

A pain, by any other name (rejection, exclusion, ostracism), still hurts the same:

The role of dorsal anterior cingulate cortex in social and physical pain.

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Several chapters in this volume have explored whether a particular dimension of social cognition can be reduced to more general cognitive processes by examining whether the social and cognitive processes share overlapping neural bases. Some chapters have argued for distinct neural processes devoted to social cognition, not shared by more general cognitive processes (Mitchell, this volume), while others have identified components of social cognition that do share properties with more general cognitive systems as indicated by overlapping neural systems (Phelps, this volume; Stone, this volume). In this chapter we examine a social phenomenon that seems an unlikely candidate for this kind of cognitive reduction analysis. We focus on social pain, the distress experienced in response to rejection, exclusion, or ostracism. This kind of experience is profoundly social and, at first glance, there is no obvious cognitive analogue to which it can be reduced.

Nevertheless, we still suggest a certain type of reduction. We propose that social pain may be profitably examined by considering its relation to physical pain. More specifically, we propose that some of the basic neural mechanisms that support the experience of physical pain also support the experience of social pain (though it is doubtful that the overlap is as complete as the extreme position staked out by our Shakespearean title). We will review evidence, from both the animal and human research literatures, suggesting that the dorsal region of the anterior cingulate cortex (dACC) is similarly involved in the distressing component of both forms of pain. Moreover, we will suggest that once a connection is established between the experience of social pain and physical pain, we can explore the underlying computations that connect these two processes. In other words, we can examine the computational function of the dACC such that it should be involved in various forms of

painful experience. We will suggest that the dACC functions as a neural alarm system, combining both the detection of a problem and the sounding of an alarm, typically found in any alarm system.

Finally, we will reexamine the function of dACC versus rostral anterior cingulate (rACC) in order to expand on how our model fits with previously held views of the function of the ACC. The current view is that dACC is involved in cognitive processes and that rACC is involved in affective processes. However, we will suggest that this view does not ultimately hold up to scrutiny when one takes into account pain studies, which typically activate dACC. We will suggest a different dichotomy of function, which can account for the previous view, our own findings, and the results from the pain literature more generally. We will suggest that both dACC and rACC are involved in conflict processing, but of different forms. dACC can best be understood as processing *non-symbolic* conflict in which the conflict is not explicitly represented but is instead best characterized as the tension level in a connectionist constraint satisfaction network. Alternatively, rACC can best be understood as processing *symbolic* conflict in which the conflict is explicitly represented with symbolic or propositional thought. The capacity to represent conflict symbolically may be unique to humans and has implications for how we regulate different types of affective experiences.

We should say from the outset that though we are focusing on the dACC as a region involved in social and physical pain, we readily admit that we are focusing there because, for the moment, that is where the light is best. There has been an enormous amount of work done in recent years examining the role of dACC in physical pain and in cognitive processing. Consequently, this region is ripe for consideration. This should not be taken to mean that dACC is the only region involved in both social and physical pain for it most assuredly is not. Right ventral prefrontal cortex is another region we will briefly address in this chapter. Though we will not focus on other regions of the ‘pain matrix’ (Peyron et al., 2000) in the current chapter, such as the periaqueductal gray, insula, and

somatosensory cortex, the reader should not be surprised if these regions are added in future work. Indeed, some work has already started along these lines (MacDonald & Leary, in press; Panksepp, 1998).

Linguistic Evidence Linking Social and Physical Pain

While a cognitive neuroscientist might bristle at the notion of something as ethereal as social pain being similar to physical pain, non-scientists might think that the truth of this idea is obvious. A layperson might point to the fact that in our culture, we talk about social and physical pain in similar ways so that they should no doubt be related. For instance, we describe physical pain with phrases like “I broke my arm” and “my leg hurts.” Similarly, we describe social pain with phrases like “she broke my heart” and “he hurt my feelings.” Indeed, it is difficult to describe social pain without reference to physical pain terminology. In fact, English speakers have no other way to describe the feelings associated with social pain except with reference to physical pain (MacDonald & Leary, in press).

MacDonald and Leary (in press) recently examined whether this linguistic overlap was unique to the English language and discovered that it was not. They asked individuals from 15 different countries, including a number of non-European countries, to provide typical ways of describing social pain. In each country, they found that social pain descriptions relied on physical pain words. This evidence, at the very least, suggests that social and physical pain may be universally linked in the mental lexica of humans around the world. This evidence, does not in itself, say much about whether there are common processes supporting the experience of social and physical pain. The relationship may simply be metaphorical, though obviously a strong metaphor for it to have spread so widely.

An Evolutionary Story for the Link

The first line of evidence to suggest that the link between social and physical pain might be more than metaphorical came from the work of Jaak Panksepp (Panksepp et al., 1978). Panksepp was examining the analgesic effects of opiate-based drugs in dogs when he discovered that in addition to altering the amount of pain the dogs could tolerate, the opiates also diminished the frequency of 'cries' produced while in isolation. Panksepp reasoned that the opiate receptor system mitigated the experience of both physical and social pain. Along similar lines, drugs that have been typically prescribed to deal with social distress and depression have more recently been found to work effectively for chronic pain (Shimodozono et al., 2002). Panksepp went on to suggest that the 'social attachment system' may have piggybacked onto or developed out of the physical pain system, which has older phylogenetic roots than the social pain system (Nelson & Panksepp, 1998).

Unlike other animals that are born relatively mature or have rapid developmental trajectories, infant mammals are unable to care for themselves for an extended period of time and human infants take the longest of all. Thus mammals have an unprecedented dependence on their caregivers. While lack of food, water, shelter, and defense against predators will lead to death for any animal, for young mammals, the meeting of these needs is entirely contingent upon the ongoing relationship with a caregiver. For mammals, then, social needs have supplanted all other biological needs in importance, at least in infancy, because the meeting of social needs is critical to the meeting of all other needs.

Not surprisingly then, mammals are one of the first species to have a social attachment system, a system that monitors for actual or psychological distance from others and elicits distress once distance is detected so that contact can be reestablished. Attachment processes exist primarily in mammalian species and thus as the social attachment system was evolving, the physical pain system was already in place and could serve as a solid foundation for the creation of this attachment system.

Whereas the physical pain system produces physical pain in response to physical injuries so that attention and other biological resources can be mobilized to prevent greater injury and promote survival, the social pain system produces social pain in response to social injuries so that attention and other biological resources can be mobilized to prevent these injuries and promote survival. It is of interest, then, that mammals are also the first species, phylogenetically speaking, to have a cingulate gyrus (MacLean, 1993). Thus, it is plausible that this new structure may be involved in these social attachment processes.

We have chosen to focus on the role of the dACC in both social and physical pain for a number of reasons. First, the ACC has one of the highest densities of opiate receptors in the brain (Vogt, Wiley, & Jensen, 1995), and thus may have been one of the primary sites of action in Panksepp's work on the social and physical pain-alleviating properties of opiates. Second, there is a large literature showing the dACC to be involved in physical pain processes in humans. Finally, there are a number of studies with non-human mammals suggesting that the ACC, and perhaps the dACC more specifically, is involved in the experience of separation distress and in the production of distress vocalizations aimed at regaining social contact.

ACC and Physical Pain in Humans

The neural regions involved in physical pain, referred to as the 'pain matrix', include the dACC, rACC, somatosensory cortex, insula, periaqueductal gray and right ventral prefrontal cortex. These regions are thought to be differentially involved in the sensory, distressing, and regulatory components of pain. Somatosensory cortex and insula are primarily, though not exclusively, linked with the sensory aspects of pain. Pain-related activity in these regions is associated with being able to identify the region of one's body that is in pain and other sensory features including intensity.

Periaqueductal gray, rACC, and right ventral prefrontal cortex are more frequently associated with the regulation of pain through opioid release and cognitive processing. Finally, dACC is generally associated with the subjectively distressing component of pain.

Sensory intensity and subjective distress associated with pain are often highly correlated and thus a few illustrations of their relationship are in order to clarify the difference between the two concepts. A useful metaphor to consider is the sound of a radio with sensory intensity likened to the radio's volume and subjective distress likened to the extent to which the music is experienced as unpleasant (Price, 1999). Above a certain threshold, increasing volume will usually be highly correlated with increasing unpleasantness. Nevertheless, the same volume can produce different levels of unpleasantness depending on the level of ambient noise from being in a quiet room versus outdoors at a barbeque or one's sensitivity to or tolerance of loud noises. Thus, intensity can be distinguished from unpleasantness such that under different conditions or across different people, the same degree of sensory intensity might produce different degrees of unpleasantness.

The consequences of damaging neural structures associated with the sensory and distressing aspects of pain also reveals this dissociation. In the 1960s, patients with chronic pain problems sometimes received cingulotomies, a procedure that involves lesioning the anterior cingulate. After cingulotomies, these patients often experienced significant pain relief, however the relief did not come as a result of all aspects of pain being diminished. Rather, only the subjective distress of pain appears to have abated. Patients would report that the sensory aspects of pain continued; they still felt the same sensory aspects of pain but it no longer seemed to bother them (Foltz & White, 1968). Alternatively, there is a reported case of a patient with damage to somatosensory cortex. When painful stimulation is applied to the body region represented by the damaged part of somatosensory cortex, the patient has difficulty reporting on the location of the stimulation but still experiences the

stimulation as distressing (Nagasako, Oaklander, & Dworkin, 2003). So while intensity and distress may feel inextricably linked, they can be separated because they depend on distinct neural processes.

Furthering this conceptual separation, Rainville and colleagues (Rainville et al., 1997) conducted a neuroimaging study in which they used hypnotic suggestion to alter the perceived unpleasantness of painful stimulation without changing the perceived intensity. During part of the experiment, subjects were given a suggestion that they would experience the painful stimulation as more or less distressing than normal. During the painful stimulation, subjects reported the pain to be more or less distressing in accord with the suggestion that had been given. These results were unlikely to be mere demand characteristics, because the changes in reports of pain distress were highly correlated with the changes in dACC activity. The changes were not correlated with activity in somatosensory cortex suggesting that this region, unlike dACC, is not a direct contributor to the experience of pain distress.

ACC and Social Pain in Animals

Until recently there has not been any research examining the neural correlates of social pain in humans, however, there are some studies from the animal literature that suggest a role for dACC in the experience of social pain. Care must be taken in the inferences drawn from the animal literature because similar neural regions in different animals do not always serve the same functions. Along those lines, two issues are worthy of note with respect to the anterior cingulate across animal and human brains. First, in older animal studies, the anterior cingulate cortex, which can be subdivided into rostral and dorsal sections, was sometimes referred to as rostral cingulate cortex (Smith, 1945). It is important to note that this designation refers to all of what would now be called anterior cingulate, including dACC. Second, strictly speaking, some primates like the macaque, may not have

had rACC at all such that the entire macaque ACC might be functionally analogous to dACC. In humans, dACC and rACC have different morphological properties (i.e., cell layer organization). In the macaque, the entire ACC has morphological properties similar to those found in dACC (Smith, 1945). This will be particularly relevant in the final section of this chapter when we suggest that rACC is associated with symbolic processes unique to humans (Lieberman, Gaunt, Gilbert, & Trope, 2002).

One set of animal studies demonstrating the link between the ACC and social pain comes from lesion work. MacLean and Newman (1988) made lesions to various overlapping subregions of the medial prefrontal cortex, including the ACC, in squirrel monkeys. The only monkeys that ceased to make separation distress vocalizations after the procedure were those for which dACC had been lesioned. It should be noted that these same monkeys also had their rACC lesioned, which may or may not be functionally equivalent to rACC in humans as the previously raised issue of rACC homology was examined in macaques, not squirrel monkeys. However, other squirrel monkeys in this study had rACC lesions without dACC lesions and did not show reduced distress vocalizations, whereas none of the monkeys had dACC lesions without reduced distress vocalizations. Moreover, the monkeys were still capable of making different kinds of vocalizations so it's not the case that the capacity for vocalizing per se was affected by the lesions. This study, then, suggests that dACC may be critical to the experience of social pain that would lead to distress vocalizations.

Electrical stimulation studies support this conclusion as well. Over half a century ago, Smith (1945; Jurgens & Muller-Preuss, 1977) observed that electrical stimulation of dACC produced spontaneous separation distress vocalizations in the absence of social isolation. Thus, these lesion and stimulation studies provide good converging evidence that the dACC plays an important role in social pain.

ACC and Social Pain in Humans

In order to examine the neural correlates of social exclusion in humans, and begin to assess whether the neural basis of social pain is similar to the neural basis of physical pain, it was critical to find a manipulation that would produce a genuine episode of social pain while simultaneously seeming plausible to a subject lying inside a neuroimaging scanner. There are numerous manipulations that have been used successfully by social psychologists over the last decade to examine cognitive and behavioral responses to social exclusion (see Williams, Forgas, & von Hippel, in press).

The most common manipulation of exclusion involves subjects finding out that no one else in an experimentally created group wants to pair up with them in the upcoming task and so they will be working on their own (Leary, Tambor, Terdal, & Downs, 1995; Twenge, Baumeister, Tice & Stucke, 2001; see also Gaertner & Iuzzini, in press). Baumeister and colleagues have also used a 'future alone' manipulation by telling subjects on the basis of their answers on questionnaires that they are the kind of person who is likely to end up alone in life, even if they have close friends and loved ones now (Baumeister & De Wall, in press). Williams and Sommer (1997) used the most direct and overt manipulation of social exclusion. In their work, a subject is waiting along with two same-sex confederates for an experiment to start. One of the confederates picks up a ball found on the table between them and begins tossing it to the other confederate and subject. After being included in the game for a short time, half of the subjects are then excluded by the confederates who never throw the ball to the subject again. Each of these manipulations has proven effective in producing behaviors and self-evaluations that would be expected to result from social exclusion including lowered self-esteem, increased aggressiveness, and increased conformity to group norms (Leary, in press).

None of these manipulations are easily transferable to the context of a functional neuroimaging study. Fortunately, the ball tossing manipulation has been converted into a virtual ball tossing game ('Cyberball'), ostensibly played online against other players, and has been shown to produce the same effects as the in-person version (Williams, Cheung, & Choi, 2000). In fact, Cyberball seems to work so well that even when subjects are informed that the other two 'players' are really just computer players controlled by the program and that the other two players will exclude them part way through the game, subjects still report feeling social pain as a result of the experience (Zadro & Williams, 1998). Cyberball, then, fits the dual constraints of producing a genuine experience of social pain while at the same time making sense in the context of a functional magnetic resonance imaging (fMRI) study.

Subjects in our study of social exclusion (Eisenberger, Lieberman, & Williams, 2003) were informed that we were working out the technical details in a new neuroimaging procedure called 'hyperscanning.' Hyperscanning, which is a real technique being used at Johns Hopkins University, involves scanning multiple subjects simultaneously while they engage in some kind of coordinated activity so that the relationship between the neural patterns of the different subjects can be analyzed. We showed subjects a write-up of this work that appeared in *Nature Neuroscience* and told subjects that we wanted to do the same kind of procedure at UCLA, but that we were still in the technical development stage. Subjects were told that two other subjects were also going to be in scanners at other locations around campus and that we would be having subjects play a simple ball tossing game so that we would have some basic coordinated neural activity to look at, in order to see if we were making progress. There was no goal to the ball tossing game, no points to be won, and no skill involved given that catching occurs automatically and subjects only decision is whether to throw it to one person or the other (an animation of the game can be seen at www.scn.ucla.edu).

Subjects went through three functional scans. During the first scan ('implicit exclusion'), subjects were told that we were having technical difficulties making a full internet link with the other two scanners, so as a result, they would be able to watch the other two players play during the first scan, but they would not be able to receive or throw the ball. This condition is visually identical to the regular exclusion condition; however, our subjects knew that they were not being intentionally excluded in this condition. This condition conceptually replicates the study by Zadro and Williams (1998), in which subjects were informed that they were playing a computer game with animated figures and would be automatically excluded part way through the game.

For the second scan ('inclusion'), subjects were told we had made the full internet link so that they would be able to play. Subjects played with the other two 'players' during this scan and were fully included such that they were thrown the ball with 50% probability. In the third and final scan ('explicit exclusion'), subjects were fully included for about 30 seconds, but then excluded by the other two 'players' for the rest of the scan. After this scan, subjects were removed from the scanner and immediately filled out a questionnaire assessing the degree of social pain experienced during the last scan.

Our primary analysis compared the brain activations during the explicit exclusion and the inclusion conditions. We observed greater activity in dACC, right insula, and right ventral prefrontal cortex during the explicit exclusion condition, relative to inclusion. Each of these regions is commonly found in neuroimaging studies of physical pain (Petrovic et al., 2000). In a follow-up analysis, we examined the extent to which the individual differences in activity in each of these regions predicted the individual differences in self-reported social pain as measured in the post-scanning questionnaire. Insula activity was not correlated with self-reported social pain, however, dACC and right ventral prefrontal activity were both strongly related to social pain. For dACC,

greater activity during exclusion relative to inclusion was associated with greater self-reports of social pain ($r=.88$). For right ventral prefrontal cortex, greater activity during exclusion relative to inclusion was associated with diminished reports of social pain ($r=-.69$).

This observed pattern of activity is quite similar to results seen in studies of physical pain. For instance, in a recent study of visceral pain regulation (Lieberman, Jarcho et al., 2004), dACC, insula, and right ventral prefrontal cortex were all more active during painful stimulation than at baseline. More importantly, the same pattern of relationships between neural activity and subjective pain reports was found here as in the social pain study; insula activity did not correlate with self-reported pain, dACC activity correlated positively with self-reported pain, and right ventral prefrontal cortex correlated negatively with self-reported pain. In fact, in both studies, dACC activity strongly mediated the relationship between right ventral prefrontal activity and self-reports of pain. These results, consistent with other pain work (Petrovic et al., 2002; Wager et al., 2004) suggest that while dACC is important in producing the subjective distress of pain, right ventral prefrontal cortex is involved in downregulating the experience of pain (see Lieberman, Jarcho et al., 2004 for a discussion of the role of right prefrontal cortex in the self-regulation of negative affective states).

In a second set of analyses, we examined the brain activations during implicit exclusion. As in the explicit condition, there was greater dACC activity during implicit exclusion than during inclusion. The activity was similar to the explicit exclusion dACC activation in position, cluster size, and intensity. This may be somewhat surprising given that subjects presumably did not consciously believe that they were being excluded during this condition. However, it should be recalled that Zadro and Williams' subjects experienced social pain even when they were told ahead of time that the game was fixed. It may be the case that humans are sufficiently hardwired to respond to exclusion and that the mere appearance of exclusion is sufficient to provoke the response. If so, this

would be similar to the way visual illusions function. In most cases, understanding the causes of a visual illusion in no way mitigates the effect; understanding the true shape of an Ames room does not prevent a child from looking as tall as a grown man. The reliability of the visual system is either so important or so ancient, that evolution has sealed its computations off from intentional modification by the owner of the visual system. Similarly, the need to detect potential exclusion may be so important or ancient that it too resists our conscious beliefs about the true meaning of an episode – in this case that it is not truly exclusionary.

Still, there ought to be some consequences of whether we consciously believe we are being excluded or not. Individuals ought to be less likely to be thinking about exclusion and its causes if they don't believe they are being excluded and should also be less likely to try to self-regulate the negative experience. Consistent with this view, there was no increased right ventral prefrontal activity during implicit exclusion, relative to inclusion, even at very liberal statistical thresholds. Given that right ventral prefrontal activity has been associated with explicit thought about negative affect and negatively evaluated attitude objects (Crockett, Eisenberger, & Lieberman, 2004; Cunningham et al., 2003) and is also associated with the inhibition of negative affective experience, it appears that in our study, subjects were not engaged in these sorts of mental activity. In other words, because the subjects had no reason to think they were being excluded, self-regulatory and attributional mechanisms were not engaged. One caveat to this account is that we cannot be sure that implicit exclusion was actually producing any distress because to have assessed social pain after the first scan would have given away our cover story.

What is the basic function of the ACC?

The results thus far, from our own work as well as from the broader physical and social pain literatures, suggest that dACC activity is related to the experience of social and physical pain. The next obvious question to ask is why. What is the function of the dACC such that it should be involved in these forms of pain? It turns out that the answer to this question depends on which end of the psychology department one goes to for an answer.

If clinical and psychopathology researchers are asked, they will probably respond that the function of the dACC is to produce attention-getting affective/motivational states like pain, anxiety, and distress. Each of these states serves important functions in motivating adaptive and appropriate behavior (Mandler, 1975). Thus, these researchers focus on the phenomenological contributions of the ACC.

If, instead, cognitive researchers are asked, they will probably respond by saying that the function of the ACC is to monitor for conflict and to detect errors. Numerous studies have suggested that dACC is activated when there is a discrepancy between one's goals and one's prepotent responses. For instance, during the Stroop task when a person is shown color words in different color ink (e.g., R-E-D written in blue ink), one's goal is to say the color of the ink that words are written in, but this goal conflicts with the prepotent tendency to read the words themselves. The dACC is activated in this context and 'notifies' lateral prefrontal cortex that top down control processing is necessary to promote contextually-appropriate responding (Botvinick, Braver, Barch, Carter & Cohen, 2001). One might expect the same thing to occur when one is required to give responses that appear racially biased when one does not want to appear racist (Amodio et al., 2004). Most researchers in this field agree that the dACC's role is limited to detecting conflict and alerting lateral prefrontal cortex, rather than being involved in resolving the conflicts directly.

Of interest in this brief tour of the psychology department is that those interested in the cognitive functions of the dACC leave the phenomenological consequences of dACC activity unexamined. At the same time, those interested in the phenomenological consequences of dACC activity have rarely expressed interest in the computations underlying that activity.

The ACC as a Neural Alarm System

We suggest that it might be profitable to consider the possibility that the dACC works as a neural alarm system. Such a metaphor might help to bridge the above explanations of ACC function that are seemingly in competition with one another. Any alarm system, whether it is a clock alarm or a smoke alarm, must integrate two functions to work effectively. First, the alarm must be able to detect the critical environmental conditions for which it is designed. A clock must be able to detect when there is a match between the current time and the time set for the alarm to go off. A smoke detector must be able to detect when the amount of smoke in the room crosses some threshold for unacceptability. Second, the alarm must be able to notify the relevant parties that the critical condition has been met. For most alarms, this means making a loud noise, either to wake a person up or let them know a room is filling with smoke and possibly fire. Conceptually, these functions are separable (e.g., a clock alarm with a broken speaker), but they must be integrated and work together for the alarm to function properly.

These two functions of an alarm system sound conspicuously similarly to the two descriptions given of ACC function. The cognitive account suggests that the ACC is sensitive to goal conflicts, conditions that are critical to detect. The phenomenological account suggests that the ACC can create attention-getting affective states. If these two processes operate together, they might function as a unitary alarm system, detecting conflicts *and* ‘making noise’ to get the person’s attention.

There are at least two ways that this alarm could be instantiated in dACC and at this point there is not enough data to differentiate the two accounts. In one account, discrepancy detection and distress may go hand-in-hand, such that the ‘alarm bell’ sounding may be the phenomenological consequence of the detection of discrepancy. It is possible that previous cognitive studies of the ACC had been producing distress in their subjects but had not attempted to measure it. The second possibility is that the conflict detector and alarm bell are instantiated in nearby but distinct regions of dACC. The two functions would still be integrated with one another, but this might help explain why performing tasks like the Stroop or oddball task don’t seem to set off major alarm bells, phenomenologically speaking.

As noted, there isn’t compelling data yet to argue for one or the other of these accounts. However, two studies have partially investigated this question by examining neural activity to pain distress and cognitive processing in the same subjects. One study (Derbyshire et al., 1998) found that the regions in dACC activated by a pain and Stroop task were adjacent to one another, but also sometimes overlapping. The ambiguity of these results is only heightened by the small sample size (N=6). A second study (Davis et al., 1997) also found adjacent regions activated by a pain and cognitive task, however, the cognitive task used in this study did not involve conflict detection and thus is not entirely on point.

Separate from determining whether these two potential subcomponents of the alarm system are in the same region of dACC or not, the more pressing question is whether the two subcomponents actually work together as they should if they really are part of an underlying alarm system. In other words, do phenomenological and conflict detection processes covary with one another? If so, this would suggest that the overall alarm system is mobilizing its subcomponents en masse, rather than

each performing its own process independently. Two studies have examined the covariation between these two subcomponents.

In one neuroimaging study (Ursu et al., 2003), individuals with obsessive-compulsive disorder (OCD), an anxiety disorder characterized by distress and worry, were scanned while performing a task involving response conflict. Individuals with OCD, compared to healthy controls, showed significantly more dACC activity to high-conflict trials. In addition, there was a trend, though not significant, such that within the OCD group, patients with more severe symptoms showed more dACC activity to conflict than those with less severe symptoms.

We conducted a neuroimaging study (Eisenberger, Lieberman, & Satpute, 2003) to investigate this issue by correlating dACC activity on a conflict detection task with neuroticism scores. Neuroticism is typically defined as a heightened tendency to experience negative affect frequently and/or intensely (Costa & McCrae, 1985). Thus, we can safely assume that neurotics tend to have ‘alarm bells’ that ring louder and/or more often. The question of interest was whether neurotics also have more sensitive conflict detection systems, even for conflicts that are generally non-distressing to detect. Our results suggested that neurotics do indeed have more sensitive conflict detection systems. The magnitude of activations to conflict, relative to non-conflict, trials correlated strongly ($r = .76$) with neuroticism.

Dorsal vs. Rostral ACC

The evidence presented thus far supports the notion of the dACC functioning as a neural alarm system involved both in the cognitive detection of critical conditions and the affective sounding of a phenomenological alarm. On the face of it, this characterization conflicts with an influential account of the distinct functions of dorsal and rostral ACC (rACC). Bush, Luu, and

Posner (2000) reviewed various cognitive and affective task paradigms that activated the ACC and the major conclusion of their review was that cognitive tasks tended to activate dACC and deactivate rACC, whereas affective tasks tended to activate rACC and deactivate dACC. Thus, our conclusion that one function of dACC is to sound an affective alarm conflicts with this conceptual organization of ACC function.

One limitation of the Bush et al., (2000) review is that there were no pain imaging studies included in their analysis. Once these studies are taken into account, the affective-cognitive distinction becomes muddled because the emotional distress of pain has been reliably linked to dACC rather than rACC activity in numerous studies (Rainville et al., 1997).

The fact that the affective-cognitive distinction seems insufficient to capture the functional differences associated with the dorsal and rostral regions of the ACC led us to consider an alternative formulation. After a search of the literature, though not an exhaustive search, we developed the hypothesis that dACC and rACC may both be involved in conflict processing but differ with regard to the extent to which the conflict is represented *symbolically* or *non-symbolically*.

Symbolically-represented conflict should vary from non-symbolically represented conflict in a number of ways. The most critical is whether there is an explicit Intentional representation of the conflict or of the source of the conflict.¹ According to this view, when conflict is symbolic, there isn't merely conflict in the system (e.g., in the ACC), rather there is an awareness of the conflict as a conflict (Lieberman, Gaunt, Gilbert, & Trope, 2002).

These two kinds of conflict processing should also vary in the kind of computational mechanisms that could support them. Non-symbolic conflict can be thought of as 'tension' between two or more competing representations or responses. Connectionist networks representing the combined outputs of multiple interconnected inputs naturally produce 'conflict maps' that represent

the total level of tension or conflict between the various inputs. When inputs are coherent and consistent with one another, the network has a low level of tension, whereas when these inputs conflict, the network has a high level of tension (Hopfield, 1982, 1984). Cohen and colleagues (Botvinick et al., 2001) have developed an elegant model of this process, which suggests that when the tension level in dACC is high, it automatically triggers a signal to lateral prefrontal cortex, which then exerts top down control over the competing inputs. Nowhere in this model is the conflict itself or the decision to resolve the conflict modeled. Indeed, its authors value the model, in part, because there is no ‘ghost in the machine’ regress in which an intelligent agent must be posited but left unexplained.

Although little or nothing is known about the process by which conflicts or anything else are represented symbolically (Lieberman et al., 2002), symbolic representations do have a number of features that are known. Symbolic processes involve conscious awareness of and attention to a specific symbolic representation. The resources of awareness and attention are limited (Miller, 1956) such that only a handful of symbolic representations can be attended to and processed at any one time (Schneider & Shiffrin, 1977). These representations are typically thought to be processed serially. Thus, while many conflicts may be non-symbolically processed, only a single symbolic conflict can be processed at any one time.

We propose that symbolically-represented conflict is processed primarily in rACC, whereas non-symbolically-represented conflict is processed primarily in dACC. With respect to cognitive conflict, there are both symbolic and non-symbolic forms. For instance, connectionist networks in which tension effects naturally emerge out of competing inputs can nicely model the standard oddball, Go-NoGo, and Stroop effects. Alternatively, error detection tasks involve an overt awareness that a particular error has been made and what the nature of the error is. Using a Talarach

y-coordinate of 30 to divide rostral from dorsal ACC activations, we find that most non-symbolic forms of cognitive conflict activate dACC (Braver et al., 2001; Bush et al., 2003; Carter et al., 2000; Weissman et al., 2003). Alternatively, error detection tasks, which involve symbolic conflict representations, tend to activate rACC (Garavan et al., 2003; Kiehl et al., 2000; Rubia et al., 2003).

Emotion can also be construed within a conflict model. Appraisal models of emotion suggest that negative emotions are the result of a conflict between desired or expected outcomes and what actually occurs (Frijda, 1986; Lazarus, 1991; Mandler, 1975). Most negative emotions (e.g., anger, fear, sadness) are thought to have a specific Intentional object such that they are, symbolically speaking, about something. When someone is afraid, they are afraid of something in particular and know what that something is. Anxiety, however, is a negative affect that is distinguished from fear in that it lacks an Intentional object (Kierkegaard, 1844/1981). Although anxiety may have a specific cause (e.g., someone in the room who makes us uncomfortable), anxiety does not involve the anxious individual knowing this specific cause. Considering neuroimaging studies of anxiety-provocation versus the induction of other emotions conforms to our symbolic/non-symbolic theory of the ACC. Studies of sadness, anger, and fear reliably activate rACC (Damasio et al., 2000; Dougherty et al., 1999; George et al., 1995; Kimbrell et al., 1999; Liotti et al., 2000; Mayberg et al., 1999; Shin et al., 2000). Studies of anxiety, however, tend to activate dACC (Kimbrell et al., 1999; Liotti et al., 2000). Along similar lines, emotion perception of discrete emotional expressions activates rACC (Ueda et al., 2003) whereas perception of ambiguous emotional expressions activates dACC (Nomura et al., 2003).

Finally, pain distress can also be divided along symbolic and non-symbolic lines. Typically, pain is a non-symbolic bottom up process (i.e., animals without symbolic capacities presumably experience pain). Consistent with this, the experience of pain is most often associated with dACC

activation (Hsieh et al., 1999; Ploghaus et al., 1999; Sawamoto et al., 2000; Tolle et al., 1999).

However, when pain is anticipated or expected it becomes more symbolic in nature and tends to be processed in rACC (Buchel et al., 1998; Chua et al., 1999; Ploghaus et al., 1999, 2003).

Thus, cognitive, affective, and pain processes are each distributed across dACC and rACC. They do, however, seem to be organized such that more symbolic forms of cognition, emotion, and pain are processed in rACC with less symbolic forms processed in dACC. It is worth returning to a point made earlier regarding the homology of function between human and primate ACC. Smith (1945) pointed that though macaques have ACC's that correspond in location to the human dACC and rACC, the morphology of the macaque's rACC and dACC are both consistent with the morphology of human dACC. Smith concluded that macaques do not, functionally speaking, have an equivalent to human rACC. This conclusion takes on new meaning in light of our claim that rACC is involved in symbolic representations of conflict, a capacity that humans have and may not share with any other animal (Deacon, 1997). Symbolic representations of conflict allow for unparalleled consideration of contextual factors such as time and place. If one is aware of the source of one's distress, one may choose to delay responding (e.g., one may choose to ignore one's distress caused by one's boss while the boss is still in the room) or consider complex strategies of response (e.g., "I'll settle this when I have lunch with my boss's boss next week"). Non-symbolic conflict simply produces tension and anxiety until it is resolved or a symbolic representation is generated.

Conclusion

In this chapter, we have suggested that because of the unique role of social attachment in mammals, the social pain system may have piggybacked onto the physical pain system during our evolution. We have suggested that the dACC may have been one of the primary sites in which this

overlap evolved such that today, this region produces similar experiences of distress in response to both physical and social injuries. More generally, we propose that the dACC may be thought of as a neural alarm system that is involved both in the detection of actual or potential threats as well as in the sounding of a phenomenological alarm that redirects our attention and motivation towards dealing with the source of the threat. Lastly, we attempted to integrate our model with what has been previously hypothesized regarding the function of the ACC by proposing a new conceptual distinction for the contribution of rACC vs. dACC to psychological processes. Specifically, we proposed that the dACC is involved in detecting non-symbolic conflict whereas rACC is involved in detecting symbolic conflict. In future work, we hope to more fully explore the ways in which physical and social pain processes are intertwined, as well as distinct, in order to better understand in what ways ‘pains by any name’ really do ‘hurt the same.’

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¹ In philosophy, when the word “Intentional” is capitalized it refers to the quality of “Intentionality” which includes, but is not limited to mental acts such as beliefs and desires. Intentionality, first described by Aristotle in *De Anima* and later by Brentano (1874) and Husserl (1913) as one of the cornerstones of continental phenomenology, refers to the fact that certain reflective acts of mental life are irreducibly *directed at* or *about* something else. Physical objects are never intrinsically about anything else, serving only as representations to the extent that they are designated as such by the Intentional acts of humans. Although mental acts can possess the quality of Intentionality, many do not. For instance, the vast majority of visual information that is processed by the brain at any moment is not overtly attended to. Parafoveal priming works, in part, because it is cognitively processed but not Intentionally; the individual has no thought about the primes.