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Author Queries

Journal: Philosophical Transactions of the Royal Society B

Manuscript: rstb20090163

Q1 References Bell (1982), Blum *et al*. (1996) and Baratgin *et al*. (in preparation) have been cited in text but not provided in the list. Please supply reference details or delete the reference citation from the text.

Q2 Please note that the reference citations Allais (1954) and Pieters & Zeelenberg (2005) have been changed to Allais (1953) and Pieters & Zeelenberg (2003) with respect to the reference list provided.

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Phil. Trans. R. Soc. B (2009) **0**, 1–9
doi:10.1098/rstb.2009.0163

Regret and the rationality of choices

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Regret helps to optimize decision behaviour. It can be defined as a rational emotion. Several recent neurobiological studies have confirmed the interface between emotion and cognition at which regret is located and documented its role in decision behaviour. These data give credibility to the incorporation of regret in decision theory that had been proposed by economists in the 1980s. However, finer distinctions are required in order to get a better grasp of how regret and behaviour influence each other. Regret can be defined as a predictive error signal but this signal does not necessarily transpose into a decision-weight influencing behaviour. Clinical studies on several types of patients show that the processing of an error signal and its influence on subsequent behaviour can be dissociated. We propose a general understanding of how regret and decision-making are connected in terms of regret being modulated by rational antecedents of choice. Regret and the modification of behaviour on its basis will depend on the criteria of rationality involved in decision-making. We indicate current and prospective lines of research in order to refine our views on how regret contributes to optimal decision-making.

Keywords: regret; predictive error signal; decision weight; addiction; paradoxes of rationality

1. INTRODUCTION

Regret can be defined as a rational emotion in the sense that its presence seems to be correlated with improved decision-making. Regret is defined as involving both cognitive and emotional components. On the basis of a comparison between what I got and what I could have got, I may experience to a variable extent the emotion of regret. On the basis of this emotion, I will attune my future decisions. Anticipated regret can then be defined as a decision criterion. Recent neurobiological evidence has tended to confirm this simple view, which gives some credibility to the incorporation of regret in decision theory that had been proposed by decision theorists in the 1980s. However, finer distinctions are required in order to get a better grasp of how regret and behaviour influence each other. Anticipated regret can be defined as a predictive error signal: the human brain on the basis of past experience forms comparative expectations on the results of available alternative courses of action. But the information on the most favourable course of action does not necessarily transpose into a corresponding optimal decision. Clinical studies on several types of patients show that the processing of an error signal and its influence on subsequent behaviour can be dissociated. We will discuss some of these data in order to refine our views on how regret contributes to optimal decision-making. We also propose a general understanding of how regret and decision-making are connected in terms of regret being modulated by rational antecedents of choice. Namely, regret and the modification of behaviour on its basis will depend on the criteria of rationality involved in decision-making. Intuitively, the more rational I think my decision was, the less I tend to regret its outcomes. But we will be interested in less clear-cut cases, like when, in particular, apparent conflicting rational decision criteria prevail in choice. The aim of this article is to suggest conceptual refinements, by evaluating the evidence of existing or ongoing experiments, on how the rationality of choices, the experience of regret and the optimization of behaviour are in principle connected and potentially disconnected in some clinical conditions.

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One contribution of 11 to a Theme Issue 'Rationality and emotions'.

2. TESTING THE REGRET EXPLANATION OF ALLAISIAN BEHAVIOUR

Regret has been incorporated into theories of rational decision-making (Bell 1982; Loomes & Sugden 1982; Hart & Mas-Collel 2000) because of the Q1 explanation it provides of apparent deviations from rationality such as transitivity and independence of choice from irrelevant alternatives. Regret-theory, notably, explains the Allais (1953) paradox. Q2

Let us represent the classical Allais paradox by the following matrix.

Matrix 1: standard Allaisian behaviour.

	P ($p = 0.01$)	Q ($p = 0.10$)	R ($p = 0.89$)
A	500 000	500 000	500 000
B	0	2 500 000	500 000
C	500 000	500 000	0
D	0	2 500 000	0

Here p, q and r are states of affairs whose probability to occur is indicated by the figures in the second line from the top. In between-groups experiments, a

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group of participants is invited to choose between options A and B and another group between options C and D. We then compare which options were favoured in each group. As underlined in bold characters in the matrix, A is the option most often chosen in the first group and D the one favoured by the participants in the second group. In within-subjects designs, when participants are presented with the whole matrix, the choice of the pair ⟨A,D⟩ also prevails. Kahneman & Tversky (1979) report the following results for Allaisian options presented to participants in extensive lottery forms:

(i) between groups: A: 82%/D: 83%
(ii) within subjects: B–C: 7/A–D: 60/B–D: 13/A–C: 5.

These results exemplify a violation of the independence axiom of Von Neumann and Morgenstern decision theory. The violation can be made intuitive by expressing it in terms of informational dispersion on the part of the subject, in the sense that she seemingly does not focus on the relevant decision-theoretical core of the matrix or lotteries she is presented with. Such normative informational focus has been labelled in terms of the elimination of common consequences of pairs of options in decision theory. It is made clear in the following matrix that states of affair *r* should be discarded as it makes apparent that A and B and C and D are, respectively, similar from that standpoint. But once stripped of their common consequences, it is also clear that A and C and B and D are equivalent and that it is irrational to modify one's choices across pairs ⟨A,B⟩ and ⟨C,D⟩.

Matrix 2: deleting common consequences.

	P ($p = 0.01$)	Q ($p = 0.10$)	R ($p = 0.89$)
A	500 000	500 000	~~500 000~~
B	0	2 500 000	~~500 000~~
C	500 000	500 000	~~0~~
D	0	2 500 000	~~0~~

Now, an obvious feature of Matrices 1 and 2 is the intuitiveness with which the respective choices A–D and B–D or A–C impose themselves on the subject's mind. Intuitiveness is by no means a criterion of rationality, but the principle of elimination of common consequences practically embodies the axiom of independence which is at the core of rational decision-theory, and makes it visually salient in Matrix 2. However Allaisian behaviour as demonstrated through Matrix 1 is also intuitive and compelling. Individuals can easily justify their choices, even though they deviate from rational standards of decision theory. One can even experience conflicts of intuitions when asked to perform a choice in this task and knowingly deviate from rationality standards, hence, perhaps, its classical denomination as a paradox. Slovic & Tversky (1974) have shown that experts in decision theory consistently exemplify Allaisian behaviour even though they are of course perfectly cognizant of the independence axiom. The problem is then to understand what makes A–D attractive in Matrix 1 and why Matrix 2 may not be a sufficiently powerful debiasing device.

An answer is given in Matrix 3 which incorporates anticipated regrets as weights of utility determining the A–D choice.

Matrix 3: introducing regret.

	P ($p = 0.01$)	Q ($p = 0.10$)	R ($p = 0.89$)
A	500 000	500 000	500 000
B	$0 + R_1$	2 500 000	500 000
C	500 000	500 000	0
D	$0 + R_2$	2 500 000	0

R_1 and R_2 are qualitative designations of levels of regret. The usual explanation goes as follows: $R_1 < R_2$, in the sense that if p occurs, you would regret more having chosen B instead of A, than if P or R occurs, you would regret having chosen C instead of D. So if B–D is the coherent pattern, R_2—conceived as an amount of anticipated regret—has no enough weight to make you chose C, while R_1 has enough of such 'decision weight' to make you chose A. Anticipated regret is then considered an explanatory factor of Allaisian behaviour. It vindicates the intuitive aspect of Matrix 1 but it also preserves rationality as presented in its crude form in Matrix 2 to the extent that it incorporates regret as an ingredient which is rationally processed in decision-making, on a par with payoffs and their associated probabilities. When one includes regret, it is clear that the elimination of common consequences does not yield equivalent choices any longer and that apparent inconsistent behaviour can be explained away. But the argument relies now on the plausibility of a view of anticipated regret as inflecting decision behaviour in the intended sense.

The integration of regret in decision theory has been supported by recent neurobiological investigation. Present studies on the neural correlates of regret take advantage of previous observations on the role of the orbitofrontal cortex in the processing of reward and its role on subsequent behaviour. Rolls (2000) has evidenced the incapacity of orbitofrontal patients to modify their behaviour in response to negative consequences. Ursu & Carter (2005) have demonstrated how the anticipated affective impact of a choice was modulated by the comparison between the different available alternatives. These reasoning patterns, consisting in anticipating contrasts between actual outcomes and counterfactual ones (counterfactual in the sense that those outcomes are the ones that I would have gotten had I taken an alternative course of action), are reflected in the orbitofrontal cortex activity. More precisely, the impact of potentially negative consequences of choices is essentially represented in the lateral areas of the orbitofrontal cortex, whereas the medial and dorsal areas of the prefrontal cortex are more specialized in the impact of positive consequences. Camille *et al*. (2004) have shown that patients presenting orbitofrontal lesions do not seem to take regret into account in experimental sessions repeating stimuli such as the following:

Partial feedback: in the partial feedback condition of Camille's experiment, subjects consider two wheels

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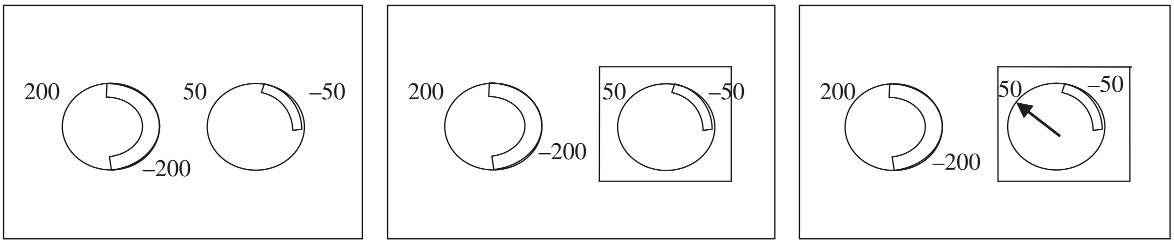

Figure 1. Partial feedback condition.

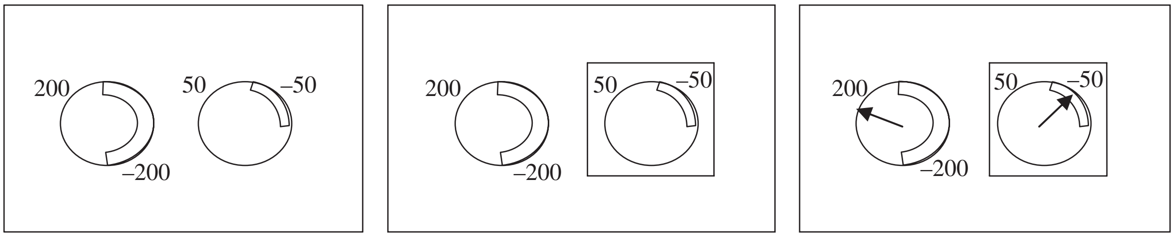

Figure 2. Complete feedback condition.

presenting possible gains and losses, they pick up one of them (squared) and get feedback only for the chose wheel (figure 1).

Complete feedback: in the complete feedback condition, subjects get also feedback for the foregone wheel, making possible a comparison between what they get (the squared circle) and what they could have got (figure 2).

Camille *et al.* (2004) and Coricelli *et al.* (2005), using the same experimental paradigm in an fMRI study, show that the orbitofrontal cortex has a fundamental role in experiencing regret and integrating cognitive and emotional components of the entire process of decision-making. Across repetition of this task, participants tend to become regret aversive. The authors speculate that the orbitofrontal cortex uses *top-down* process in which cognitive components, such as counterfactual thinking, modulate emotional and behavioural responses tending to increased regret aversion.

Regret is understood as an emotion guiding decision-making, fitting well with Damasio's (1994) understanding of the contribution of emotions to rationality. The understanding of brain activities reflecting anticipated affective impacts makes possible the neurobiological validation of the regret hypothesis in orienting decision-making towards apparent non-normative behaviour. Laland & Grafman (2005) test lotteries on medial orbitofrontal patients and observe higher coherence among them than among healthy participants, although patients are not more risk-seeking. This is quite interesting because it shows that these patients—the same population with respect to which Damasio has elaborated his somatic marker hypothesis—do not show incoherence owing to inconsiderate risk-taking in decision-making.

Given plausible data on the connection between orbitofrontal lesions and the absence of regret, it would be interesting to directly tackle the original motive for which regret had been introduced in decision theory, namely to provide a plausible explanation of seemingly irrational behaviour, such as the one provoked by the Allais problem. We speculate that if the finding that orbitofrontal patients present an impaired treatment of regret is robust, and if anticipated regret is a correct explanation for the type of behaviour usually induced by Allais problem, then those patients should behave normatively when facing Allais paradox stimuli. Unlike healthy subjects, they should not violate the independence axiom, rather they would show consistency across their choices and ironically behave normatively in a task that has been considered a staple of irrationality among decision theorists. Bourgeois-Gironde and Cova (in progress) directly test Allais problems on patients presenting focal orbitofrontal lesions, and first results tend to document coherence, rationality and limited risk-seeking behaviour among these patients. These data would tend to confirm the overall plausibility of the regret hypothesis in explaining Allaisian behaviour. In cases in which anticipated regrets are a source of apparent biased decision-making, their presumed absence seems to make behaviour tend towards rationality as normatively encapsulated by the axiom of independence. But a better view remains to be acquired on the mechanisms through which an emotional and cognitive state such as regret manages to inflect behaviour in one way or the other.

3. REGRETS AS ERROR SIGNALS AND/OR DECISION WEIGHTS

Anticipated regret can be understood in neuroscience and learning models as a predictive error signal which is accompanied or not by an emotional state. This signal can be simply defined as the difference between an actual outcome and a fictive or counterfactual outcome. On the basis of this signal, learning can take place in sequential rewarding tasks, as in the case in Camille and Coricelli's studies. In those studies the underlying hypothesis is that orbitofrontal patients do not generate such signals and consequently cannot modify their behaviour by processing anticipated regrets. But an alternative hypothesis is that even

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though some patients may be unable to generate predictive error signals, some others may generate them while these signals may not help modify their behaviour. In the absence of regret-aversive behaviour, indeed, we need to discriminate between non-generation versus inefficiency of error signals in patients' brains. The role of the orbitofrontal cortex may be associated with the integration of properly generated error signals into behavioural strategies. In case of lesions of the orbitofrontal cortex, this integration does not take place, but an alternative cause of non-integration, in the presence of impaired orbitofrontal cortices, is a dysfunction in the production of error-signals.

The question was raised by Chiu *et al.* (2008). They observed that chronic smokers showed a reduced influence of predictive error signals on subsequent behaviour. However, given the neural response in the caudate typically associated with the generation of predictive errors (e.g. Lau & Glimcher 2007), the authors were also in a position to infer that there was no loss in the production of these signals. There was an observable dissociation, then, between the generation of error signals and the modification of behaviour. It was as if the correct treatment of comparative information between actual experience and what might have been the case had no weight in improving subsequent repeated decision-making. Cognitive processing of information on potential outcomes and behavioural control were not integrated.

To get a precise specification on how caudate based generated error signals fail to play a role in optimizing behaviour of addictive smokers, Chiu and his colleagues used the sequential investment game which **Q3** can be abstractly represented as follows (figure 3).

A subject starts in the state S_t, in the centre square, and moves to state S_{t+1}, in the upper square. This is what the subject actually does. She has access to her actual gains. But she can also retrieve information about fictive experience, i.e. what she would have experienced had she followed another path, represented by lateral arrows in the schema, and experienced alternative gains. In Chiu's experiment, the decision to move to S_{t+1} or to alternative states corresponds to investments of a portion of an individual endowment on a realistically reproduced fluctuating market. After each move the subject could compare the results of his investment decisions with the market returns history. Predictive error over gains is then computed as the difference between the maximum gain made possible by the market history and the actual gain realized by the individual. Two distinct groups of participants have performed this sequential market task: smokers and non-smokers. In one experimental condition, smokers have been satiated while in the other they have been deprived of nicotine.

In order to determine the role played by predictive error signals in decision-making, Chiu *et al.* have concentrated their analysis on predictive errors in the case of gains, i.e. only in situations in which participants earned something below the possible maximum market return. The question is to observe whether behaviour at $t+1$ is dependent on less than optimal

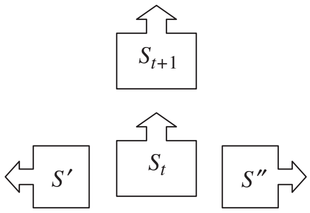

Figure 3. Sequential investment game.

positive returns at t. Individuals in the control group (non-smokers) illustrate this dependence as we observe among them a positive influence on the foregone maximal possible return on the subsequent investment decision. This is not the case either for sated or for non sated smokers. Behavioural patterns on this sequential investment task show that predictive error signals have no weights in smokers' decision-making. However, brain-imaging data show that fictive error signals are equally generated among smokers and non-smokers. Activity in the bilateral ventral caudate nucleus has been correlated with the treatment of predictive errors in the investment game (Lohrenz *et al.* 2007). Chiu *et al.* conclude that the intact neuronal response to predictive errors in smokers' brains does not translate into corrective behavioural strategies. This dissociation between error signals and behaviour can be further interpreted as a failure of integration between emotion and rationality. Significant activity in the anterior cingular cortex in nicotine deprived smokers, which can in fact be interpreted as a response to negative salient emotionally laden stimuli, show that a 'feeling of error' is experienced by this group of participants, even though it is not enough to modify their subsequent decisions.

As Ahmed (2004) clearly puts it 'drug addicts are often portrayed as irrational persons who fail to maximize future rewards. [...] (But) to prove that addiction is an irrational behaviour, one needs to show that addicts would be better off if they had been prevented from taking drugs in the first place'. The tacit postulate in the application of learning models, and conceptual constructs such as 'predictive error signal', to suboptimal behaviour is that among distinct group of populations (addicts versus non-addicts) there is a homogeneous and exogenous appraisal of actual and counterfactual rewards. One can differently speculate that this very ability to deal with equanimity with such comparisons is precisely what is impaired in addictive brains (Redish 2004). Chiu himself interprets his results by confirming the idea that addicts may be thought to have a diminished response to biological rewards: actual gains are not treated as rewards in the smokers group and are not positive reinforcers on which learning is normally based. But Chiu stops short of positing an endogenous dependence between the 'internal' supervisor which compares actual and foregone outcomes and addictive behaviour, because he observes that comparisons are intact while behaviour does not take as inputs those cognitive, possibly associated with strong emotions, anticipated signals of regret.

Many studies have documented the role of midbrain dopamine neurons in generating predictive error

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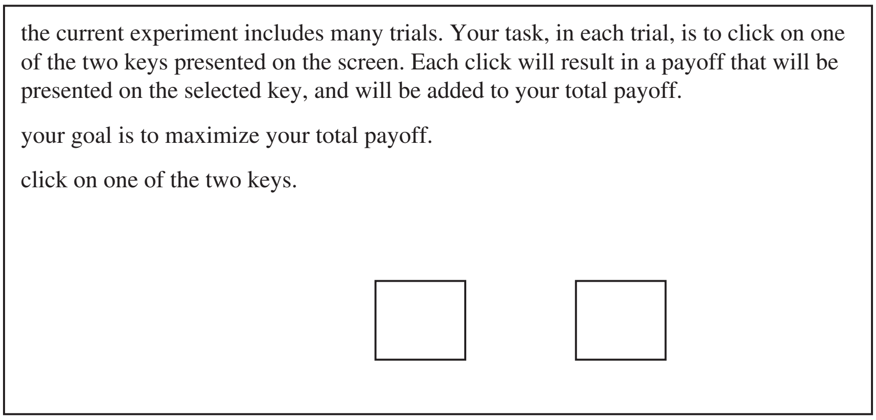

Figure 4. The clicking paradigm.

signals (Schultz & Dayan 1997) and that dopamine was more sensitive to the prediction of reward than to the reception of reward (Heikkila *et al*. 1975). In Redish's model of addiction changes in the output of dopamine cells are supposed to signal to the forebrain discrepancies between prediction of reward and actual reward. The role of dopamine in learning models can also be phrased in terms of a distinction between monitoring and control functions more familiar to students of metacognition. Addictive individuals seem able to generate proper signals of error in the light of their past and present decisions but they are not able to maximize future rewards by conferring more weights to decisions that will issue on optimal outcomes. Monitoring is intact but disconnected from cognitive control. This squares well with complementary data on discounting behaviour in non-smokers and smokers, the latter choosing comparatively smaller immediate gains over larger more delayed ones (McClure *et al*. 2004). What is usually described in this context in terms of lack of control, impatience or myopia may be more generally interpreted as the behavioural manifestation of a more general deficiency in the efficiency of dopamine based error signals to guide decision-making in an optimal sense.

The main lesson we can draw is the dissociation in certain individuals between the presence of signals of regret, both at cognitive and emotional and at implicit and explicit levels, and the correlative absence of strategic decision-making owing to the inefficiency of these signals in view of behavioural control. We can envision the reverse dissociation that would consist in over regret-aversive behaviour uncorrelated to the presence of reliable error signals. We saw in addictive patients that error signals were generated, that a course of action could be cognitively estimated to be the most optimal and that, yet, this estimation was not transposed into actual behaviour. Observing manifestations of Tourette's syndrome, one is tempted to describe a reverse sequence: an action is selected, which escapes cognitive and motor control (it is felt as an urge or a tic), and post hoc regret, if experienced, cannot be translated into a reliable error signal for the next occurrence of an action of this type. Blum *et al.* (1996) argue that the dopaminergic system, and in particular the dopamine D2 receptor, has been profoundly implicated in deficiencies of reward mechanisms in Tourette's syndrome. Overproduction of dopamine by the brain may induce a patient to produce involuntary and uncontrolled actions. These involuntary actions should not in principle be associated with efficient predictive error signals as they are uncontrolled.

An attempt at capturing this general prediction through a precise experimental paradigm is still tentative and we simply suggest a possible way of making use at this juncture of the well-known behavioural economics so-called clicking paradigm (Erev & Barron 2005) (figure 4).

Simple decision tasks such as the clicking paradigm present the opportunity to manipulate the information on expected outcomes and feedback in a very flexible way. It is first possible to leave gains and their probabilities unknown at the moment of choice. Participants decide in a state of full ambiguity in the sense, then, that no information is made available. One can then vary the expected gains as the task unfolds, making it an implicit learning task, on the model of the classical Iowa Gambling Task (Damasio 1994). It is also possible to provide a feedback, either partial or complete, once a choice is made between the two boxes. This reproduces the two major conditions in Camille and Coricelli's experiments. But in the absence of explicit information at the moment of choice, the difference, again, is that no calculus is explicitly made at the moment of choice. The regret task is then embedded in an implicit learning task. In other terms, regret, as the task unfolds, will not tap directly into a cognitively elaborated anticipated counterfactual reasoning process, but directly into the experienced value of each box.

Another layer in the clicking paradigm can be manipulated, which more closely relates to the normative dimension of regret we are interested in. In previous studies on the neurobiology of regret, the question whether regret was rational or not has been left aside. However, one can presume that regrets are finely modulated by their normative antecedents. Schematically, if an individual is not responsible for any bad consequence she faces, that individual is less liable to experience regret than if she can attribute to herself the authorship of the act leading to that consequence (Zeelenberg 1999). Responsibility and

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self-attributed authorship figure among what we label the rational antecedents of regret. Availability of information about the consequences of one's choices is another obvious component of the rationality of regrets. In the clicking paradigm, one relevant combination in order to study the adaptive impact of regret among Tourette patients would combine implicit learning, explicit feedback and an experimental manipulation of the connection between choices and consequences. More precisely, patients will sometimes get a feedback for choices they have not made, whereas the box they have actually clicked will yield no feedback. If one is in a position to observe no difference, in terms of regret aversive behaviour, for outcomes that correspond and outcomes that do not correspond to actual patients' choices, it would constitute starting evidence in favour of a disconnection between regret and a typical rational antecedent of choice such as authorship or responsibility.

It has been more generally noted that Tourette's syndrome patients had paradoxical (or, at least, difficult to understand) attitudes with self-attribution of responsibility (Schroeder 2007). Those patients are presumably over-attributers of self-responsibility, which would be confirmed by a salient behavioural pattern over our crucial condition of the box-clicking experimental design. This invites to further questions over the alleged constitutive connection between regret and its rational antecedents. The introduction of regret in decision theory in terms of decision weights must be refined in order to take into accounts the cases in which anticipated regret is under-weighted (e.g. in addictive patients) or over-weighted (e.g. possibly in Tourette's patients).

4. DECISION TYPES AND REGRET

One type of normative antecedents that can modulate the triggering of post hoc or anticipated regret in decision-making is the type of procedure one follows and the awareness with which one follows that procedure. Imagine one is deliberately negligent in deciding in the Allais matrix, it is possible that having not experienced anticipated regret she will experience no post hoc regret either. She has left the outcome to chance and at best she will be more or less disappointed by her lack of luck or, inversely, may experience non-normatively rejoicing if lucky enough. But it may be abusive to properly speak of regret in the case of negligence and luck, except may be of post hoc second-order regret not to have devoted more time and energy to pondering one's decision. Evocative of the conceptual difficulties surrounding moral luck when defining an agent as morally responsible (Williams 1981), we expect our emotions to be attuned to our normative status: scruples are the mark of moral deliberation in the same way as anticipated regret could be of our rational decision-making.

One case in point, then, is to be able to experimentally discriminate between regret linked to outcome and regret linked to procedure. Pieters & Zeelenberg (2003) underline two sources of regret: outcome and procedure. The use of poor decision procedures,

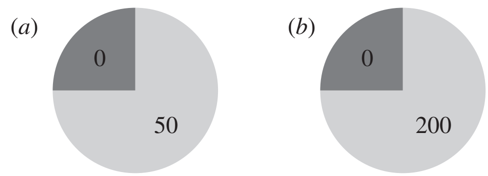

Figure 5.

when recognized by the subject, may arouse regret of its own. We will distinguish the case in which subjects have given more or less dedication to their decision procedures, on a scale that goes from complete negligence to extreme conscientiousness, with the other case in which subjects may hesitate between competing procedures possibly embodying alternative criteria of rationality. As we have already glossed with respect to the Allais problem, alternative solutions may self-impose to an individual's mind. This is what makes this decision problem a paradox. But how regret, in such paradoxical situations, may become a mark of rationality?

Regret is usually provoked by the emotional impact of the foregone alternative. When the choice of the latter has weak normative appeal the standard prediction is that in spite of a negative outcome following it, the choice of the more normatively appealing alternative is itself sufficient to block post hoc regrets. Let us give a very simple example of this situation. Choose between lotteries A and B (figure 5).

Imagine you choose B but get 0 and A yields 50. You would certainly be disappointed but do you have anything to regret? It would have been a clear irrational choice to prefer A over B. For some individuals, the rationality of choosing B may be enough to block regrets, would the imagined situation have occurred. Note that this situation is not symmetrical with respect to lucky issues. Imagine you choose A, get 50 and would you have chosen B it would have yielded 0. Now it is hard to refrain one's rejoicing on the basis of post hoc rationalization.

Our issue is with decision problems for which there is no such normative gap between the alternatives. There is a special problem in situations in which it is particularly hard to make up one's mind about the respective normative appeal of the choices presented. In paradoxes such as Allais's problem, a lucid participant may mentally balance the intuitiveness of one type of choice versus the other with no clear decision criterion to use but, precisely, the attempt to minimize anticipated regrets. Procedural indeterminacy, in that very case, may turn potential regret linked to outcome into the sole rational decision criterion at hand. The investigation of how regret is a mark of the rationality/irrationality of choice procedures must include, in those special contexts in which subjects may hesitate to apply alternative norms and procedures, an independent measure of the decisiveness or confidence with which the decision has been made.

We can conceive of two ways in view to add this crucial measure, direct and indirect. One can consistently, along the performing of a task, elicit the degree of confidence that accompanies the decision performance. Confidence scales provide a common means, along imagine a being with great predictive powers.

you are confronted with two boxes: B_1 and B_2. B_1 is opaque and B_2 is transparent, you can see that it contains €1.

B_2 contains €1; B_1 contains either €10 or nothing.

you may choose B_2 alone or B_1 and B_2 together.

if the being predicts that you choose both boxes, he does not put anything in B_1; if he predicts that you choose B_1 only, he puts €10 in B_1.

what should you choose?

Figure 6. A Newcomb problem.

with post-wagering methods (Persaud 2007) and other confidence elicitation methods favoured by experimental economists (Holt & Laury 2002). We will not dwell upon the further methodological difficulties affecting the addition of those measures to the repetitive unfolding of an experimental session, as we propose to proceed in a completely different in-built manner. We will take advantage of a classical decision problem, Newcomb problem (Nozick 1969), presented as involving a paradox of rationality in which the choice of alternatives coincides in principle with types (rather than levels) of confidence vis-à-vis one's Q1 choice (Baratgin *et al.* in preparation).

Newcomb problems have the following structure Q3 (figure 6).

Let us label people one-boxers and two-boxers according to their decisions in the Newcomb problems. What is the presumed mental typology associated with those decision-types and how does it connect to the issue of normative antecedents of regret? Two-boxers go against the prediction. The decision criteria they presumably follow have been characterized, in the philosophical branch of decision theory, as causalists versus evidentialists (Joyce 1999). Two-boxers show, so to say, a higher autonomy, that is, a higher level of decisiveness, in their choices than do one-boxers, whose possible faith in their choice amounts to a form of alienated confidence or credulity. But integrating in one's decision-criteria predictions, signs and symbolic value may not be altogether irrational (Nozick 1993). It is at least pervasive enough, as in convincing oneself of one's good health by accomplishing acts that could be signs of one's good health or of the influence of one's vote in national elections by going to vote (Quattrone & Tversky 1984).

Shafir & Tversky (1992) have run the first empirical investigation of Newcomb problems. They submitted to their subjects a Newcomb problem as a bonus problem at the end of a series of Prisoner's Dilemmas via computer terminals. Their cover story was that 'a program developed at MIT was applied during the entire session (of Prisoner's Dilemma choices) to analyze the pattern of your preference, and predict your choice (one or two boxes) with an 85 per cent accuracy'. Although it was evident that the money amounts were already set at the moment of choice, most experimental subjects opted for the single box. It is 'as if' they believed that by declining to take the money in Box B2, they could change the amount of money already deposited in Box B_1. They have not tested whether regret was different when outcomes are revealed to one-boxers and two-boxers.

We formed the prediction that one-boxers, when facing negative outcomes, would experience a greater amount of regret than would two-boxers in the same situation. This is due, we speculate, to the lesser decisiveness or autonomy with which those choices are made, in spite of their greater faithfulness to the prediction. If a difference emerges between types of decision and amount of regret in the Newcomb problem, this can be considered as a step forward a better understanding of how regret taps into rational antecedents of choices and can be modulated by competing criteria of rationality. We proceeded in a way comparable to Shafir and Tversky's as our participants were told that if the program had predicted that they would now choose the two boxes, Box B_1 would be empty, and if it had predicted that they would choose Box B_1 only, it would contain €10.

The game was framed so that Box B_1 would always be empty when participants chose it. So when participants chose Box B_1 + Box B_2, they would earn €1 and nothing when they chose Box B_1. We added a retrospective measure of regret on a 5-point scale. Our results show a significant difference between types of choices and levels of regret as captured on this scale. The following table presents descriptive statistics for the variable Regret for each type of decisions (one-boxers or two-boxers) in the Newcomb problem.

Q4

analysis	number	means of regret	IC
two-boxers	20	2.25	0.6
one-boxers	10	4.23	1.21
total	30	2.93	0.66

Two-boxers experience a statistically significant lesser amount of regret than one-boxers in spite, of course, of the disappointment of discovering that the second box is empty. The reason is that two-boxers acted with a higher level of confidence and made a choice that was less dependent on external guidance than one-boxers. It is true that one-boxers having put their faith in the Newcomb prediction feel fooled by the experiment. The disappointment is in principle the same among the two types of deciders in the sense that they both miss €10 that they expected, but the way in which they have lost it radically differ. In the case of disappointed one-boxers, they think that they should have not trusted the prediction; in the other case of disappointed two-boxers, they have less reason to think that things would have been otherwise would have they chosen Box B_1 only. This result tends to show that regret is sensitive to the way disappointment occurs as well as to the fact whether I can retrospectively assess my decision criterion as being the most rational, when conflicting decision principles were available at the moment of choice.

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5. CONCLUSION

We addressed the question whether regret is modulated by the rationality of decision procedures on the basis of existing or prospective experiments on patients and healthy subjects. We think that a variety of rational antecedents of choice explains the impact of regret on subsequent decision behaviour. Extant neurobiological studies by Camille *et al*. (2004) and Coricelli *et al*. (2005), on the adaptive role of regret in decision-making, rightly emphasize the necessary integration of emotional and cognitive components in view of optimal decision behaviour. We think that further conceptual distinctions are useful, in particular between regrets considered as error signals and regrets as decision weights, in order to uncover the cognitive and neural mechanisms through which regret positively influences behaviour. Dissociations between the ability to anticipate regret on the basis of information on alternative rewards and the ability to implement a behavioural strategy in accordance with this piece of information may occur in certain types of patients. We labelled this difference in terms of regrets as error signals and regrets as decision weights. Regrets can be under-weighted or over-weighted in decision-making, loosening the connection between a proper processing of error signals and behaviour. In healthy individuals, we postulate a calibration between the rational processing of information in the decision task and the level of regret experienced. In chronic smokers and Tourette syndrome patients, we observe, on the contrary, that the generation of error signals may be inefficient in reinforcing optimal behaviour, either because information has no weight on decision-making or because it is improperly processed.

Regret is not only dependent upon the quality of information processing relative to past and future outcomes. It is, as we termed them, also dependent upon an array of rational antecedents of choices, i.e. factors that make it more or less rational to experience regret. Being sure that I have properly processed information that was available to me is one of these factors. When I realize that I neglected some relevant aspects of the situation in making a decision that issued in a poor result, I am liable to experience more acute pangs of regret than if I were meticulous. Conversely, I may feel regret only for outcomes vis-à-vis which I bear some degree of responsibility. When nature or hazard has yielded the outcome, I have no reason to blame myself for what happens. This conflict between responsibility and nature (or God) is what is paradigmatically encapsulated in the famous Newcomb paradox. We addressed the issue to know whether regret associated with the experience of disappointing outcomes in an experimental Newcomb test was dependent on the types of decision subjects were invited to make. We observed that when subjects were not deferring their decision-criteria to an external guidance they tended to experience less regret than in the contrary case. This is but a seemingly paradox to say that regret is both triggered by my implication in a course of action and attenuated by the feeling that I acted as an autonomous agent. Future clinical and neurobiological studies on regret will probably tackle this deep philosophical issue of the connection between self-blame and free will.

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