Regret, Responsibility and the Brain

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Regret describes an emotion that arises from a variety of circumstances. We focus here on a particular type of regret, decision regret, which comes to the study of decision making by way of traditional economics, along with insights from psychology. This is clearly not the only formal description of regret, but it bears resemblance to variations studied in other fields. The benefits of this regret definition are its formalization, its operationalized measurability and its attendant body of literature in neuroimaging. This last is critical for comparison to the neural bases of other phenomena.

Regret refers to a specific set of conditions and responses, which include learning from an imagined alternative outcome that could have been reached through different action by the person feeling the emotion. This arises after an actor or agent has made a choice, sees its outcome, and then realizes that another outcome — the result of a different choice of hers — is more desirable. Decision-based regret or "decision regret" is proportional to the magnitude of the difference between the obtained and missed outcomes. These elements are the definitive components of decision regret: learning, responsibility and counterfactual information. Other emotions may arise from any one or two of these elements, but all three must be present for regret. These situational requirements have long guided the psychological description of regret (Zeelenberg et al. 1996; Zeelenberg and Pieters 2007), and they persist in the economic definition of decision regret (Loomes and Sudgen 1982). Decision-making studies operationalize this description, using both behavior and a modified utility function to quantify the effects of the emotional experience (Bell 1982; Loomes and Sudgen 1982).

Like most decision processes, moral decision-making pits multiple options against one another in an effort to arrive at the most desirable outcome. Moral norms are personal convictions reflecting rules of conduct one ought to adopt in a given situation. They represent socially derived, internalized values attributed to a pattern of behavior thought to be appropriate (Manstead 2000). Moral norms play an important role in decision making

because internalized values attributed to a particular course of action are likely to guide behavior. Consequently, behaving in contradiction to one's own moral norms is likely to elicit strong negative emotions. In such a situation, regret is likely to arise, especially if the norm violation results in a negative outcome. Some studies suggest that feelings of regret are anticipated at the prospect of violating one's moral norms (Parker, Manstead, and Stradling 1995). Other studies have shown that anticipated regret and moral norms are confounded in explaining choices, especially those with moral implications (Newton et al. 2013; Rivis, Sheeran, and Armitage 2009). Despite preliminary evidence from social psychology of a possible overlap between anticipated regret and moral norms, the cognitive mechanisms linking the two concepts have not yet been deeply investigated. Evidence from neuropsychology, however, suggests that the brain mechanisms underlying regret anticipation and the implementation of moral norms might involve similar neural circuits.

By tracing the brain activity associated with moral decision making and decision regret behaviors, it becomes clear that some of the same brain areas are similarly implicated in both processes, suggesting that some connections between the two categories of choices may be identified. Here, we explore this potential connection between moral- and regret-based decisions by reviewing their features and neural bases.

Counterfactual information

Regret arises from comparison to an alternative result: one that has not actually occurred. It requires the imagination of an alternative reality that results from a different choice than the one made. The process of deconstructing the present to imagine a different reality, called counterfactual thinking, is at the core of regret. Counterfactual thoughts are often generated after goal failure (Byrne 2002). The functional role of upward counterfactual thinking, and thus, associated regret, is to learn from mistakes, to generate variant courses of action suspected to prove more successful when similar situations are encountered in the future.

In a simple illustration of the definition and measurement of decision regret, imagine a game of chance: a slot machine. A gambler can pull the lever in exactly one way and take whatever result comes. Win or lose, his actions make no difference (other than the choice to play the game in the first place). Nature, wearing the guise of probability, determines the outcome every time. If he loses, the gambler by definition feels disappointment (and if he wins, satisfaction), but not regret. Now imagine two slot machines next to each other. The

gambler must choose one to which to stake his fortunes, yet when he pulls the lever, the wheels spin on both machines, and he can see both outcomes. Now he sees both his actual winnings or losses on the machine he chose, as well as what he would have won or lost had he selected the other machine. If his slot machine loses while the other wins, he can imagine a world in which he made a different, winning, choice. This identification of the counterfactual precipitates regret. A notion, even an imprecise one, that the counterfactual outcome was better may give rise to regret, but the discrepancy between specific values of obtained and foregone allow for clearer interpretation at this point. Simulations of this situation have been used in various experimental settings to measure and compare regret to disappointment (Camille et al. 2004, Nicolle et al. 2011, Gillan et al. 2014).

Regret is further characterized by a negative-valence error, which differentiates it from relief. The error is the difference between the obtained outcome and the imagined counterfactual outcome. This is an important distinction in regret: that the error must have negative valence, rather than the obtained outcome itself. This underscores the idea that regret is the negative result of comparison between outcomes, which may give rise to changes in behavior. In the slot machine study, even when subjects won with a certain choice but saw that they could have won more had they made a different choice, the net emotional sensation was negative (Camille et al. 2004). People describe their emotions as more negative with a better foregone choice, even when the obtained outcome is the same. This comparison is so clear that the emotion following a good outcome of a choice made (winning $50) compared to a very good outcome of a foregone choice ($200) can be rated even lower than that following a bad obtained outcome (-$50) compared to a very bad outcome avoided (-$200) (Camille et al. 2004). That is, despite winning more money, people said they felt worse—because they compared their winnings with what they could have won had they made a different choice. This ability to imagine an alternative reality after the fact informs decision problems not yet encountered. In fact, after experiencing regret, subjects made choices in subsequent tasks that were consistent with trying to minimize that feeling of regret (Coricelli, Dolan, and Sirigu 2007).

Learning value

In a more complex scenario that employs regret in learning, we might assign the two machines different probabilities of paying out. We could task the decision maker with earning the most money and therefore the goal of choosing the right (i.e. more likely)

machine to play more often over the course of a number of opportunities. Such a sequential task (as employed in Daw et al. 2006) allows the exploration of learning and the comparison of various models, which can include those that incorporate regret learning. Lohrenz and colleagues adopt the regret-learning model and rename it "fictive learning" to discard emotional connotations and to maintain only the error signal of an unobtained outcome (Lohrenz et al. 2007). Subjects played an investment game, in which the researchers saw that incorporating fictive error (the difference between chosen-obtained and foregone-obtained) over gains better predicted the subject's subsequent bet than simple reward prediction error: the difference between what the subject thought she would win/lose and what she actually won/lost.

In the scenario of sequential choices of two different gambles, the difference between the results of the choice the gambler made and those of the one he did not—precisely the measure we call decision regret—can be described as a signal enlisted to learn to make better choices. That ability depends on computing that difference, then employing it to foresee a possible recurrence before the next choice is made, and finally making a different, presumably better choice (Coricelli et al. 2005). Anticipation of regret induces a disposition to change behavioral strategies (Ritov 1996), and characterizes an emotion-motivated learning process in decision making (Zeelenberg et al. 1996). In theories of adaptive learning driven by regret-based feedback (Megiddo 1980; Foster and Vohra 1999; Hart and Mas-Colell 2000; Foster and Young 2003; Hart 2005), learning occurs by adjusting the propensity to choose an action according to the difference between the total rewards that could have been obtained with the choice of that action and the realized total rewards. That is, the tendency of choosing machine A depends on how much would have been won by choosing that machine all along compared to how much the gambler has actually won. As gamblers, humans tend to be pretty good at this. Following regret-based learning models, decision makers converge to optimal choices (Coricelli and Rustichini 2010).

Responsibility

People show strong regularities in the nature of the event they "undo" when reflecting on a bad situation. One of these regularities, the agency effect, is particularly at stake in the experience of regret: though people feel regret both for actions taken and inaction – and although nostalgia and autobiographical retrospection often highlight missed opportunities

– people in fact more often generate counterfactuals that undo some undertaken action, rather than inaction (Byrne 2002). Thus, people have greater regret for actions they have taken, more so than for those they failed to take—at least in the short term. When no action could have been taken to prevent a bad outcome, and in the absence of agency, people report feeling disappointment rather than regret. Disappointment is also elicited by counterfactual thought, though the critical outcome must be due to circumstances beyond the agent's control, absolving him of responsibility. The key distinction is this: Disappointment arises from recognizing that a better outcome might have come given the same choice; regret, from identifying a better outcome given a different choice (Zeelenberg et al. 1998). Both emotions come from examining outcomes and seeing that a better one could have been obtained, but regret is associated with the responsibility of having caused the sub-optimal outcome by taking a specific action. Because regret comes with the outcome of a forgone choice, it does bring with it greater information, but its effect on subsequent decisions amounts to more than simply the addition of that data. Rather, the increased information allows for the recognition of agency, along with counterfactual comparison.

Zeelenberg and colleagues sought to differentiate regret from both disappointment and a general sense of happiness by repeating and expanding on studies by Connolly, Ordoñez, and Coughlan (1997). They asked college students to consider scenarios in which fictional college students changed their class assignments — either by their own choice or by computer fiat. The results of these changes for the fictional students range from improvement to neutral to downgrade. The subjects rated how the fictional students would feel along scales measuring happiness, regret and disappointment, as well as to what extent students in the stories were responsible for their outcomes. The researchers found that happiness tracked outcome but not responsibility, while disappointment and regret were assessed inversely depending on level of responsibility: that is, the more responsibility subjects perceived, the greater the amount of regret they believed the character would feel in downgrade outcomes.

Children as young as 5 seem to have some grasp of their agency. In a choice task involving two boxes containing different amounts of stickers, children reported greater happiness or unhappiness when they chose which box to open than when the choice was determined by an experimenter or a roll of dice (Weisberg and Beck 2012). Though it was long unclear at what age the notion of personal responsibility in choices emerges, recent research suggests that agency does not influence the emotional response to outcomes in children younger than 6 (Guerini, FitzGibbon, and Coricelli 2018). Using a modified Wheels of Fortune task (with stickers rather than money as the winnings) on children between ages 3

and 10, Guerini and colleagues found that children were more sensitive to the outcomes of the choice they made than those the computer made for them — but only in trials with complete feedback, and only significantly for children ages 6 and older. That is, both counterfactual outcome and responsibility were required in order for the child to feel the outcome with greater magnitude. In trials with just partial feedback, the children's sensitivity to outcomes was similar when they made the choice and when the computer made the choice — situations that generate disappointment rather than regret. This evidence of differentiation at young ages further supports the necessary role of agency in regret.

Neural Circuits of Regret

The comparison between the outcome of a choice and the foregone outcome of an alternative option triggers specific brain responses. The ventromedial prefrontal cortex (vmPFC) encodes the difference between what has been obtained and the outcome of the non-chosen option (Coricelli et al. 2005). The vmPFC is a functional area that includes the anatomical medial orbitofrontal cortex (mOFC), an area that encompasses the most central parts of both hemispheres at the very front of the brain. The vmPFC is believed to hold on to reward value over time, possibly through tonic activity, then to send that signal to other areas involved in choice, like the dorsolateral prefrontal cortex and the medial caudate (Hampton, Bossaerts, and O'Doherty 2006; Behrens et al. 2008). Findings from neuroimaging studies support the understanding that responsibility is a necessary component of experiencing regret. Indeed, during the lottery task, activity of the OFC in response to a gain or a loss was modulated by the outcome of the non-chosen lottery (Coricelli, Dolan, and Sirigu 2007). However, when the outcome of the non-chosen lottery remained unknown, the counterfactual process between losses (or wins) and any missed outcome of the chosen lottery was accompanied by a weaker effect in OFC activity. Thus, the OFC appears to encode the counterfactual comparison between obtained and unobtained outcomes, but only when the result comes from a choice, rather than misfortune. vmPFC signals the value of the obtained outcome compared to that of the non-obtained outcome, suggesting that these regret signals are related to the way the brain evaluates choices and their consequences. It exhibits activity that correlates with regret at all stages of the choice process: preference, expectation and reward (Montague, King-Casas, and Cohen 2006).

Correlates of regret have also been measured in parts of the brain considered to have key roles in assessing and communicating the value of choice (Nicolle et al. 2011). In neuroimaging studies, the anterior cingulate cortex (ACC) and hippocampus have also shown

increased activity correlated with regret during choice tasks (Coricelli et al. 2005). The hippocampus, a cortical folding below the cerebral cortex, is implicated in consciously accessible declarative memory, which is important for making future decisions based on past events (Coricelli et al. 2007), such as trying to avoid previously encountered sub-optimal outcomes. This ability to guide future actions is a key component in anticipating regret based on experience.

The vmPFC increased activity during the reported experience of regret reoccurs in the period just before making subsequent choices—the period leading up to a decision in which regret would be anticipated (Coricelli et al. 2007). Because the signal measured in the vmPFC appears in other areas, this reoccurrence suggests that the measurement is not merely of happiness, nor simply an outcome value (Coricelli et al. 2005; Van Hoeck, Watson, and Barbey 2015). It suggests that regret is computed by one brain area and then conveyed to others that modulate and implement it in subsequent decisions. Critically, the differentiation of experience and anticipation is clear, though they both involve the vmPFC/mOFC (Coricelli et al. 2005). Thanks to that error signal, along with the opportunity to make a different choice, modeling regret anticipation is a reliable predictor of choice probability in certain sequential decision tasks (Coricelli et al. 2005; Marchiori and Warglien 2008). Marchiori and Warglien found that incorporating a regret signal into even a simple learning neural network better predicted human behavior than long-employed models like reinforcement learning and a hybrid model that combines reinforcement learning with a player's beliefs about other players. Coricelli and colleagues observed that, as players experienced more regret in complete-feedback trials of a sequential Wheels of Fortune task, they decreasingly chose options more likely to lead to regret. They also saw that the more a given choice had lead to regret before, the less likely the subject was to choose it again (Coricelli et al. 2005). Regret, then, is not merely a negative emotion, but a calculated signal that guides agents away from choices that could reproduce that signal. This effort to minimize regret is a key differentiator in its role as a learning mechanism: the emotional experience alone would have little meaning beyond sensation, were it not to guide future behavior.

The examination of choice behavior of patients with lesions in the vmPFC reveals insight into the causal link between regret-related brain activity and behavior. vmPFC patients are typically described as making disastrous life decisions despite apparently intact cognitive abilities. A famous example is the case of ERV, a patient who had a successful career and stable marital life before he developed a meningioma compressing his OFC. He

then lost his job and, against his family's advice, invested all his savings in a business partnership with a man of questionable reputation. He went bankrupt, got divorced and then a month later married a prostitute, a union that lasted just six months. Yet he passed all neuropsychological tests of intellectual, memory and verbal skills with normal scores (Damasio, Tranel, & Damasio, 1990). Alongside such calamities in their daily lives, experimental evidence shows that people with vmPFC lesions display abnormal emotions elicited by reward and punishment (Bechara, Tranel, & Damasio, 2000; Bechara, Tranel, Damasio, & Damasio, 1996). Careful investigation of the underlying computational deficits has revealed a general deficit in integrating values attributed to various actions with the current goals (Camille, Griffiths, Vo, Fellows, & Kable, 2011), function that has been assigned to the vmPFC in brain imaging studies. Patients are able to assign a subjective value to options;however they will not commit to the option with the highest value. Additionally, vmPFC lesions result in an inability to feel regret after a bad choice, and consequently in anticipating future regret during the decision process (Camille et al., 2004). Both reported subjective ratings of the outcome of their choices and the associated skin conductance responses of vmPFC patients were different from that of controls. Behavior of vmPFC patients was not significantly changed by knowing the outcome of the alternative option, an absence of the signature feature of regret. While healthy control subjects changed their choices to avoid regret over the course of the task, vmPFC patients did not.

While the fMRI and lesion studies mentioned above have identified common neural mechanisms for experienced and anticipated regret, more recent findings suggest that people with psychiatric and neurological dysfunction can exhibit one stage of the process but not another (Gillan et al. 2014; Levens et al. 2014). Although brain areas associated with the several stages of processing and anticipating regret overlap, they are not coextensive. Damage to the vmPFC may allow the recognition and experience of regret but not its application to future decisions (Levens et al. 2014). Various dysfunctions of this regret mechanism offer at least partial explanations of the behavior of people with evidence of neurological disorders. Both obsessive-compulsive disorder patients and people with high indications of psychopathy report feeling regret more keenly but do not avoid it in future choices to the same extent as healthy subjects (Gillan et al. 2014; Hughes, Dolan and Stout 2013).

The vmPFC, which represents a crucial portion of a proposed regret circuit, also plays a key role in some emotional components of moral decisions (Moll et al. 2002; Koenigs et al. 2007; Blair 2007). Brain imaging studies of moral decision making have implicated some of the same areas and networks in the frontal cortex that are associated with emotion and deliberation – often finding these regions to be in competition during difficult choices. A study of moral judgment (without any decision component) implicated the mOFC as part of a neural circuit that showed higher activity when subjects read sentences with a moral component. The same areas, which also included the temporal pole and the superior temporal sulcus, did not show higher activation when subjects read statements with emotional components but no moral element (Moll et al. 2002). Researchers have developed a range of these problems to probe the spectrum of moral decision making, and this has yielded distinct differences in choice and brain activity. Among the most well-known set of dilemmas is the family that arises from the trolley problem. Subjects read about a hypothetical situation in which they are standing next to a set of railroad tracks, while some distance away, a group of workers is standing on the track. The subjects are told that they see a streetcar coming down the tracks with no chance of stopping before striking and killing the five workers. The subjects are told they are standing next to a lever, which, if they pull it, will switch the car and send the train onto a side track, where there is a lone worker who will be struck and killed. Though this would be a difficult situation in real life, in the hypothetical, it is characterized as easy and impersonal — because the subject's level of involvement from the consequences is distant and most people presented with the question answer quickly and in the same manner (Greene et al. 2004). Most people choose to pull the lever, making a simple utility calculation (Greene et al. 2001). A variant of this dilemma that brings the decision closer to the subject, however, is the footbridge problem. Now, the subject is on a bridge over the railroad tracks. He can still see the workers, and there is still a street car barreling toward them, but instead of a switch, the subject has the opportunity to save the workers by pushing a large person, who is also on the bridge, off the bridge and into the path of the street car, saving the five workers but killing the innocent person. Given simple calculation of number of people saved versus killed, these situations are identical. Yet according to measures of three features of these dilemmas identified by Greene (2007): expectation of bodily harm, agency of actor and specificity of victims, some dilemmas are more "up close and personal." The "closeness" of the action brings the emotional salience of the problem into conflict with the pure utilitarian calculation. This antagonism seems to be carried out in the brain in both processes and areas that bear resemblance to the experience of regret (Koenigs et al. 2007).

Another family of moral decisions brings an even sharper contrast. It starts with the easily solved infanticide dilemma, which poses the question of whether or not a teenage mother should kill her unwanted newborn baby. The prospect of killing a baby in service of discomfort is easily rejected, and subjects respond quickly and uniformly in the negative. Brain imaging during this decision showed lower levels of activity in the ACC and the dlPFC, suggesting little conflict between the overwhelming emotional aversion to the choice to kill the baby and the low level of utility. Subjects also consider a more difficult analogue of this problem: the crying baby dilemma, in which subjects are asked to imagine a group of people hiding from a group of outlaws. Among the people hiding are a mother and her newborn baby, which begins to cry, which could alert the outlaws to the presence of the hiding people, resulting in the death of all of them, including the baby. Subjects are asked if it is morally permissible for the mother to smother her baby to death, saving the people but killing her own baby. Here, the calculation leads to a simple utilitarian conclusion that more people are saved by killing the baby. Yet this stands in conflict with the stark emotional opposition to killing a baby.

Observations in other brain areas support this framework. Greene and colleagues observed increased activity in the anterior cingulate cortex (ACC) and the dorsolateral prefrontal cortex (dlPFC) during more difficult dilemmas like the crying baby and the footbridge problems, as compared to easier dilemmas. They argue that this indicates that the ACC detects these conflicts and that the dlPFC then deliberates and resolves them. Supporting this proposal, the dlPFC shows even greater activity when the problem results in a utilitarian judgment that violates personal morality. But it is also possible that the dlPFC instigates a period of cognitive control, delaying the decision to allow the ACC enough time to employ a utilitarian cognitive response, thus overriding a more immediate affective response (Greene et al. 2004). If the ACC is a general arbiter of antagonism, then it is no surprise that it would be more active both in cases of difficult moral dilemmas and for discrepancies between predictions and realities, as in experiences of regret. This shared step in decision making connects the two processes and suggests that cognitive resolution of conflicts of any type may be handled with some similarity.

Notably, the several types of moral dilemma—personal and impersonal, distant and close—incorporate degrees of action, though Greene et al. (2004) differentiate between the greater agency of "authoring" and the impersonal deflection of a threat, described as "editing". Regret similarly requires a personal agency—that responsibility attenuated only if the choice giving rise to the emotion is shared with others (Nicolle et al. 2011). The role of

responsibility links the two considerations and carries the question of decision-making regret to a moral level. The more a person gauges himself responsible for an outcome, the more keenly he feels regret (Frijda, Kuipers, and ter Schure 1989). Both ranges of moral decision — those that favor utilitarian decisions and those with a greater emotional component — employ brain areas that compose part of the regret circuit. This observation suggests that the ability to feel accountable for one's choice and the phenomenon of feeling regretful in the case of a bad decision might be the premises for making non-utilitarian decisions in moral dilemmas. It does not prove the existence of a causal link between the two. Nevertheless, gathering evidence approaching a causal link, we report the cases of two different populations of patients — patients with lesions in the vmPFC and psychopaths — which exhibit a co-occurrence of difficulties with all previously mentioned processes.

OFC Lesions Modulate Regret and Morality

Patients with particular types of brain damage can demonstrate how those portions of the brain are implicated in specific processes. Brain lesions are disactivations of sections of the brain due to events like tumors, stroke or head injury. Depending on the type of precipitating event, lesions may occur in similar regions. Their specific location, while not uniform, can be established for each patient through the use of anatomical MRI and other brain scanning techniques. By comparing the behavior of healthy controls to that of patients with lesions in the same region, the role of that brain area in the process can be described. So people with lesions to areas implicated in moral decision making or regret decision making may exhibit behavior significantly different from people whose brains are fully functional in that region. Similarly, people with psychological disorders that have either brain-based causes or implications, may exhibit similar types of different behavior from healthy controls.

Patients with lesions in the vmPFC, like those who demonstrated difficulty with applying anticipated regret, also exhibit trouble in following social norms. Both types of unusual decision outcome accompany damage to the vmPFC, implicating this area in a key role of both moral and regret choice. Specifically, when presented with the footbridge problem, which demands proximate action, most healthy people cannot overcome the

emotional aversion of the proposition. Conversely, vmPFC patients — whose lesions deactivate portions of this brain area — exhibited utilitarian behavior, choosing to sacrifice one life in favor of five, a decision that appears to consider only the final tally of the choice and to ignore the emotional aspects (Koenigs et al. 2007). In a battery of hypothetical situations, these patients were presented with choices of sacrificing one life to save multiple other lives. Among the best-known non-emotionally salient dilemmas is the trolley problem, in which the trolley is diverted by a lever onto a track with one person, avoiding the death of five. In this dilemma, vmPFC lesion patients make the choice to pull the lever about as often as healthy controls do, making a pure calculation about the impersonal action of pulling a lever. Given that these patients had impaired autonomic activity in response to emotionally charged pictures, the authors conclude that the problem in generating "normal" moral judgments come from impaired emotional processing. This was supported by two other studies showing that vmPFC patients do not experience aversive emotional responses to moral violations (Ciaramelli and di Pellegrino 2011; Gu et al. 2015). When a personal element is involved, healthy people choose to intervene much less frequently (Greene et al. 2001). Not so lesion patients, who continue to make the utilitarian choice at about the same rate as they did in the less-emotional impersonal scenario (Koenigs et al. 2007).

Importantly, vmPFC lesions also impair the experience of self-conscious emotions such as shame or embarrassment (Beer et al. 2003). Moreover, the social behavior of lesion patients in social-norms reinforcing games has been compared to that of psychopaths (Koenigs, Kruepke, and Newman 2010). It should also be noted that we do not suggest that the moral dilemmas described elicit regret. Rather, because the outcome of the choice has consequences for other people, the anticipated negative counterfactual emotion involved in these situations would better be described as remorse or guilt: cognitively distinct from regret (Baskin-Sommers, Stuppy-Sullivan, and Buckholtz 2016). Nonetheless, the results from the vmPFC patient studies mentioned here suggest that taking responsibility for one's own actions, questioning oneself, feeling regret and reinforcing social norms rely on the same neural circuitry.

Psychopathy

Psychopathy is characterized by diminished inhibitory control, impulsive behavior and violence. Notably, the psychiatric condition is also attended by unusual morality judgment, including the conflation of conventional and moral violations (Blair 1995). While healthy

people see great differences in a conventional violation such as wearing inappropriate clothes in public and a moral violation such as hitting another person, psychopaths see less difference between the two types of transgression. Psychopaths are also more tolerant of moral transgressions against other people, which may stem from a lack of sufficient aversion to distress in others (Blair 2007). They display a similar deficiency for aversion in cost-benefit choice series.

The impaired decision making by people with psychopathic tendencies has long been attributed to their curtailed experience of emotions involving responsibility (Koenigs et al. 2012), but recent studies suggest that the breakdown in learning via regret happens further downstream, at the point of employing regret values in subsequent choices (Hughes, Dolan and Stout 2013; Gillan et al. 2014; Baskin-Sommers, Stuppy-Sullivan, and Buckholtz 2016). This would suggest that people with psychopathy do indeed feel regret but do not incorporate the signal into future decisions, a model consistent with some findings about the moral decision making of psychopaths. Considering the implication of the vmPFC is such feed-forward mechanisms, the breakdown may well stem from a diminished vmPFC, which in psychopathic individuals, has been shown to be reduced in every dimension: volume, thickness and surface area (Yang et al. 2005; Baskin-Sommers et al. 2016). If other considerations are equal, healthy people make the choice that carries the least expected regret, sometimes even at the cost of profit. Yet the higher people scored on a psychopathy scale, the less likely they were to avoid regret in a repeated wheels of fortune task (Baskin-Sommers et al. 2016). sIt was not simply that the missed opportunity bothered them less – they reported negative emotions at about the same level as controls, and sometimes even more. In fact, the highest scorers on the psychopathy self-report scale reported negative emotions after a bad outcome comparison, yet they seemed to ignore that information. The bad outcome comparison that serves as a signal to healthy people was not being used by the people with psychopathy. Their behavior indicated that they employed only the simpler signal of expected value. This suggests some link between psychopathy and regret avoidance, though a study that searched explicitly for such a connection in criminal offenders did not find one (Hughes, Dolan and Stout 2013).

People with psychopathic indications are thus apparently capable of imagining alternative realities and generating and experiencing the negative emotion associated with the comparison to actual reality, suggesting that psychopathy is characterized not by a deficit of emotion but by weakened general cognitive processes like .the ability to maintain previous

counterfactual information and to apply it to subsequent decisions. So if these people were experiencing the emotion but apparently not employing it in choice tasks immediately following arousal, it raised the possibility that the information was not being applied to guide future choice in the manner of predictive models.

The understanding of moral processing in psychopaths is not well understood. Though people with psychopathy have long been observed to engage in amoral behavior, the mechanism of that deficiency has only recently been explored. Psychopathy has been ascribed to a depleted ability to empathize with a person being harmed as well as a deficient mechanism to inhibit violence (Blair 1995). In a study by Blair, criminal offenders considered several scenarios of moral and conventional violations set in a school, showing that psychopaths significantly did not differentiate permissibility between the two types of violations, while non-psychopaths did. Blair rejects several models in which psychopaths experience moral emotions but do not employ them in mentalization or fail to take perspectives of others. Rather, he proposes a fault in a separate system, a "violence inhibition mechanism." Cima and colleagues (2010), by contrast, argue that while people with psychopathic traits may have some emotional deficits, enough emotion is preserved (or in fact may be unnecessary) to make similar moral judgments to healthy controls. The fact that they can identify the rightness or wrongness of moral actions, but then by definition act in contrivance, indicates that they may simply not care about morality, the study suggests. This would again be consistent with psychopaths experiencing regret but not applying it to subsequent choices. Whatever emotional component that is lacking in people with psychopathy may be the element responsible for the application of the moral understanding toward future decisions.

Yet by refining groups of people by placement on the psychopathy scale and with greater precision in the moral dilemmas presented, Koenigs and colleagues find that a counterfactual mechanism may indeed be at fault for some abnormal moral choices by people with psychopathy (2012). Using inmates from a Wisconsin prison, the study considered only those participants who scored in the highest and lowest portions of psychopathy indications, further refining the high scorers in terms of assessed anxiety in consideration of a theory that psychopathy is too broad a term for several possible conditions. Using the same situations as in the Greene study, both high-anxious psychopaths and non-psychopaths endorsed the utilitarian outcome of personal dilemmas with approximately the same lower frequency. But

low-anxious psychopaths judged the utilitarian choice acceptable more often than either other group. The finding suggests that some subtypes of people with psychopathic indications resolve the emotion-utility conflict in a similarly unusual manner to that with which psychopathic people eschew regret. Where the breakdown occurs in either population and in either mechanism — or even the certainty that the causes are the same — is still up for debate: psychopaths and lesion patients may experience emotion less, or they may experience emotion and simply not apply it. Either way, it is clear that people with psychopathic tendencies do not change their choice behavior in emotional situations to the same extent that healthy people do, both after experiences that typically generate regret and when confronted with moral dilemmas.

A Social Dimension of Regret and Agency

The consideration of others connects with regret not only in representing levels of responsibility. The regret circuit co-locates with neurological phenomena that involve consideration of others via social versus private situations (Bault et al. 2011; Zhu, Mathewson, and Hsu 2012). Studies on levels of strategic thinking have shown higher levels associated with the same areas as counterfactual emotions like regret (Bault et al. 2011). In an experimental game called the "beauty contest" or guessing game, the choices a player makes indicate the extent to which he is thinking about other players and how much he thinks they are thinking about him. Increased amounts of this recursive thinking are associated with higher levels of brain activity in the mOFC (Coricelli and Nagel 2009), the location of most of the vmPFC, a key component of the regret circuit. As with so many co-located brain activities, however, it is necessary to note that anatomical proximity does not necessarily indicate a functional relationship. Nevertheless, the notion of thinking about the activity in other brains (in the case of the recursive thinking demanded in the beauty contest) is different from other types of input in a similar way that the calculation and experience of counterfactual-based emotions (as in the case of regret) varies from other input—that is, it is largely internal.

Studies have associated the vmPFC/mOFC with thoughts about others (Frith and Frith 1999; Gallagher and Frith 2003; Hampton, Bossaerts, and O'Doherty 2006; Suzuki et al. 2016). These areas become active not only when thinking about others—when evaluating violations of social norms, for example—but also when it comes to representing our own mental state, including emotion (Gallagher and Frith 2003). When subjects were directed to think about a friend or someone who was similar to them, the vmPFC showed stronger

activations (Mitchell, Macrae, and Banaji 2006). Given the vmPFC/mOFC association with processing information relevant to the self, Mitchell and colleagues suggest that thinking about related others may depend on self-evaluations in the vmPFC. This introduces the possibility of a connection between internal and external considerations: between regret's internally oriented self-evaluation and thoughts about others.

In fact, despite regret's essential interior aspect, it has been shown to be modulated by the actions of others. If an individual experiences regret that comes as the partial result of the actions of others, the brain appears to shift some of the blame for the less-then-optimal outcome to these others—thus reducing at least the anticipation of regret (Nicolle et al. 2011). As described above, measurable regret is defined by the notion of agency. It is usually addressed in a polar manner, however: with agency, the negative feeling associated with a different outcome is regret; and in its absence, disappointment (Zeelenberg et al. 1998). But within those categorizations, there appears to be room for gradation. Nicolle et al. had participants complete a task in which they made similar gambling choices as in standard regret tasks, but on some trials, the choice was determined not by the participant alone, but by vote (they were told) of a group of which they were a member, ranging from 2 to 8 people in all. In this case, the participant's action alone did not determine the choice and its attendant result. The measured effect saw reduced activity in the amygdala, compared to trials in which the participant was solely responsible for choices. The amygdala, implicated in emotional memory, is associated with activity involving personally relevant information. It is also known to integrate the relationship between stimulus and reward and to send it on to the vmPFC, where the information is used in subsequent choices (Coricelli et al. 2005). So increased activity during instances of regret in which the participant is the only decision maker suggests a kind of "self-blame regret", Nicolle and colleagues argue. The diminished sense of responsibility attenuates the negative feeling of regret, and that consequently appears also to dampen the learning effect. A better response in an alternative reality becomes clearer in the amygdala with greater individual responsibility. A related question, unexplored to this point, is how, if at all, shared responsibility for positive outcomes might modulate brain activity compared to that of negative outcomes, or for positive outcomes that result from solo choices.

Conclusion

The goal of any decision process is to arrive at the optimal outcome, given the conditions. But when several important factors come into conflict in a decision, the brain

must mediate among them. Separately, the processes for moral decision making and choices involving decision regret have been further explored via brain imaging and lesion studies. These have shown that segments of these processes share some anatomy and even similar dysfunction among people with psychopathy or lesions to the vmPFC. Our understanding of both systems still needs clarity before they can be considered to play any part in each other, but some recent research proposes frameworks that hint at how they might be joined. Blair argues that the learning systems in the vmPFC are the foundations of moral decisions that concern harm to other people (2007). These same systems undergird error signals that include decision regret, showing heightened activity during both the experience and anticipation of regret. The work on moral decisions by Greene and colleagues suggests that the vmPFC might serve in a regulatory role, delaying decisions during high-conflict or difficult dilemmas — especially those involving competition between emotional and utilitarian outcomes.

Moll and de Oliveira-Souza, however, push back on the Greene model, saying this conflict framework is too complex. They hold instead that the lesions attenuate the prosocial influence of the vmPFC, thus allowing utilitarian decisions without the interference of emotion. The inverse logic is that in healthy people, by contrast, the vmPFC encourages greater consideration of other people, in contrivance of purely numeric considerations. Yet this runs against the tonic activity of the vmPFC that maintains value information during a series of choices. Moral and regret decision processes appear to share patterns, but if those are reflections of shared pathways in the brain, studies to this point present contradicting roles for these areas.

Those who see the greatest connections between learning signals and moral decisions include Thomas and colleagues, who argue that the vmPFC's role is similar across reasoning processes — including moral and complex decision making. In their model, the vmPFC integrates emotion into judgments of complicated decisions, acting as adjudicator when considering future consequences (Thomas, Croft, and Tranel 2011). The vmPFC would be responsible for assimilating the emotional effects of regret experience or imagination of harm to another into a decision that would otherwise address only the utilitarian concerns of economic value or number of people protected from harm. Such a broad function could incorporate either of the Greene or Moll/de Oliveira-Souza proposals.

Separating these competing goals and observing how special populations deviate in their decisions from they typical allows us to see that regret and morality are at least occupying some of the same space in the brain. Moral decisions play serious emotional

consequences against preserving the lives (or limbs) of others. Similarly, decision regret pits the possible emotional pain of making a sub-optimal choice against maximizing gains. In both cases, the effort to avoid negative emotions comes into competition with the achieving the most utilitarian outcome. Though the implications of moral versus economic decisions are on different scales, the human brain appears to process similarly some portion of them. Crucially, they both require the previous experience or understanding of emotional outcomes and the incorporation of their possible reoccurrence into a new decision. Thus, these complex types of decision require the ability to consider the impact of the choice before it is made — they demand the conception of realities both encountered and imagined. These processes use the past and a conceptual future to put new realities in conflict with each other to judge one the most desirable.

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