head system and sampled at a rate of 1 kHz. Magnetic activity was recorded continuously with a low-pass filter set at 330 Hz. In order to control for head movements coils were placed on the head surface and their position was measured prior and after one run. If there was a head movement larger than 5 mm across a session, the session was repeated. Stimulus presentation and data acquisition were controlled using E-prime software package (PST, Inc., Pittsburgh, PA), running on a Windows computer, and presented by a projector. Responses were made by using two optically isolated response buttons.

2.5. Data analysis

Preprocessing of MEG data was done for each subject individually by using SPM8 EEG-MEG toolbox (Wellcome Department of Cognitive Neurology, London). Recorded epochs lasted from 200 ms before to 1000 ms after each feedback onset, that is, after the feedback for the chosen and for the unchosen outcome. Standard preprocessing procedures were used on both feedback onsets within each trial. All epochs of the MEG session were visually inspected for artifacts. Epochs containing blinks or eye movements were rejected. Average within subjects and grand average across subjects were performed before parameterizing the MEG data. In order to obtain local brain activity, analyses were performed on the planar

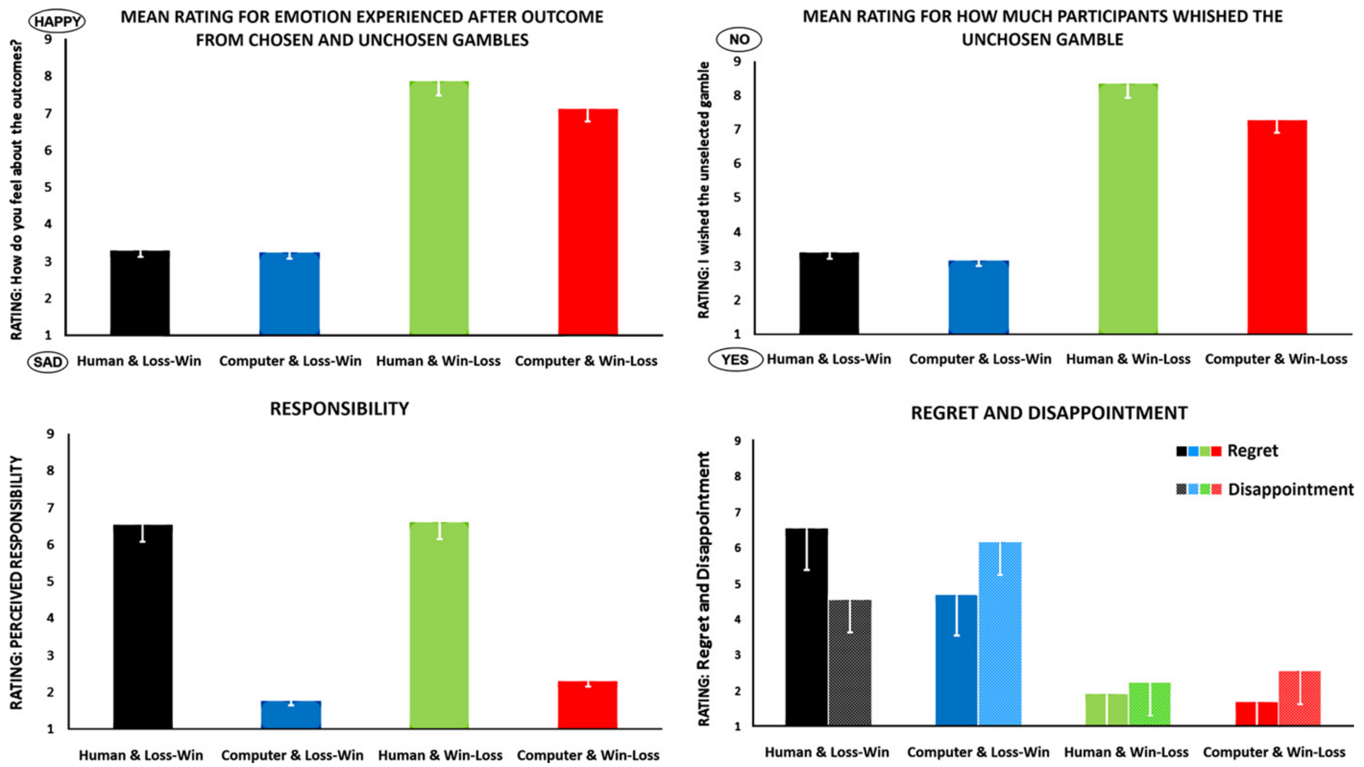

Fig. 2. Emotional ratings. Participants' average (a) outcome ratings and (b) choice ratings after each emotion induction in Training Phase, and participants' average (c) experienced regret and disappointment and (d) perceived responsibility after each emotion induction in Debriefing Phase. Standard errors are shown. The conditions displayed are those where participants were informed about both outcomes from chosen and unchosen gambles. The label "Human & Loss–Win" means personal choice with chosen loss and unchosen win and is referred to regret; "Computer & Loss–Win", means computer choice with chosen loss and unchosen win and is referred to disappointment; "Human & Win–Loss" means personal choice with chosen win and unchosen loss and is referred to rejoice; "Computer & Win–Loss" means computer choice with chosen win and unchosen loss and is referred to elation.

gradiometers. In order to investigate when the differential brain activity between feedback and agency regret and disappointment occurs we computed the Global Field Activity (GFA). The GFA is the root-mean-square of the evoked magnetic activity across all channels and gives a single value per time point representing the overall brain activity across the whole scalp. We used GFA measurement as a first exploratory approach, to better assess the proper time window of interest. This method has frequently been used in both MEG and EEG research. In order to investigate where the differential component activities were localized on the scalp we also computed the Local Field Activity (LFA). The scalp was divided into 9 smaller regions determined by: 3 lateralization (left vs. mid vs. right) X 3 positions (anterior vs. central vs. posterior). These regions are spatially localized sensors clusters, with 22–24 gradiometers per each LFA region. For visualization purposes, cortically constrained Minimum Norm Estimate (MNE) source reconstruction images, for significant time points, have also been performed. Data were then analyzed using STATISTICA.

3. Results

3.1. Emotional ratings

3.1.1. Training phase

Fig. 2 (a and b) illustrates results from "Outcome" and "Choice" ratings in all of the four emotion conditions. A $2\times2\times2$ mixed ANOVA analysis [Emotion Valence (Positive vs. Negative) X Agency (Human vs. Computer) X Rating Type (Outcome vs. Choice)] revealed a main effect of Emotion Valence, $F(1,\ 12)=5.3$, $p<0.05$. That is, positive emotions (defined by obtained wins and foregone losses) received stronger emotional ratings than negative emotions (defined by obtained losses and foregone wins). A main effect was found for Agency, $F\ (1,\ 12)=52.66$, $p<0.001$, where personal choices yielded higher emotional ratings than when the computer made the selection. We also found an interaction between Emotion Valence, Agency and Rating Type,

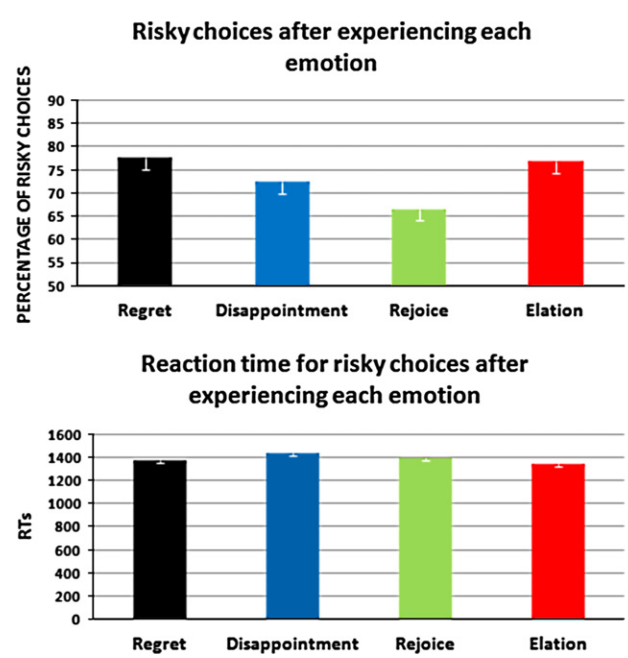

Fig. 3. Decision behavior. Participants' average of the percentage of risky choices made after having experienced each emotion and the reaction time spent to make risky choices after experiencing each emotion. The emotion named "regret" refers to the trials where the personally chosen gamble was a loss and the unchosen gamble a win; "disappointment" refers to the trials where the computer made the choice and the chosen gamble was a loss and the unchosen gamble a win; "rejoice" refers to the trials where the personally chosen gamble was a win and the unchosen gamble a loss; "elation" refers to the trials where the computer made the choice and the chosen gamble was a win and the unchosen gamble a loss.

$F(1, 12)=7.08$, $p<0.05$. In particular, the condition associated with more happiness and less likelihood of changing choice was the one where participants personally made the choice, obtained a gain and avoided a loss ($p<0.005$ for all comparisons; Bonferroni corrected).

Table 1
All effects for GFA analyses are reported below.

Factors	*F*	*p*
Feedback	4.45	0.06
Outcome	0.54	0.48
Agency	3.35	0.09
Feedback × outcome	4.2	0.06
Feedback × agency	8.8	0.01*
Outcome × agency	1.88	0.19
Feedback × outcome × agency	4.7	0.05*

Note: The asterisks refer to all significant effects.

3.1.2. *Debriefing phase*

Fig. 2 (c and d) illustrates main ratings collected after the MEG session. A within-subject 2 × 2 ANOVA analysis [Emotion Valence (Positive vs. Negative) X Agency (Human vs. Computer)] was performed separately on perceived responsibility and each experienced emotions separately. Participants felt more responsibility when they made the choice themselves than when the computer made the choice, $F(1, 12)=50.42$, $p<0.001$. For regret, these results showed a main effect of Emotion Valence (more regret after losing as compared to winning), $F(1, 12)=36.03$, $p<0.001$, of Agency (more regret for personal choice than for computer choice), $F(1,12)=6.94$, $p<0.05$, and an interaction effect of Emotion Valence x Agency interaction $F(1,12)=6.07$, $p<0.05$. As expected, higher experienced regret was expressed in regret conditions ($p<0.01$ for all the comparisons; Bonferroni corrected). With regard to disappointment we found a main effect of Emotion Valence (more disappointment after losses than after wins), $F(1, 12)=36.26$, $p<0.0001$. Additionally, t-test analyses showed that in the

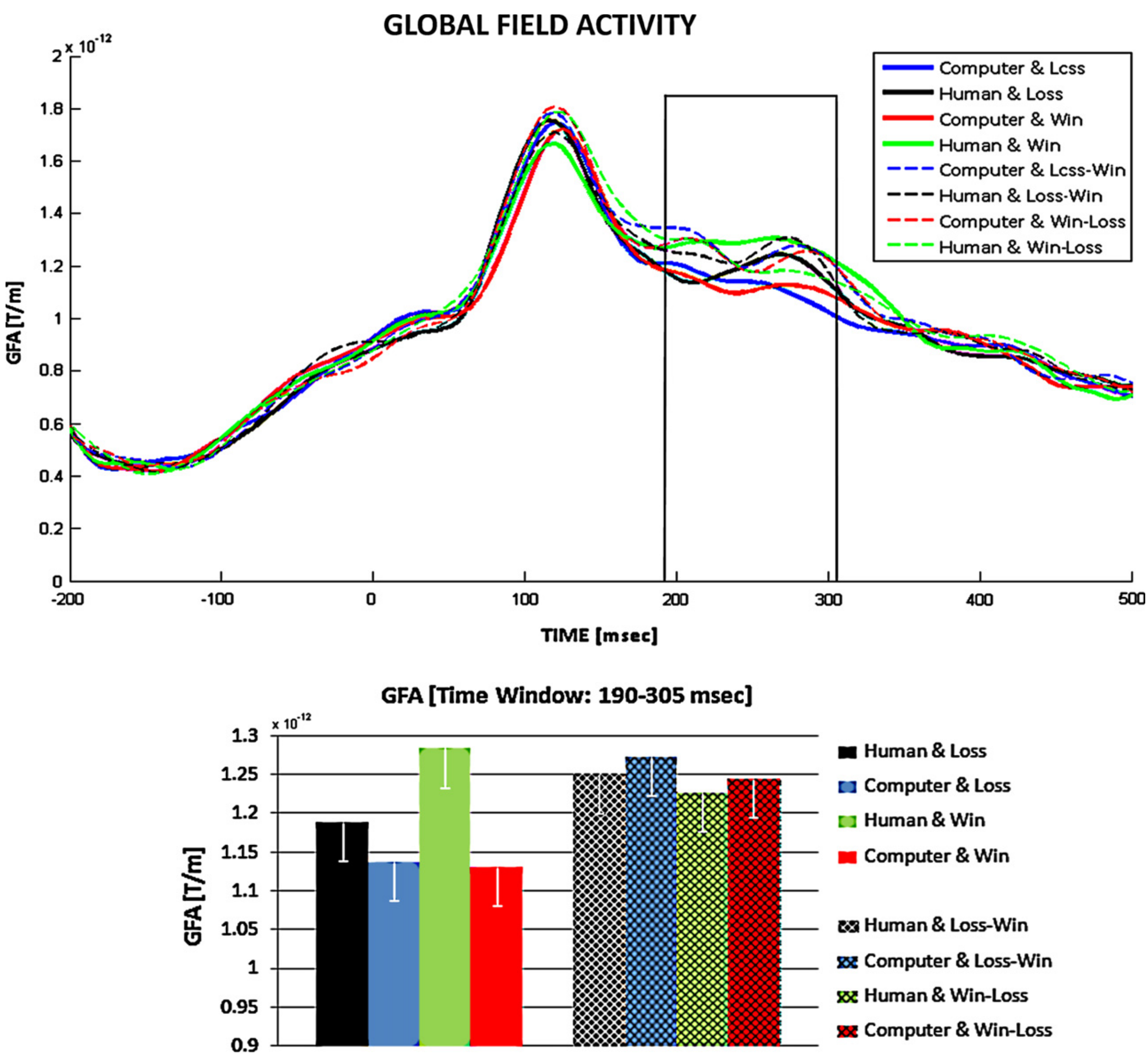

Fig. 4. Global field activity. Time course and mean amplitudes of GFA over the whole scalp are depicted. Time course of the cortical neuromagnetic response to each of the eight conditions [“feedback” (chosen gamble vs. unchosen gamble) X “outcome” (win vs. loss) X “agent” (computer vs. human)] is represented on top. The labels “Computer & Loss” and “Computer & Loss–Win” are for disappointment; “Human & Loss” and “Human & Loss–Win” are for regret; “Computer & Win” and “Computer & Win–Loss” are for elation; “Human & Win” and “Human & Win–Loss” are for rejoice. The vertical bar indicates the time window of interest (190 ms–305 ms). Lower part: GFA amplitude over the whole scalp at latencies of 190–305 m for each condition. GFA amplitude is significantly higher ($p<0.05$) in: “Human & Loss–Win” than “Human & Loss”; “Human & Loss” than “Computer & Loss”; “Human & Win” than “Human & Loss”.

condition where the computer made the choice, the chosen gamble outcome was a loss, and the unchosen gamble outcome a win, the experience of disappointment was significantly higher than that of regret [$t(12)=3.07$, $p<0.01$]. This last result allowed us to assign computer choice trials as the disappointment condition. In contrast, in the condition where the choice was personally made, the chosen gamble outcome was a loss and unchosen gamble outcome was a win, the experience of regret was rated as stronger than that of disappointment [$t(12)=3.37$, $p<0.05$]. When we checked for the other emotions our results showed a main effect of losses vs. gains for both anger [$F(1,12)=42.14$, $p<0.0001$] and happiness [$F(1,12)=29.83$, $p<0.0001$]; stronger ratings of anger after losses ($M=6.42$; $SD=1.86$) than gains ($M=3$; $SD=1.94$) and of happiness after gains ($M=7.54$; $SD=2.06$) than losses ($M=2$; $SD=1.94$). However, these emotions do not discriminate between agency, as analyzed by t-test comparisons. Taken together, these results confirmed the validity of our experimental manipulation, that is, that the specific emotions of regret and disappointment were indeed elicited.

3.2. Decision behavior results

In order to assess participants' risk-taking behavior, the mean percentage of risky and safe choices made by each participant was determined. Results [$t(24)=10.38$, $p<0.0001$] showed that participants made a higher number of risky ($M=75.24$; SD$=13.76$) than safe choices ($M=24.76$; $SD=13.76$). The average reaction time for risky choices ($M=1336.35$; $SD=216.16$) was not significantly different [$t(24)=-0.74$; $p=0.5$] than that of safe choices ($M=1404.66$; $SD=297.74$). In order to check for the effect of each emotional experience (regret, rejoice, disappointment and elation) on the subsequent choices, the mean percentage of risky choices and associated reaction times were determined. ANOVA analyses, with risky choices as the dependent variable and Emotion Valence (Positive vs. Negative) and Agency (Human vs. Computer) as independent variables, showed no main effect of Emotion Valence [$F(1, 12)=0.097$, $p=0.8$] nor of Agency [$F(1, 12)=1.6$, $p=0.23$], but did demonstrate a significant interaction effect [$F(1, 12)=13.03$, $p<0.005$]. Post-hoc analyses showed that differences on subsequent choices existed only for the human agency condition. That is, after having experienced regret participants made a higher number of risky choices on the subsequent trial than after experiencing rejoicing ($p<0.05$). ANOVA analyses with reaction time as dependent variable and Emotion Valence (Positive vs. Negative) X Agency (Human vs. Computer) as independent variables showed no significant main effects of Emotion Valence [$F(1, 12)=0.097$, $p=0.8$] and of Agency [$F(1, 12)=1.6$, $p=0.23$], nor any significant interaction between them [$F(1, 12)=3.4$, $p=0.09$]. See Fig. 3.

3.3. MEG results

3.3.1. Global field activity [GFA]

In order to explore the early differences between regret and disappointment, evoked root-mean-square analyses focused on GFA within 500 ms after the outcome of the chosen and of the unchosen option. A three-way ANOVA with factors Feedback (chosen gamble vs. unchosen gamble), Outcome (win vs. loss) and Agency (computer vs. human) was performed on GFA values. In the time window of 190–305 ms, this analysis (see Table 1) did not reveal any main effects ($p>0.05$), but showed a significant interaction between Feedback and Agency [$F(1, 12)=8.82$, $p<0.01$], and importantly, a significant interaction among all the three factors: Feedback, Outcome and Agency [$F(1, 12)=4.756$, $p<0.05$] (Fig. 4). Post-hoc analyses demonstrated significant differences related to the following conditions of interest:

Table 2
All effects for LFA analyses are reported below.

Factors	*F*	*P*
Feedback	4.02	0.07
Outcome	0.68	0.4
Agency	2.77	0.1
Lateralization	2.88	0.07
Position	15.21	0.001*
Feedback × outcome	4.44	0.06
Feedback × agency	8.68	0.01*
Outcome × agency	2.29	0.16
Feedback × lateralization	0.71	0.5
Outcome × lateralization	2.24	0.13
Agency × lateralization	1.32	0.29
Feedback × position	1.22	0.3
Outcome × position	0.28	0.76
Agency × position	0.22	0.8
Lateralization × position	6.8	0.001*
Feedback × outcome × agency	4.75	0.05*
Feedback × outcome × lateralization	1.16	0.3
Feedback × agency × lateralization	1.70	0.2
Outcome × agency × lateralization	0.4	0.67
Feedback × outcome × position	5.13	0.01*
Feedback × agency × position	0.08	0.92
Outcome × agency × position	0.87	0.43
Feedback × lateralization × position	1.12	0.36
Outcome × lateralization × position	0.88	0.48
Agency × lateralization × position	2	0.11
Feedback × outcome × agency × lateralization	3.13	0.06
Feedback × outcome × agency × position	1.3	0.29
Feedback × outcome × lateralization × position	1.5	0.22
Feedback × agency × lateralization × position	0.74	0.57
Outcome × agency × lateralization × position	1.57	0.2
Feedback × outcome × agency × lateralization × position	2.56	0.05*

Note: The asterisks refer to all significant effects.

1. Stronger brain activity when participants saw the outcome of the unchosen gamble (full feedback) vs. the outcome of the chosen gamble (partial feedback) ($p<0.05$ for regret, disappointment and elation conditions). Brain activity was lower ($p<0.001$) when participants saw a loss from the unchosen gamble (full feedback) vs. a gain from the chosen gamble (partial feedback), and the choice was personally made (rejoice condition).
2. Stronger brain activity when participants obtained a loss after choosing for themselves than when a loss was chosen by the computer ($p<0.05$).
3. Stronger brain activity when participants obtained a win when choosing for themselves as compared to a personally-chosen loss ($p<0.005$).

Thus, further analyses focused on electromagnetic activity occurring in this time window.

3.3.2. Local field activity [LFA]

A five-way ANOVA with factors Feedback (chosen gamble vs. unchosen gamble), Outcome (win vs. loss), Agency (computer vs. human), Lateralization (left vs. mid vs. right) and Position (anterior vs. central vs. posterior) was performed on LFA in the 190–305 ms time window. This analysis (see Table 2) revealed a main effect of Position [$F(2, 24)=15.21$, $p<0.001$]. Significant interactions were found on the following factors: Feedback × Agency [$F(1, 12)=8.68$, $p<0.01$]; Lateralization X Position [$F(4, 48)=6.8$, $p<0.001$]; Feedback × Outcome × Agency [$F(1, 12)=4.75$, $p<0.05$]; Feedback × Outcome × Position [$F(2, 24)=5.13$, $p<0.01$]. Importantly, we found a significant interaction effect between all factors [$F(4, 48)=2.56$,

$p < 0.05$]. Therefore, post-hoc analyses between conditions of interest were performed.

3.3.3. Differential LFA amplitudes associated with the role of feedback

First, we investigated brain activity in trials where the participant personally made the choice, examining the differences in the two feedback conditions (the display of the chosen and unchosen gamble respectively). This analysis allowed us to test our hypothesis regarding the role of feedback on the experience of regret and disappointment. We found significant differences between these conditions in the right anterior ($p < 0.003$) and right posterior ($p < 0.004$) regions (Fig. 5), with results showing that brain activity was higher after participants saw the win on the unchosen gamble, or full feedback (condition for regret), than after they saw the loss on the chosen gamble, or partial feedback (that is, condition for disappointment in fMRI studies). In the controlateral brain regions no differences were found between these two conditions of interest ($p=0.08$ for the left anterior region and $p=0.9$ for the left posterior region).

Importantly, in order to check for the difference between the role of partial and full feedback in both regret and disappointment, we also compared brain activity, once participants saw a win on the unchosen gamble and a loss on the chosen gamble, between the human and computer agency conditions. Here, we found significant difference in the right anterior region (respectively, mean $1.1^{-12} \pm 0.21^{-12}$ T/m and mean $0.97^{-12} \pm 0.18^{-12}$ T/m) ($p < 0.05$) but not in the right posterior region (respectively, mean $1.55^{-12} \pm 0.62^{-12}$ T/m and mean $1.62^{-12} \pm 0.63^{-12}$ T/m) ($p=0.2$).

Additionally, post-hoc analyses were performed on the brain activity after participants saw the loss on the chosen gamble (partial feedback) and the win on the unchosen gamble (full feedback) in the computer agency condition. Here, there was no significant difference

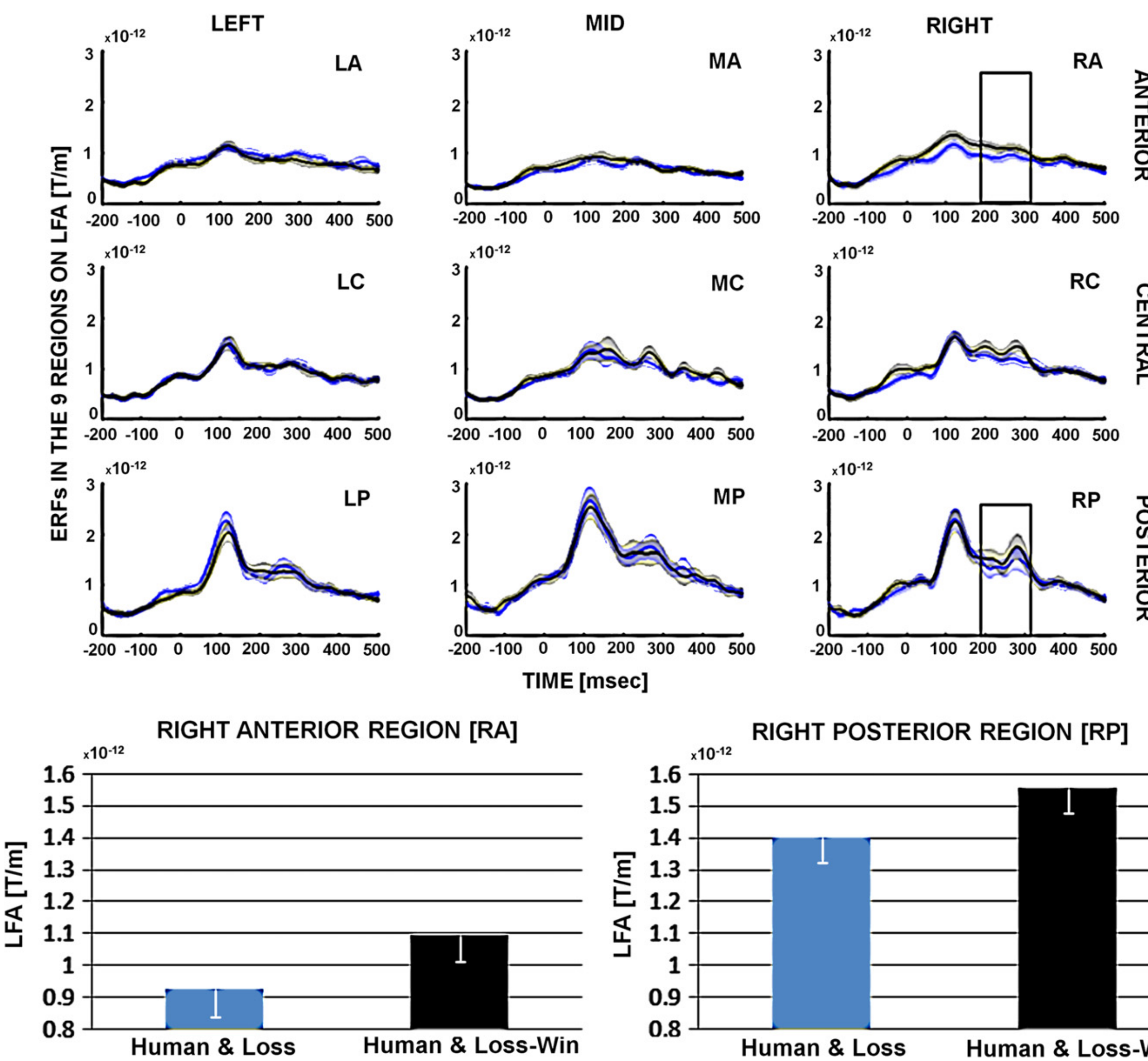

Fig. 5. Local field activity for the role of feedback: chosen gamble vs. unchosen gamble. LFA amplitudes divided into 9 smaller regions determined by: 3 lateralization (left vs. mid vs. right) X 3 positions (anterior vs. central vs. posterior) are depicted. Time course of the cortical neuromagnetic response to the conditions where participants found that the unchosen gamble would have won (following a loss) and where participants found that they had lost itself (respectively, "Human & Loss–Win" and "Human & Loss") is represented on top. Vertical bars in the upper part of the graphics indicate the time window of interest (190 ms–305 ms) over the Right Anterior and Right Posterior Regions. The bar plots on bottom show as at latencies of 190–305 ms LFA amplitudes over the Right Anterior and Posterior Regions are substantially higher in "Human & Loss–Win" than in "Human & Loss".

in the right anterior region (respectively, mean.$95^{-12} \pm 0.23^{-12}$ T/m and mean $0.97^{-12} \pm 0.18^{-12}$ T/m) ($p=0.7$) but only in the right posterior region (respectively, mean $1.46^{-12} \pm 0.45^{-12}$ T/m and mean $1.62^{-12} \pm 0.63^{-12}$ T/m) ($p<0.05$).

3.3.4. Differential LFA amplitudes associated with the role of agency

Next, we separately examined the differences in the two agency conditions (human and computer). Here, we compared brain activity after the loss of the chosen gamble was revealed in the human and computer choice conditions respectively. This analysis allowed us to test hypothesis regarding the role of agency on regret and disappointment. Results indicated that brain activity in the left anterior region was stronger for regret than for disappointment ($p<0.05$) (see Fig. 6). In the controlateral brain region, that is, in the right anterior region, no differences were found between human choice leading to a loss (mean $0.93^{-12} \pm 0.21^{-12}$ T/m) and computer choice leading to a loss (mean $0.95^{-12} \pm 0.23^{-12}$ T/m) ($p=0.6$).

3.3.5. Differential LFA amplitudes associated to wins and losses

Finally, to be consistent with previously published studies on neural responses to financial outcomes, we also investigated whether different outcomes of the chosen gamble (namely wins vs. losses) were associated with different brain activity.

Results showed that such differences are supported by differential LFA signals in the Right Anterior region, within 190–305 ms of the display of the chosen gamble outcome. However, this differential brain activity was only found when participants made the choice themselves ($p<0.001$), with greater activity for wins (mean $1.13^{-12} \pm 0.23^{-12}$ T/m) than losses (mean $0.93^{-12} \pm 0.21^{-12}$ T/m), but not when choices were made by the computer ($p=0.6$) (mean $0.92^{-12} \pm 0.17^{-12}$ T/m for wins, and mean $0.95^{-12} \pm 0.23^{-12}$ T/m for losses). We also found differential LFA signals in the Right Posterior region, in the same time window, when the choice was made by the computer, again with a greater activity for wins than for losses ($p<0.05$) (mean $1.36^{-12} \pm 0.49^{-12}$ T/m for wins, and mean $1.46^{-12} \pm 0.45^{-12}$ T/m for losses). This difference, in the Right posterior region, was not found when the choice was made by the participants themselves (mean $1.47^{-12} \pm 0.59^{-12}$ T/m for wins, and mean $1.4^{-12} \pm 0.56^{-12}$ T/m for losses) ($p=0.15$).

These results, in agreement with the literature (e.g., Coricelli et al., 2005), demonstrate that agency is crucial in discriminating between wins and losses.

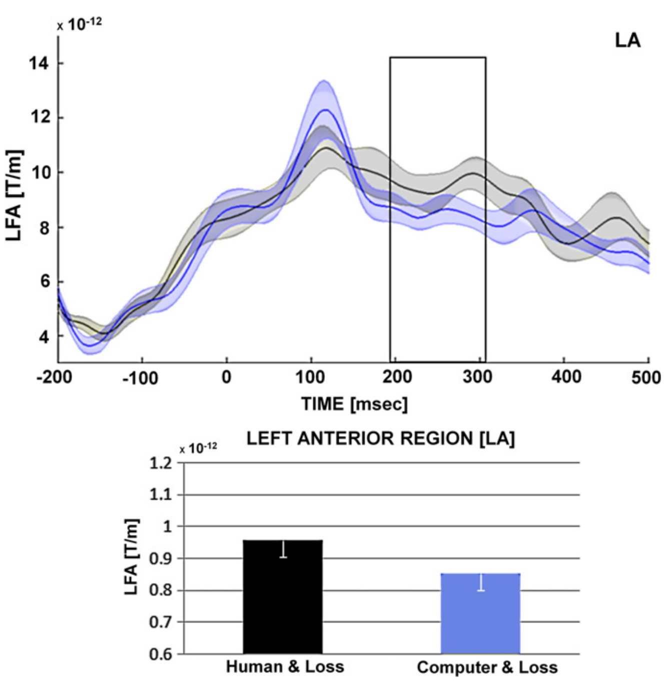

Fig. 6. Local field activity for the role of agency. LFA amplitude over the Left Anterior Region. Time course of the cortical neuromagnetic response to the conditions where participant had chosen a gamble and lost ("Human & Loss") and where the computer chose a gamble leading to a loss ("Computer & Loss") is represented on the top. The vertical bar in the upper part of the figure indicates the time window of interest (190 ms–305 ms). The bar plots on the bottom show that at latencies of 190–305 ms the LFA amplitude over the Left Anterior Regions is substantially higher ($p<0.05$) in "Human & Loss" than in "Computer & Loss".

3.3.6. Differential LFA amplitudes between feedback-regret and agency-regret

An additional experimental question was to examine the similarities and differences between feedback-regret (stemming from the comparison between outcomes from chosen and unchosen gambles) and agency-regret (related to the degree of personal responsibility). Thus, we analyzed the differences in the brain activity related to the role of feedback and agency on regret on the three target areas found in the previous local field amplitudes analyses, namely the left anterior, right posterior and right anterior regions (Fig. 7). To do this, we examined the difference between brain activity after seeing the unchosen gamble outcome and that after seeing the chosen gamble outcome (feedback-regret), and also the difference between brain activity after seeing the chosen gamble outcome after a personal choice and brain activity after seeing the chosen gamble outcome after a computer choice (agency-regret). Analyses demonstrated that the activity related to agency-regret was significantly higher in the left anterior region as compared to feedback-regret [$t(12)=2.7$, $p<0.02$]; feedback-regret showed higher activity than agency-regret in the right posterior region [$t(12)=2.25$, $p<0.05$]; the right anterior region showed no selectivity for either components of regret [$t(12)=1.36$, $p=$n.s.].

4. Discussion

In this study we investigated the neuronal response to emotions following risky decision-making, primarily in regard to the evoked states of regret and disappointment. In the field of decision-making these are two well-investigated emotions (e.g., Bell, 1982, 1985; Loomes & Sugden, 1982, 1986; Mellers, Schwartz, Ho & Ritov, 1997; Zeelenberg & Pieters, 2005) which have been shown to play a crucial role in making choices (e.g., Bell, 1982, 1985; Loomes & Sugden, 1982, 1986). In neuroscience (e.g., Camille et al., 2004; Chua et al., 2009; Coricelli et al. 2005) these affective states have mainly been differentiated on the basis of feedback, with partial feedback (only the outcome from chosen gamble presented) defining disappointment, and full feedback (the outcome from unchosen gamble also presented) underlying regret. However, more broadly within the psychological literature they have been also distinguished by agency attribution, where regret, but not disappointment, is related to personal responsibility (Frijda et al., 1989; Gilovich & Medvec, 1994; Giorgetta et al., 2012; Ordöñez & Connolly, 2000; Zeelenberg et al., 1998). Therefore, in this study we separately examined the neural correlates of both feedback- and agency-based accounts of regret and disappointment. We explored, for the first time, whether these emotional reactions share a common neural representation, or rather whether they activate different brain regions. In order to acquire more sensitive brain information on the time course of the affective response while playing the gambling task, we utilized magnetoencephalography (MEG). Although previous neuroimaging studies of regret and disappointment (Chua et al.,

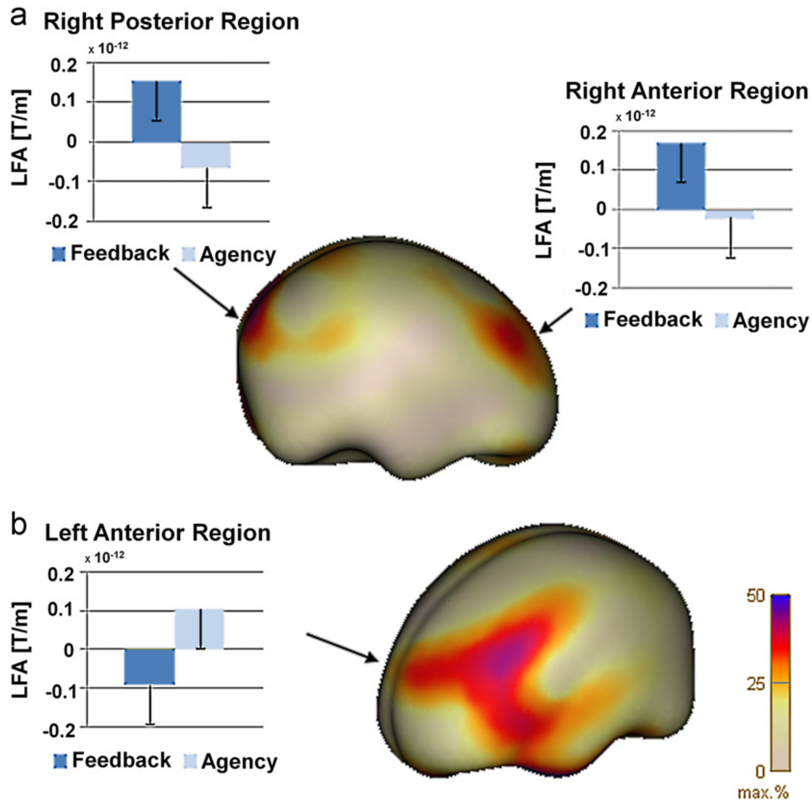

Fig. 7. Differential effects of feedback and agency on regret. Panel (a) the effects of feedback are stronger in the Right Anterior and Posterior Regions when: 1. comparing "Human & Loss-Win" to "Human & Loss", as displayed in the source reconstruction image; 2. compared to the effects of agency, as shown in the bar plots. Panel (b) the effects of agency are stronger in the left anterior region when: 1. comparing "Human & Loss" to "Computer & Loss", as displayed in the source reconstruction image; 2. compared to the effects of feedback, as shown in the bar plot.

2009; Coricelli et al., 2005) have suggested mainly frontal and parietal activity in the brain, none to date have identified its cerebral temporal dynamics and importantly, these previous findings were based on the role of feedback and not of agency.

Our behavioral results revealed that regret and disappointment were indeed the only two emotions showing significant effects in both human-agency and computer-agency conditions, as assessed by subjective ratings. Importantly, the emotions showed a differential effect on the subsequent choices, with regret exerting a more substantial effect on the choice. Our neurophysiological results demonstrated that regret and disappointment are differentially processed in the brain, and that this activity occurs relatively early, between 190 ms and 305 ms after the presentation of the decision outcome. In contrast, they exhibit very similar cortical activity after 305 ms. More specifically, we confirmed previous fMRI findings by showing that the role of feedback is localized in the right anterior and posterior brain regions. However, and importantly, we were also able to highlight the role of agency and its differential localization in the brain, showing stronger activation in the left anterior region for regret than for disappointment. Additionally, in this early time window we found differential brain activity for the role of feedback and agency respectively on feelings of regret. Thus, we show that both feedback and agency play a role when differentiating regret from disappointment, and also that the right and left side of the brain appear to be differentially involved in their respective processing.

4.1. Using MEG for studying relevant emotions in decision-making.

We used MEG in the present study to better determine the temporal course of neuromagnetic cortical components linked to the emotions of regret and disappointment in decision-making (e.g.: Anderson, 2003; Canessa et al., 2009; Coricelli et al., 2005; Gilbert, Morewedge, Risen & Wilson, 2004; Zeelenberg, 1999). Only a few studies have used this high temporal resolution functional imaging method to explore brain activity related to emotions, and none has to date attempted to identify the cerebral temporal dynamics of cognitive-based emotions such as regret and disappointment. Therefore, it has remained unclear when regret and disappointment actually occur, and whether they occur sequentially or in parallel. Indeed, the existing MEG literature on emotions is based on investigations of primary emotions, such as those elicited by standard IAPS stimuli. In these studies, differences were observed in the early cortical responses between emotions stemming from pleasant/unpleasant stimuli as compared to neutral stimuli. That is, differential ERF activity related to these emotions happens quite early, around 120–310 ms (e.g., D'Hondt et al., 2010; Peyk et al., 2008. Accordingly, we found that the main differential neural activity related to regret and disappointment occurred between 190 and 305 ms after the outcome was seen, as befits more cognitively elaborate emotions.

4.2. Role of feedback and agency on regret and disappointment: experienced emotions

Emotional ratings help to explain differences related to regret and disappointment as a function of feedback and agency manipulations. As both regret and disappointment stem from counterfactual thinking (e.g., Zeelenberg et al., 1998a), we did not find for either a desire to change choice after experiencing regret and disappointment, nor did we observe differential outcome evaluation in terms of sadness. This is in contrast to previous studies (e.g., Chua et al., 2009), and can be ascribed to the feedback-based similarity between regret and disappointment (that is, in both types the outcome from chosen gamble was a loss and the outcome from unchosen gamble was a gain). In contrast, regret was experienced more strongly when the participant was personally responsible for the choice, whereas disappointment was prevalent when the computer was responsible for the (incorrect) choice, thus showing a responsibility-based difference between regret and disappointment. While we do not wish to suggest that these are the only emotions that play a role in risky choice, we believe that this study does demonstrate the presence and the processing of *both* the emotions of regret and disappointment, and potentially provides a useful template by which to examine affective influences on decision-making. Indeed, highlighting this difference per se represents progress in the assessment of emotional aspects involved in decision-making. Previous studies (e.g., Camille et al., 2004; Chua et al., 2009; Coricelli et al., 2005; Mellers et al., 1999) using this well-characterized gambling task intended to specifically induce regret and disappointment simply asked participants about their feelings on a happy/sad continuum.

Moreover, our emotional ratings show how in this task participants were equally engaged in both conditions. Indeed, differently from disappointment and regret, human and computer conditions did not differ for happiness and anger. Also results from training phase did not show differences between human and computer conditions, in particular for negative emotions. Instead, in previous studies (e.g. Yeung, Holroyd & Cohen, 2005), using a similar gambling task, a different involvement was found between the human and computer conditions. This difference may be related to the fact that our task was fully randomized, whereas in Yeung et al.'s study human and computer conditions were presented in separated blocks, and participants knew, before they started to play, that they were not going to give a response. Therefore, our findings suggest how differences in experimental design affect the involvement in such gambling tasks.

4.3. Effect of regret and disappointment on subsequent choices: behavioral results

Overall, in agreement with previous studies investigating risky decision-making by using options with the same expected value (zero EV) as in our gambling task (e.g., Gehring and Willoughby, 2002; Polezzi, Sartori, Rumiati, Vidotto & Daum, 2010; Yeung & Sanfey, 2004), participants made a higher number of risky than safe choices. However, participants did not show differential reaction times between safe and risky choices. Importantly, our behavioral results also confirmed that regret has a more substantial influence on choice than disappointment: participants chose a higher number of risky choices after losses than after gains, but only when they personally made the choice (regret condition) and not when the computer made the choice (disappointment condition). Therefore, in agreement with previous literature, riskier behavior after having experienced regret can be seen as utilizing the possibility to "make up" after a mistake (e.g., Nicolle et al., 2011b). This was not the case after experiencing disappointment.

4.4. Role of feedback on regret and disappointment: imaging results

Interestingly, our results showed that between 190 ms and 305 ms after the outcome, the role of feedback on choices personally made was associated with more neural activity in the right anterior and posterior regions, whereas no differences were found in the right anterior region for the role of feedback on choices made by the computer. These findings bear a close resemblance to activation previously found in fMRI studies, namely a right lateralization for regret-related activity. Indeed, results from previous fMRI studies have found activation in the right dorsolateral prefrontal cortex, right lateral orbitofrontal cortex and inferior parietal cortex after the experience of regret (e.g., Coricelli et al., 2005; Coricelli, Dolan & Sirigu, 2007). Right lateralization when comparing outcomes from personally chosen and unchosen options was also found in an EEG study (Yeung & Sanfey, 2004) using a simple monetary gambling task. Thus, it appears that negative emotions can engage cognitive-based right hemispheric responses (Simon-Thomas, Role & Knight, 2005).

In addition, as in Chua et al. (2009), we also found that activity in the right frontal region was higher for regret after full feedback than after partial feedback (for regret than for disappointment, as denoted in the fMRI literature). In this previous study the differential activity was found comparing across trials, that is, comparing those with only partial feedback to those with only full feedback. We were able to extend this result to show that brain activity for full feedback is stronger, even when both outcomes from the chosen gamble (partial feedback) and the unchosen gamble (full feedback) are included in the same trial. As in a previous study (e.g., Coricelli et al., 2005), this result may well be due to the increase in punishment-related activity in lateral orbitofrontal cortex (Kringelbach & Rolls, 2004; O'Doherty, Kringelbach, Rolls, Hornak & Andrews 2001), possibly associated with mechanisms of cognitive control, which are required more when one is personally responsible for the choice.

4.5. Role of agency on regret and disappointment: imaging results

This study was able to demonstrate the crucial role played by agency in the emotional experience of regret and disappointment. Our results not only show differential neural activities for regret and disappointment as a function of feedback, as already known, but also as a function of agency. Notably, a novel finding of our study is the association between the role of agency on regret and disappointment and the differential activity in the left frontal region. We found that between 190 ms and 305 ms after the presentation of the outcome, brain activity in the left frontal region was higher when the loss was a consequence of personal choice as opposed to when it was due to a computer choice. This result highlights a new role for the left frontal region: cognitive-based negative emotions, such as regret, can recruit this area when we are personally responsible for the negative consequences of our actions. The novel finding related to the role of greater activity in the left anterior region when there is a sense of personal responsibility than external responsibility can be applied to better understand the lateralization effect of the brain of clinical populations, such as anxious apprehension, where personal responsibility is experienced at exaggerated levels, and which is indeed associated with greater left frontal brain activity (Heller, Nitschke, Etienne & Miller, 1997). Importantly, several studies on patients with schizophrenia show higher activation of the left frontal lobe (e.g., De Vico Fallani et al., 2010; Glahn et al., 2005) as well as a tendency to over-attribute agency to themselves, with this having a causal effect on subsequent events (Daprati et al. 1997; Franck et al., 2001; Maeda et al., 2012; Synofzik, Their, Leube, Schlotterbeck & Lindner, 2010; Voss et al., 2010). Therefore, our findings on agency/responsibility can add relevant knowledge in both the fields of research of neuroeconomics and psychopathology.

4.6. Role of lateral OFC in regret processing

Our findings show that there is differential lateralization for the two crucial factors underlying regret. Previous neuroimaging studies have shown that regrettable decisions lead to OFC activation (Chandrasekhar et al., 2008; Chua et al., 2009; Coricelli et al., 2005; Liu et al., 2007), with this area implicated in counterfactual thinking and in the emotional salience of regret. However, these studies also showed different associations of lateral OFC with regret. Coricelli et al. (2005) found a correlation between medial OFC and regret, and bilateral OFC activity for both regret and disappointment. Chua et al. (2009) showed a positive correlation between right lateral OFC and regret, a correlation between regret and bilateral OFC was shown by Liu et al. (2007), and a correlation of right lateral OFC with both regret and rejoice was shown by Chandrasekhar et al. (2008). An explanation for this inconsistency has been that these studies employed different tasks (for a review see Sommer, Peters, Gläscher and Buchel, 2009), and additionally that the foci of activity in anterior and/or posterior OFC may have differed across the studies. Our results suggest that differential lateral frontal activity can be ascribed to the differential effects of feedback and agency on regret. Importantly, this factor has not previously been examined, and indeed we believe it can explain the lateralization differences found in the previous studies.

Our study can also contribute to the existing literature on frontal brain asymmetry, a very prominent area of investigation within emotion. Indeed, the relationship between the frontal brain asymmetry and the affective-valence and motivational-based hypotheses has been widely studied (for a review, see Coan & Allen, 2004). According to affective-valence hypothesis, left prefrontal cortex (PFC) is associated with positive emotions, whereas the right PFC is associated with negative emotions (e.g., Davidson, 1984, 1998, 2004; Heller, 1993; Heller & Nitschke, 1998; Silberman & Weingartner, 1986). According to the motivational-based approach, left frontal activity is associated with a behavioral activation motivational system, whereas greater right frontal activity is associated with a more withdrawal motivational system (e.g., Coan & Allen, 2003; Davidson, 1992; Harmon-Jones & Allen, 1997; Harmon-Jones, 2004; Harmon-Jones, Lueck, Fearn & Harmon-Jones, 2006). Research has found that the greater left brain activity is related to anger and aggression (e.g., Harmon-Jones & Sigelman, 2001) and with subjective anger to ostracism (Peterson Gravens, & Harmon-Jones, 2011). Also, frontal asymmetry has been found to be associated with psychopathology: with panic disorder (Wiedemann et al., 1999), social phobia (Davidson, Jackson & Larson, 2000) and depression (Bruder et al., 1997; Henriques & Davidson, 1991) associated with greater right frontal activation, and anxious apprehension (generalized anxiety disorder) associated with greater left frontal brain activity (Heller, Nitschke, Etienne & Miller, 1997). Our findings suggest that frontal asymmetry may be associated with different aspects of the cognitive-based emotions involved in decision-making, with greater right frontal activity associated with the processing of feedback, and greater left frontal activity associated with agency. This hypothesis could be usefully tested in future studies. Also, studies such as those described here have the potential to connect studies in neuroscience to those in psychopathology, especially in light of the increasing evidence for lateralized brain activity in disorders such as schizophrenia, anxiety, and depression.

4.7. Wins vs. losses

Interestingly, our findings reflect a distinction between gain and loss trials, which resembles the feedback related negativity (FRN) component previously found in EEG studies on gambling tasks (e.g., Gehring & Willoughby, 2002; Hewig et al., 2007; Marco-Pallarés et al., 2008; Nieuwenhuis, Yeung, Holroyd, Schurger & Cohen, 2004; Polezzi et al., 2010; Yeung & Sanfey, 2004; Yeung et al., 2005), as well as in a more recent MEG study (Doñamayor, Marco-Pallarés, Heldmann, Schoenfeld & Münte, 2011). However, whereas in these studies choices were always made personally, Yeung et al. (2005) used a task where the choice was also made by the computer. This study showed that the differential activity between loss and gain trials, occurring between 248 and 296 ms after stimuli onset, was greater when the choice was made personally than when it was made by the computer. This can help explain why we did not find differences in the Right Anterior Region in the computer choice trials, even though this difference was found in the Right Posterior Region. Findings from the present study, although confirming differential brain activity related to gains and losses, clearly show a differential role of the right anterior and posterior regions, potentially related to the affective significance of the outcomes.

4.8. Limitations and directions for future research

Due to the exploratory nature of this study and its novelty, some limitations of the design of the study should be pointed out. Here, we used for analysis purposes only trials displaying feedback for both the chosen and unchosen options whereas we did not consider the control condition were only partial feedback was employed. Indeed, in order to use trials with only feedback on chosen options in a meaningful way we would have had to add at least another 60 trials for each relevant emotion, resulting in an additional 240 trials, likely then exceeding subjects' attention span and interest levels. However, use of these trial types could have helped avoid potential confounds such as, possible expectancy effects at the time of the first feedback, or habituation effects at the time of the second feedback. We attempted to address this possible problem by using filler trials, where the second feedback could have been the same valence than the first feedback. Therefore, future studies could control potential confounding variables by also adding partial feedback trials. After having gained some evidence for the existence of the role of both feedback and agency on these emotions, specific aspects of regret should be addressed using findings from the present study, which clearly highlight the dissociation between regret and disappointment. This can be done, for example, by investigating only emotions related to personal choice (regret vs. rejoice). Another possible limitation of the study arises from potential carryover effects from the first (obtained) feedback to the second (unobtained). Though we performed separate preprocessing for each feedback window within each trials, we cannot exclude at all the presence of possible carry-over effects. Therefore, use of partial feedback trials could also help with this issue. These future studies would contribute further to distinguishing between agency- and feedback-regret.

Last, but not least, due to the limited number of trials, we could not control for the effects of outcome magnitude. The question regarding the effect of the outcome magnitude is still an open issue in neuroscience. Some studies have found that, on our same time window (which resembles the FRN) the outcome magnitude does matter (e.g., Doñamayor et al., 2011; Wu & Zhou, 2009) whereas others have failed to find any effect or have found it but on later timing, that is on the P300 that follows the FRN (e.g. Hewig et al., 2007; Nieuwenhuis et al., 2004; Yeung & Sanfey, 2004). Therefore, we cannot exclude that also outcome magnitude may have affected our findings, which we were unable to investigate due to a relatively low number of trials for each outcome amount. However, future studies could usefully address the interaction between different emotions and outcome magnitude.

Exploring these and other questions will allow continued advancement of the study of important emotions in decision-making, such as regret and disappointment, thereby further exploring both their behavioral consequences and neural dynamics.

5. Conclusion

The present study shows that there is differential electromagnetic activity in the brain associated with the processing of regret and disappointment not only as a function of feedback, as has previously been shown, but also as a function of agency. Tying together the divergent literature on regret and disappointment, these results argue that both the role of feedback (Chua et al., 2009; Mellers et al., 1999), and the role of agency (Ordönez & Connolly, 2000; Zeelenberg et al., 1998; Zeelenberg et al., 2000) can combine to produce, either separately or in concert, the emotional states of regret and disappointment. Neurocortical activity reflects both of these two crucial aspects of emotional experience, which are differentially processed in the brain. The cortical differentiation between regret and disappointment outlined in this study helps to better understand their role in decision-making and how they differ in biasing choice. At a neural level, results show that agency-based differences between regret and disappointment do exist even when full feedback is not known. Whereas, when full feedback is known, our findings suggest a differential brain activity related to both agency and feedback effects on emotions. Thus, future studies should consider that regret can be characterized by both the knowledge of obtained and unobtained outcomes, as well as by the attribution of responsibility. Future studies should also take into consideration that, although there is a solid body of behavioral evidence that regret is a multi-faceted experience and that both agency- and feedback-related regret are conceptually (and experientially) similar, the use of neuroscientific methods are particularly appropriate for examining whether these aspects of regret are differentially processed.

Notably, the emotion of regret not only has an important impact in 'normal' decision-making (Hart & Mas-Collel, 2003; Marchiori & Warglien, 2008) but has also been implicated in several clinical disorders such as schizophrenia (Larquet, Coricelli, Opolczynski & Thibaut, 2010; Roese, Park, Smallman & Gibson, 2008), depression (Leahy, 2001), and obsessive-compulsive disorder (Sachdev & Malhi, 2005). It also has a strong influence on important real-life decisions, such as those concerning medical treatment (Clark, Wray, & Ashton, 2001; Connolly & Reb, 2005) as well as for the understanding of "chasing" behavior in pathological gambling (Nicolle et al., 2011b). Thus, given the wide-ranging importance of regret in decision-making more broadly, investigating its neurocognitive mechanisms is of particular relevance.

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