



A neurobehavioral evolutionary perspective on the mechanisms underlying empathy

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ABSTRACT

In mammals, empathy is crucial for living in social groups and caring for others. In this paper, we consider the structural and functional organization of empathy. We propose that empathy subsumes a variety of neurobiological processes and partially dissociable information processing subsystems, each of which has a unique evolutionary history. Even the most advanced and flexible forms of empathy in humans are built on more basic forms and remain connected to core subcortical and neurohormonal mechanisms associated with affective communication, parental care and social attachment processes. Considering empathy within a framework that recognizes both the continuities and the changes within a phylogenetic perspective provides a richer understanding of empathy and related neurobehavioral processes.

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Contents

1. Neuroevolution of empathy-related behaviors	39
2. Evolution of empathy from parenting behavior	41
3. Parental care is rewarding	41
4. Neural circuits associated with the perception of others' distress	42
5. The lack of empathic arousal contributes to callous disregard to others' welfare	43
6. Aspects of empathy specific to humans	44
7. Empathy as an adaptive response	44
8. Conclusions	45
Acknowledgements	46
References	46

Mammalian reproductive fitness and survival depend crucially on the ability of conspecifics to communicate with each other, sharing information about their emotions and intentions and appropriately responding to their offspring or relatives needs.

Although organisms can develop a variety of understanding of others, empathy entails more than just understandings or expectations. When individuals empathize, they vicariously feel the emotions of others, which not only promote affective communication but depending on the context and social relationships may motivate to behave pro-socially towards other conspecifics (Decety, 2011).

Empathy has been a focus of speculation in philosophical and psychological investigations throughout written history (Batson, 2009). Recently, the scientific understanding of empathy has blossomed into a vibrant and multidisciplinary field of study

Abbreviations: ACC, anterior cingulate cortex; AIC, anterior insular cortex; aMCC, anterior midcingulate cortex; fMRI, functional magnetic resonance imaging; mPOA, medial preoptic area; PAG, periaqueductal gray; SMA, supplementary motor area.

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appealing to those in developmental and cognitive psychology, evolutionary biology, and affective and social neuroscience (Mason and Ben Ami-Bartal, 2010). Considerable evidence now exists to suggest that empathy has deep evolutionary, neuroendocrine, and neurophysiological underpinnings.

One likely source of empathetic responses in mammals comes from the phylogenetically ancient practice of caring for one's offspring. For example, caregiving to offspring can be observed in birds (Cockburn, 2006), fish (Goodwin et al., 1998), and a minority of reptiles (Clutton-Brock, 1991). Moreover, caregiving of offspring is a characteristic of all mammals (Bell, 2001). While parental care for offspring is not necessary for evolutionary success, in some cases it provided a fitness advantage for the offspring of particular species and the genes that promoted this behavior were passed onto subsequent generations. Over countless generations, mammals developed ever more complex physiological (e.g., lactation) and behavioral (e.g., perceiving the needs of their offspring) processes associated with improving offspring survival (Bell, 2001). The neurobiological and behavioral manifestations of parental care also provide the means through which individuals within a social group are able to care for one another. Kin selection models of social behavior presume that the pro-social tendencies within groups resulted from the fact that organisms that assist their genetic relatives are better able to propagate a fraction of their own genetic legacy into future generations (e.g., assisting sibling's offspring which share 25% of one's genes) (Wilson, 1975). However, kin selection models of pro-social behaviors within groups do not actually specify how these behaviors are motivated and do not assume that individuals must be able to detect genetic relatedness (Bell, 2001). Thus, any evolved motivational system that increases the fitness of kin will produce the same results in terms of fitness regardless of fact that this motivational system may also apply to non-relatives (Bell, 2010). The ability to model the emotions of non-relatives and react appropriately within a social group would likely confer some fitness advantages (e.g., better able to communicate and detect distress in group members). For example, the motivational systems that may have originally developed to care for offspring has likely been co-opted and used in the service of facilitating positive relationships between unrelated group members. In humans for example, our relationships with spouses, friends and co-workers are highly valued and require vast amounts of psychological resources to maintain. In fact, the perception that such relationships are threatened engenders profound emotional and physiological stress responses (Norman et al., 2012a). Conversely, feeling well connected with friends and family provides a strong behavioral and physiological buffer that can actually diminish stress responses and result in improved health (Uchino et al., 1996). Therefore, while the motivational components of pro-social behaviors such as empathy may have originally developed in service of parental care, they have now become invaluable tools for the formation and maintenance of strong social bonds between unrelated individuals.

More recently, neuroscientists have begun to examine the neurobiological mechanisms that instantiate empathy, especially in response to signals of distress and pain, and how certain dispositional and contextual factors modulate its experience and behavioral manifestations. Functional neuroimaging studies in humans document a circuit – including the anterior insula, dorsal anterior cingulate cortex, anterior midcingulate cortex, supplementary motor area, amygdala, brainstem, and periaqueductal gray – that responds to the perception of others' distress (Lamm et al., 2011).

While it is important to consider the broad range of species-specific behaviors when dealing with motivated behaviors (e.g., sex, hunger and thirst), a clear evolutionary continuity of behaviors has been conserved across organisms such as parental behavior in

mammals (Insel and Young, 2001; Panksepp, 1998). This continuity has important implications for the study of human social behaviors as it allows for the application of animal models to better understand neurobehavioral processes including empathy (Panksepp, 2010). Indeed, as will be discussed in further detail below, human and animal studies have revealed that the perception of distress in others tends to activate a highly conserved neurobiological circuit to produce an aversive response in the observer, which can inhibit aggression and prompt pro-social behavior (Decety and Michalska, 2010; Eisenberg and Eggum, 2009).

Animal research has shown that the ability to share and be affected by the emotional state of another is organized by basic systems subserving attachment-related processes, involving the brainstem, preoptic area of the thalamus, and paralimbic areas (Panksepp, 1998; Watt, 2000). As a result of the importance of social connections for mammalian survival, these attachment systems appear to exploit the well developed physical pain system, borrowing the aversive signals associated with pain to indicate when relationships are threatened (Cacioppo and Hawkley, 2009; Eisenberger, 2011; MacDonald and Leary, 2005). Moreover, higher level cortical structures have been proposed to reflect a system involved in detecting, processing and reacting to the occurrence of salient events regardless of the sensory modality through which these stimuli are conveyed; basic operations by which the neural structures detect stimuli that can represent a potential threat for the integrity of the self (Legrain et al., 2011). Therefore, just as the physical pain system alerts organisms to the presence of a noxious environmental stimulus so too does the social pain system; the experience of social pain alerts an individual to potential threats in their social environment and can induce various coping strategies to attempt to mitigate the threat (e.g., increase motivation to strengthen relationships) (MacDonald and Leary, 2005).

In addition to the pain system mentioned above, the dopaminergic reward system also appears to have been partially co-opted for attachment and caring, and thus plays a role in empathic concern (see Box 1 for definition of concepts). Indeed, mammals are highly motivated to care for their offspring and experience this interaction as a highly rewarding experience (Mayes et al., 2009). Although empathy in humans is assisted by other general high-level cognitive abilities such as executive functions and language, which introduce contextual control and expand the repertoire of behaviors that can be driven by empathy and emotional connection, it also operates on more primitive reward processes and is highly dependent upon these lower level processes to achieve higher order goals associated with affective communication, social attachment, parental care, and motivation to cooperate.

Here we consider the evolutionary origins and neuroarchitectural characteristics of empathy and empathy-related processes in social mammals. We review evidence that empathy-like responses are apparent across a broad range of non-human animals and that empathy subsumes a variety of neurobiological processes and partially dissociable social-cognitive subsystems each having a unique evolutionary history (see Box 2) (Fig. 1).

1. Neuroevolution of empathy-related behaviors

At the behavioral level, it is apparent from the descriptions of ethologists that behaviors homologous to empathy and concern can be observed in other mammalian species, and even avian species. For instance, the presence of specific behavioral (e.g., increase alertness, decreased preening behavior) and physiological (eye temperature) changes in hens observing their chicks being exposed to a mildly aversive stimulus indicates a responsive capacity that is distinguishable from the hens' own experiences of the same stimulus (Edgar et al., 2011).

Box 1. Key concepts

- Altruism refers to pro-social behaviors that benefit the recipient at a cost of resources to the donor.
- Attachment is an innate biological system promoting proximity seeking between an infant and a specific attachment figure in order to increase the likelihood of survival.
- Emotional contagion is an automatic response resulting in similar emotion being aroused in the observer as a direct result of perceiving the expressed emotion of another.
- Empathy is as an integrated affective response stemming from the perception of another's emotional state or condition similar to what the other person is feeling or would be expected to feel in the given situation.
- Empathic concern is another-oriented emotional response congruent with the perceived welfare of someone in need.
- Emotion regulation is the ability to respond to the ongoing demands of an emotional experience in a manner that is socially tolerable and sufficiently flexible to permit spontaneous reactions.
- Theory of mind is the ability to explain, predict, and interpret behavior by attributing mental states such as desires, beliefs, intentions and emotions to oneself and to other people.
- Emotional distress is an aversive self-focused reaction to the expression of another's negative emotion, often leading to avoidance behavior.
- Pro-social behavior refers to actions that are intended to help or benefit another individual or group of individuals.

Box 2. Re-representation of empathy across the neuraxis

The evolution of empathy and empathy-like processes in humans involves conservation across species through a co-option and elaboration via a re-representation of function across the neuraxis. The evolutionary emergence of “higher level” neural structures did not entail the replacement of more primitive neural systems. Instead, the brain is organized so that the same information is simultaneously processed at multiple levels, with the responses orchestrated at lower levels of the central nervous system embellished at and modulated by higher levels of the neuraxis. The evolutionary development of higher neural systems, such as the limbic system and cerebral cortex, endowed organisms with an expanded behavioral and motivational repertoire that enabled them to capitalize on experience-dependent associative knowledge, information-processing networks, and cognitive strategies that anticipate and prepare for appetitive and aversive encounters (Norris et al., 2010). It is important to note that the representation of function across the neuraxis does not entail that lower level structures are entirely subject to commands from higher level. In fact, a large percentage of neural processes occur without the engagement of neo-cortical structures. Indeed, the need for higher level cortical processing may be necessary only in situations with high ambiguity and low predictability (Parvizi, 2009).

The evolution of the central nervous system has maintained primitive lower-level responses that can respond quickly although somewhat reflexively to environmental stimuli (including caregiving motivation and behavior) while simultaneously allowing for the development of more integrative and elaborated information processing characteristics of more rostral brain structures. Thus primitive and rapid empathetic-like responses, such as orofacial mimicry, somatovisceral responses and physiological resonance of stress occur automatically and more elaborated emotional and cognitive empathy-related processes, such as perspective taking, occur through interactions between limbic and cognitive structures (Buchanan et al., 2012; Decety and Jackson, 2004; De Waal, 2008).

Although progressively higher level systems receive a wider array of inputs, have greater circuit complexity and computation capacity, they do not operate in isolation but depend upon and interact with lower levels in the neuraxis (Berntson and Cacioppo, 2008). The adaptive flexibility characteristic of higher level neural structures comes at a cost, however: a slower serial-like mode of processing as a result of a less rigid relationship between inputs and outputs and a greater range of information that must be processed. Consequently, the evolutionary layering of higher processing levels onto lower substrates has adaptive advantage in that lower and more efficient processing levels may continue to be utilized. These lower-level circuits are embedded in multilevel networks, however, and are not immutable, as higher neurobehavioral processes can modulate the expression of lower level systems. This view is compatible with neural reuse theories, which posit that it is quite common for neural circuits established for one purpose to be exapted (exploited, recycled, redeployed) during evolution or normal development, and be put to different uses, often without losing their original functions (Anderson, 2010).

Numerous empirical studies with rodents have shown that affective arousal and emotional contagion prompt efforts to alleviate the distress of a conspecific. For instance, rats that had learned to press a lever to obtain food stop doing so if their action is paired with the delivery of an electrical shock to a visible neighboring rat (Church, 1959) and rats will press a bar to lower another rat suspended in mid-air (Rice and Gainer, 1962). Similarly, rats will intentionally free a cagemate locked in a restrainer even when social reward was prohibited (Ben-Ami Bartal et al., 2011). Additionally, this latter study found that when liberating a cagemate was pitted against a highly palatable food (chocolate chips) contained within a second restrainer, rats opened both restrainers and typically shared the chocolate.

Furthermore, a number of studies have demonstrated that rodents show social modulation of emotional responses and learning. In one such study, pain sensitivity was modulated in mice by the presence of other mice displaying pain behaviors (Langford et al., 2006). Interestingly, this relationship is conditional upon the identity of the target mouse such that observing pain-behaviors in conspecifics only influences pain behavior when the target mouse is their cage mate. Similarly, female mice show more freezing behavior when exposed to the pain of a close relative than when exposed to the pain of a more distant relative, suggesting that it serves an adaptive function (Jeon et al., 2010). To investigate whether such pain behavior can serve the function of soliciting a primitive form of empathic concern, Langford and his colleagues (2010) used a social approach paradigm to test mice in various dyadic or triadic conditions. Some conditions involved restrained mice that were in pain as a result of intraperitoneal injection of acetic acid and test mice free to approach or avoid the restrained mice. Results showed a sex-specific effect whereby female, but not male, test mice approached a familiar same-sex conspecific in pain more frequently than an unaffected familiar or unfamiliar, but affected, conspecific. Furthermore, the frequency of contact by the test mouse was negatively correlated with the pain behavior of the jailed mouse, suggesting that the proximity of a familiar unaffected conspecific has analgesic properties. Moreover, another study has

demonstrated that socially isolated mice display significantly higher levels of mechanical pain sensitivity as well as depressive-like responses following peripheral nerve injury as compared to their pair housed counterparts, potentially through a mechanism involving the neuropeptide oxytocin (Norman et al., 2010). Results from these studies can also be interpreted as evidence of an effect of social support on the experience of pain; a finding consistent with human literature. Indeed, the presence of an individual who provides passive or active support reduces experimental pain in

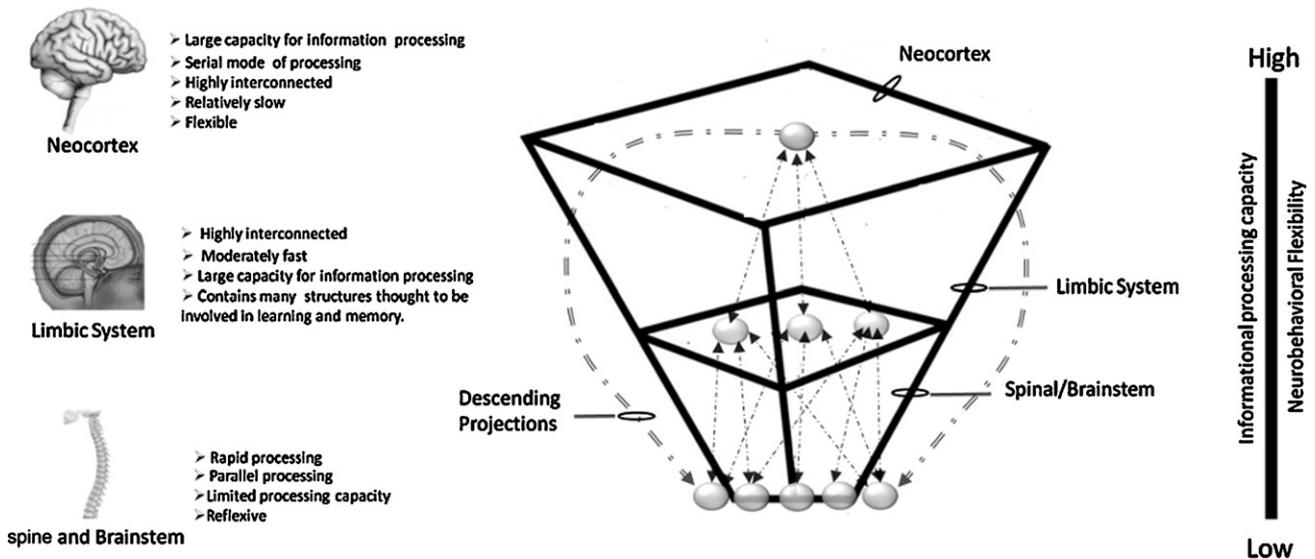


Fig. 1. Heterarchical information processing in the neural axis. Left: basic description of low, medium and high levels of arousal. Middle: a three dimensional depiction of evaluative space. Lowest levels are characterized by more reflexive or bipolar modes of activation. As one moves to higher levels of the neuraxis, activation patterns are capable of more complex bivariate activation patterns. Furthermore, heterarchical projections allow higher levels to bypass intermediate levels and directly modulate lower levels. This pattern allows higher level cognitive and emotional processes to directly influence basic motor responses to create complex behavioral patterns. Right: higher levels of the neuraxis can be characterized by increasing behavioral complexity, and informational processing capacity.

humans (Brown et al., 2003). Similarly, a study determined that the presence of others and perceived empathy (defined as participants' knowledge of the extent to which observers felt they understood and shared their pain) can modulate subjective and autonomic responses to physical pain; and these influences can be explained by individual variations in pain coping strategies and social attachment (Sambo et al., 2010).

Empirical studies of empathic reaction in apes indicate they too, have an appreciation for the situation of conspecifics (Warneken et al., 2007). Primitive aspects of empathy, such as emotion contagion (i.e., an automatic response resulting in similar emotion being aroused in the observer as a direct result of perceiving the expressed emotion of another), parental care, and consolation have been demonstrated in chimpanzees (De Waal, 2008). For example, an experiment in which peripheral skin temperature was measured in chimpanzees while they viewed an emotionally laden video demonstrated a decrease of skin temperature, indicative of sympathetic arousal, when they viewed videos of conspecifics injected with needles or videos of the needles themselves, whereas these changes were not observed when the chimpanzees viewed videos of a conspecific chasing the veterinarian (Parr, 2001). Thus, when chimpanzees perceive a conspecific exposed to painful stimuli, they show physiological changes similar to those observed in humans (Hatfield et al., 2009). Providing contact comfort to distressed others is an expression of empathic concern, and such other-oriented behavior is now well documented in chimpanzees (Romero et al., 2010). Indeed, consolation in chimpanzees reduces behavioral measures of stress in recipients of aggression, and was found to occur more frequently between individuals with the strongest social relationships (Fraser et al., 2008). Therefore, various mammals display aspects of empathy and understanding how these processes function in related animals provides an important insight into their role in human social behavior.

2. Evolution of empathy from parenting behavior

Mammalian species whose progeny have long periods of dependency must care for the offspring sufficiently long that they too can reproduce to ensure the genetic legacy of the parents.

Accordingly, the ability to perceive and respond with care to emotional expressions of hunger, pain, distress or fear in one's progeny – that is, to emit and understand rudimentary empathic behaviors – contributes to an individual's genetic legacy. Thus, empathy may be viewed as an evolved adaptation to respond with care the needs of offspring.

The study of comparative neuroanatomy makes clear that motivated behaviors to provide care for offspring evolved earlier than complex cognitive capacities such as perspective taking or theory of mind. The brainstem, hypothalamus, and limbic system – that play a major role in integration of affective value to incoming sensory signals – antedated the expansion of the neocortex. It was proposed that empathic concern emerged with the evolution of mammals, which gave rise to new classes of behavior, including parenting and attachment, that support dependent juveniles, and the extended embryonic plasticity of their brains (MacLean, 1985). When mammals developed parenting behavior, the stage was set for increased exposure and responsiveness to emotional signals of others, including signals of pain, separation, and distress. Panksepp (1998) provided evidence that the social attachment system is built up from more primitive regulation systems such as those involved in place attachment, thermoregulation, and physical pain. Evidence suggests that the medial preoptic area (MPOA) in the rostral hypothalamus and adjoining bed nucleus of the stria terminalis (BST) give rise to neural circuits which specifically regulate maternal motivation. These neurons are responsive to visual, audible and chemosensory signals expressed by offspring and through their projections to the mesolimbic DA systems, and to the anterior hypothalamic nucleus/PAG system, they increase proactive voluntary maternal responses while decreasing defensive behavior and avoidance (Numan, 2006). While this system evolved to ensure care in postpartum mothers, a generalized parental nurturance seems the most likely evolutionary basis of empathic concern – even for strangers (Batson, 2011; Taylor, 2002).

3. Parental care is rewarding

Parental nurturance has evolved as a result of its obvious survival benefits to offspring. Similar to the evolutionary

development of hedonic responses to caloric food, maternal (and sometimes paternal) nurturance of offspring is highly rewarding. The endogenous opioids are well known to influence social bonding and affiliative behavior: opioids are released during social contact and this release is rewarding (Maestriperi, 2010). A wealth of studies on maternal behavior across a range of species reveal a direct effect of oxytocin on dopamine release within the mesocorticolimbic dopamine system, a process thought to be directly related to the experience of reward in animals (Ferris et al., 2005). This dopaminergic pathway is involved in reward seeking and may help to strengthen the pup–dam bond (Ferris et al., 2005). Mother rats that exhibit consistently increased pup licking and grooming (LG) (i.e., high LG mothers) by comparison with low LG mothers show increased oxytocin expression in the medial mPOA and the paraventricular nucleus of the hypothalamus and increased projections of oxytocin-positive cells from both mPOA and paraventricular nucleus of the hypothalamus to the VTA, ostensibly reflecting increased signaling within areas related to the hedonic properties of maternal care.

Human mothers with secure attachment show increased activation of mesocorticolimbic reward brain regions, on viewing their own infant's smiling face. Furthermore, mothers show an increase in peripheral oxytocin responses while interacting with their infants, which is positively correlated with activation of dopamine-associated reward processing regions of the brain (Strathearn et al., 2009).

Caring behaviors in humans are reinforced both by endogenous reward (dopamine system) and positive social feedback from others. Behavioral and functional neuroimaging studies have demonstrated that caring for others is associated with the activation of neural structures known to be associated with reward including projections from the brainstem to the nucleus accumbens (Brown et al., 2009). For instance, the fronto-mesolimbic reward network is engaged to the same extent when individuals receive monetary rewards and when they freely choose to donate money to charitable organizations (Moll et al., 2006). In another study, neural activity was recorded while participants decided how to split \$100 between themselves and a local food bank. Donations (costly to the subject) to the food bank were associated with activation in the ventral striatum (Harbaugh et al., 2007). Furthermore, medial orbitofrontal–subgenual and lateral orbitofrontal areas, which play key roles in more primitive mechanisms of social attachment and aversion, mediate decisions to donate or to oppose societal causes. One functional MRI study reported that the mere presence of observers increased donation rates and significantly affected activity in the striatal regions (Izuma et al., 2010). The cortical re-representation of more primitive caregiving functions at the level of the brainstem, midbrain and limbic system was accompanied by an increase in the plasticity and flexibility provided by the prefrontal cortex. This increased flexibility has allowed for the symbolic representation of pro-social behaviors within large social groups of non-related individuals (e.g., philanthropy, blood donation).

4. Neural circuits associated with the perception of others' distress

The long history of mammalian evolution has shaped maternal brains to be sensitive to signs of suffering in one's own offspring (Haidt and Graham, 2007). Even very young infants of 6 months of age are capable of pre-verbal evaluations when viewing social interactions. Babies are more likely to smile, clap, etc. when viewing prosocial events, and to frown, shake their heads, and look sad or otherwise upset during antisocial events (Bloom, 2012). The earliest forms of empathic concern appear around 8–16 months and continuing to develop into the second year (Roth-Hanania

et al., 2011; Vaish and Warneken, 2012). In many primates and other mammals, this sensitivity has extended beyond the mother-child relationship, so all normally developed individuals generally dislike seeing others suffering. Pain serves adaptive functions not only by warning the suffering individual, but also by impelling expressive behaviors that attract the attention of others that may provide assistance (Craig, 2009). Crying for instance is one prototypical attachment behavior. It is only an advantage to the extent that crying attracts the caregiver faster than it attracts the predator. Thus, pain can be considered a subjective experience triggered by the activation of a mental or neural representation of actual or potential tissue damage. This representation involves somatic sensory features, as well as affective-motivational reactions associated with the promotion of protective or recuperative visceromotor and behavioral responses (Fig. 2). It is the affective experience of pain that signals an aversive state and motivates behaviors to terminate, reduce, or escape exposure to the source of noxious stimulation. Furthermore, the expression of pain also provides a crucial signal that can motivate soothing and caring behaviors in others (Jackson et al., 2005). Therefore, in addition to removing the potential threat, the expression of pain behaviors allows individuals to obtain assistance from other individuals within the group.

In humans, a number of neuroimaging studies have documented reliable activation of a neural network involved in the processing of pain, including the anterior midcingulate cortex (aMCC), anterior insular cortex (AIC), supplementary motor area (SMA), and periaqueductal gray (PAG) when individuals watch facial expressions of pain (Botvinick et al., 2005; Lamm et al., 2007) or body parts being injured (Jackson et al., 2005; Cheng et al., 2008), imagine the pain of others (Jackson et al., 2006), or simply observe a signal indicating that someone will be hurt (Singer et al., 2004). It is worth noting that vicariously instigated activations of the pain matrix are not specific to the sensory qualities of pain, but instead are associated with more general survival mechanisms such as aversion and withdrawal when exposed to danger and threat (Decety, 2010). Of particular importance, the aMCC, a region that implements a domain-general process that is integral to negative affect, pain and cognitive control contains pain-responsive neurons that are activated by both anticipation of pain and instrumental escape from pain (Shackman et al., 2011). Activation of the AIC is nearly ubiquitous in studies of pain empathy: this response can even be elicited automatically as shown when participants viewed color photographs depicting human body parts in painful or nonpainful situations and performed either pain judgment (painful/nonpainful) or laterality judgment (left/right) of the body parts in the absence of explicit task requirements and attentional demands (Gu et al., 2010). It has been proposed that the AIC and aMCC form the core of a salience network that segregates the most relevant among internal and extrapersonal stimuli in order to guide behavior (Menon and Uddin, 2010).

These findings demonstrate the ease with which an individual can integrate the pain of another into their own bodily somatic representation. Consistent with Jackson's notion of neuroevolutionary re-representation of function (Jackson, 1884), it has been proposed that the anterior insula and its array of projections, serves to compute a higher order meta-representation of primary interoceptive activity, which is related to the feeling of pain and its emotional awareness (Craig, 2007). These representations play an important role in the learning and adaptation of social behavior in addition to basic decision-making and homeostatic processes, and play a critical role in empathy.

In a recent study, participants watched a short series of visual scenarios in which an individual was either intentionally harming another person or easing the other's pain and were required to mentally simulate being the perpetrator or the recipients of those

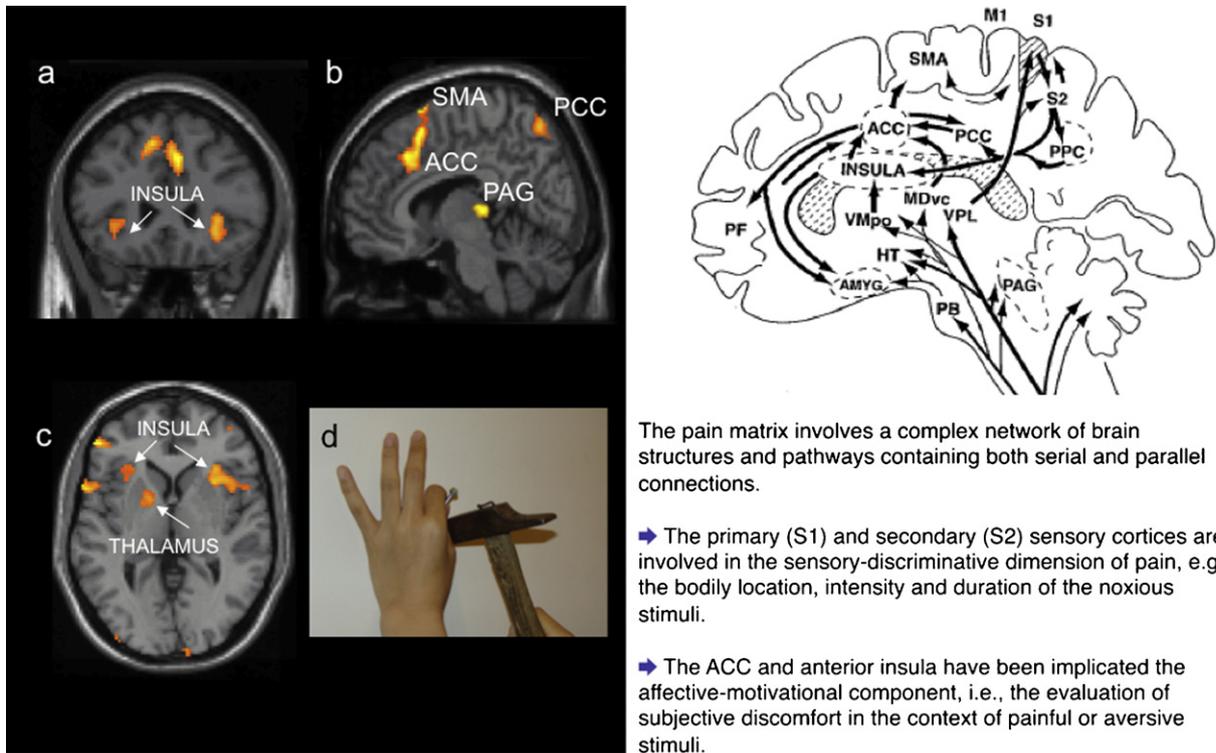


Fig. 2. (a–d) Neural network involved in perceiving others in distress and pain largely overlap with the processing of nociceptive information. Neurophysiological research on pain processing points out a distinction between the sensory-discriminative and the affective-motivational domains. The former domain engages stimulus localization and intensity and is assessed with ratings of pain intensity while the latter one involves the affective component of pain and is measured with ratings of unpleasantness. This duality is also framed in terms of medial and lateral thalamic processing and extent for cortical structures including somatosensory and anterior cingulate cortices, respectively based on thalamic afferents. These two dimensions of pain processing are underpinned by discrete yet interacting neural networks. A growing number of neuroimaging studies recently demonstrated that the perception of pain in others (like in d) recruits brain areas chiefly involved in the affective and motivational processing (ACC, insula), as well as the somatosensory cortex and PAG (Lamm et al., 2011 for a meta-analysis). The anterior insula lies between the lateral and medial systems and is involved in processing associated with each system including sensory coding, body state assessment, and autonomic regulations as well as emotional awareness. The cingulate cortex mediates the three aspects of pain processing that may use affect but is explicitly involved in avoidance/nocifensive behaviors.

actions (Decety and Porges, 2011). Functional connectivity analyses demonstrated that positive agency (easing the pain of another) was associated with increased activity in ventral striatum, a structure previously associated with reward (Carlezon and Thomas, 2009). When asked to simulate being the perpetrator of the harmful act, individuals showed a marked decrease in ventromedial prefrontal cortex and activation in the amygdala. These data suggest that even within the context of mental simulation, perspective taking has a profound impact on neurobiological processes associated with reward and aversion. Furthermore, the neural overlap between the first-hand experience of pain and its perception or even imagination is consistent with neural reuse theories which posit as a fundamental principle of brain evolution that neural circuits continue to acquire new use after an initial or original function is established (Anderson, 2010).

5. The lack of empathic arousal contributes to callous disregard to others' welfare

There are people who possess specific personality traits which point to stunted emotional development and a general lack of empathy. A paradigmatic example is psychopathy, which has been associated with an uncommitted approach to mating, increase sexual coercion, lack of parental investment, increased number of sexual partners, and sexual promiscuity. Psychopaths are often callous, shallow, and superficial. They lack fear of punishment, have difficulty regulating their emotions, and do not experience insight into or empathy for the effect their poor behavior has on others. Offenders with high levels of psychopathy show reduced

autonomic arousal when viewing a confederate receiving electric shocks (Aniskiewicz, 1979).

Individuals with high levels of antisocial behavior and callous-unemotional traits show consistent deficits in empathic arousal and empathic concern across childhood and adolescence (Hawes and Dadds, 2012). These abnormal responses to the distress of others may be evident as early as childhood. For example, children with psychopathic tendencies exhibit reduced electrodermal responses to distress cues (e.g., a crying face) and threatening stimuli (e.g., a pointed gun) relative to controls (Blair, 1999). One neuroimaging study recently investigated this phenomenon by assessing how callous-unemotional traits in juvenile psychopaths are related to empathic arousal deficits. In this study, youth offenders with high callous-unemotional traits, juvenile offenders with low callous-unemotional traits, and age-matched typically developing adolescents were shown images of people in pain while EEG/ERPs were recorded (Cheng et al., 2012). Results demonstrated that youth with high callous-unemotional traits exhibit atypical neural dynamics of pain empathy processing in the early stages of affective arousal. This abnormality was exemplified by a lack of the N120 component, thought to reflect an automatic aversive reaction to negative stimuli, and was coupled with relative insensitivity to actual pain (as measured with the pressure pain threshold). Nevertheless, their capacity to understand intentionality in the social interactions depicted in the stimuli (associated with the P300 component) was not impaired. Such uncoupling between affective arousal and emotion understanding may contribute to callous disregard for the rights and feelings of others.

Adult psychopaths fail to experience distress cues as aversive, an ability which is critical for the experience of empathic concern, as distress cues are assumed to activate predispositions to withdraw in any observer who processes them, regardless of whether that observer is the aggressor or a bystander (Blair, 1995). To be motivated to be concerned about another's welfare, one needs to be affectively and empathically aroused, and to anticipate the cessation of mutually experienced personal distress (Barnett and Thompson, 2001). This signal may be lacking in psychopathic individuals who exhibit weaker psychophysiological reactions such as skin conductance reactivity to emotional stimuli and poor passive-avoidance learning (Kosson et al., 2006). The atypical processing of negative emotional stimuli coupled with poor inhibitory control, may account for morally inappropriate behavior in psychopaths. Evidence for such deficiencies is found not only in behavior, but also at the neural level of analysis. Dysfunction of the connectivity between the amygdala and vmPFC seems to partially explain low socio-emotional responses to others' distress (Anderson and Kiehl, 2012), though it is important to note that a lack of empathic arousal alone does not explain offensive behaviors.

6. Aspects of empathy specific to humans

Humans can feel empathic concern for a wide range of others in need, even dissimilar others. The development of human empathy has been elaborated through the integration of other abstract and domain-general high-level cognitive abilities such as executive functions, language, and theory of mind, underpinned by the prefrontal cortex, which expand the range of situations that can elicit empathy and the range of behaviors that can be driven by empathy (Stone, 2006).

Human language is a powerful tool to create and share emotional states, both by its content and prosody, which is not found in other species. By its very nature, language acts at distance across space and, in the case of written language, across time (Harris, 2000). Conversation helps to develop empathy, for it is often here that people learn of shared experiences and feelings. Verbalization of feelings can help reduce distress and can improve physical and psychological well-being. Several empirical studies have now demonstrated that affective language dampens amygdala response (Lieberman et al., 2007) and facilitates exposure-related attenuation of autonomic reactivity to aversive stimuli (Tabibnia et al., 2008). Thus, the ability to communicate emotional states with others through speech and linguistic expression provides humans with a powerful means to share their emotional states with others and to extend the reach of empathic concern across space and time. Importantly, language production and comprehension are grounded in internal bodily states, and seem to involve circuits long associated with motor control functions (Pulvermuller, 2005), and thus should not be considered as separate from evolutionary history.

Another seemingly unique aspect of empathy in humans is perspective taking, the cognitive ability to explicitly put oneself into someone else's shoes to represent his or her knowledge or emotional experience as compared to one's knowledge or affective experience. Such a capacity requires additional computational mechanisms (working memory and inhibitory control to hold simultaneously two perspectives in mind) needed for its development, plays a critical role in promoting empathic concern. Neuroimaging studies have revealed a specific network of brain regions that are recruited when one puts oneself in another person's shoes' to represent his or her knowledge or experience as compared to one's knowledge or affective experience. Adopting a third-person perspective, as opposed to a first-person has been associated with neural activation in the posterior STS and medial prefrontal cortex (Jenkins and Mitchell, 2011; Ruby and Decety,

2003, 2004). Studies in social psychology have demonstrated that empathic concern is enhanced when participants are told of another individual's plight and asked to imagine how that person feels (Batson et al., 1997). However, when the same individuals were asked to imagine instead how they would feel in the place of the other person, feelings of anxiety and personal distress were evoked. These results suggest that perspective-taking helps keep feelings of personal distress at a distance, thereby permitting the emergence of empathic concern. To test this hypothesis, a functional MRI study was performed in which participants viewed video-clips of individuals exhibiting facial expressions of pain, purportedly the result of a painful medical treatment (Lamm et al., 2007). Participants were instructed to either imagine how they would themselves feel if they were in the patient's situation, or imagine what the patient was feeling. The former perspective was associated with a strong hemodynamic increase in the amygdala, AIC, and ACC, as well as reports of anxiety and personal distress. When the participants were imagining what the patients were feeling, a significant reduction in activity was detected in the amygdala, with reduced feelings of anxiety combined with increased reports of empathic concern.

As illustrated by the example above, the evolutionary development of newer neural systems, such as regions of the prefrontal cortex involved in perspective taking, has thus conferred greater behavioral flexibility and contextual control. For instance, Lamm et al. (2010) used fMRI to examine how participants empathize with the feelings of patients who reacted with no pain to surgical procedures but with pain to a soft touch. Results showed that empathizing with someone whose bodily and affective representations are distinct from our own recruited areas of the prefrontal cortex involved in theory of mind (medial PFC) and cognitive control (right inferior frontal gyrus), and these regions increased their functional connectivity with more phylogenetically older regions such as the amygdala, brainstem, insula, and periaqueductal gray, that serve basic protective functions, including affective arousal.

Cognitive, sensorimotor and somatovisceral mechanisms are thus intimately connected, and in line with neural reuse theories (Anderson, 2010) partly share similar computational resources. One salient example comes from work on humans that are experimentally induced to feel they have been socially rejected. As one would expect, the rejected participants tended to perceive the event as aversive. However, when the identical study was done in an MRI scanner something far more interesting was detected. The act of social rejection actually brought about an increase in the activity of brain structures known to mediate the physiological response to pain (Eisenberger, 2011; Kross et al., 2011). Just as pain is a response to remove the organisms away from a noxious stimulus, the aversive feelings associated with social rejection represent a personal alarm alerting one that their status within the group may be compromised and motivates the individual to rebuild and reconnect social relationships (Cacioppo and Patrick, 2009). In this way evolutionary processes are able to exploit an already on-line system that is fully capable of detecting and avoiding threats. Accordingly, knowledge regarding primitive neurobehavioral processes (e.g., pain, thirst) can provide important insights into higher level processes such as empathy that operate through an elaboration of these evolutionary ancient and highly effective survival mechanisms.

7. Empathy as an adaptive response

Empathy is dependent upon various social and contextual factors that moderate its induction and expression. It would not be adaptive to respond with care and to extend one's empathic concern to all. As mentioned above, rodents do not react

indiscriminately to other conspecifics in distress (Langford et al., 2010). Recent neuroimaging studies with human volunteers have indicated that the neural network implicated in empathy for pain is modulated by various social and interpersonal factors. For instance, one fMRI study demonstrated that empathic arousal is moderated early in information processing by a priori attitudes toward other people (Decety et al., 2009). Study participants were significantly more sensitive to the pain of individuals who had contracted AIDS as the result of a blood transfusion as compared to individuals who had contracted AIDS as the results of their illicit drug addiction (sharing needles), as evidenced by significantly higher pain and empathy ratings and significantly greater hemodynamic activity in areas associated with pain processing (i.e., AIC, aMCC, PAG). Furthermore, activity in the pain matrix network is enhanced when people viewed their loved-ones in pain compared to strangers (Cheng et al., 2010), reduced if the person in pain has been unfair in a prior interaction (Singer et al., 2006) or are from a different ethnic group (Xu et al., 2009). Another neuroimaging study demonstrated that the failures of an in-group member are painful, whereas those of a rival out-group member gives pleasure – a feeling that may motivate harming rivals (Cikara et al., 2011). Empathic arousal is also modulated by an individual's knowledge and experience with pain. Two neuroimaging studies directly investigated how physicians react to the perception of others' pain. One study compared the neuro-hemodynamic response in a group of physicians and a group of matched control participants while they viewed video clips depicting face, hands and feet being pricked by a needle (painful situations) or being touched by a Q-tip (non painful situations) (Cheng et al., 2007). The results demonstrated activation of the pain matrix in the controls when they attended to the painful situations relative to the non-painful ones. A different pattern of signal change was detected in the physicians when they watched painful procedures. Cortical regions underpinning executive functions (dorsolateral and medial prefrontal cortices) and executive attention (precentral gyrus, superior parietal sulcus and temporo-parietal junction) were found to be activated, and unlike in the control group, no signal increase was detected in the pain matrix. A second study recorded event-related potentials (ERP) from physicians and matched controls as they were presented with the same visual stimuli (Decety et al., 2010). The results showed early N110 differentiation between pain and no pain, reflecting negative arousal, over the frontal cortex, as well as late P300 over the centro-parietal regions in control participants. In contrast, no such early ERP response was detected in the physicians. Thus, incoming sensory information is constrained by appraisal and reappraisal, processing, which may be unconscious or conscious, and shapes the emergence of the experience of empathy and behavioral outcomes. The dampening of "state" reactivity influences the availability of higher brain structures involved in regulating behaviors.

8. Conclusions

Empathy is not an all or none phenomenon, nor is it automatic or reflexive, as many social and contextual factors affect its induction and expression. It stems from evolutionarily ancient subcortical mechanisms (e.g., brainstem and hypothalamic circuitries) associated with affective sensitivity, attachment and parental care of young (Tucker et al., 2005). As discussed above, empathy-related behaviors have co-opted more primitive homeostatic processes involved in reward and pain systems in order to facilitate various social attachment processes. One salient example of the evolutionary representation of neurobiological function can be seen in the relationship between the neuropeptide oxytocin and mammalian social behavior (Box 3). This evolutionary perspective is compatible with Panksepp's nested brain-mind hierarchies

Box 3. Neuropeptides and empathy-related behaviors

Oxytocin is a nine amino acid peptide primarily synthesized in hypothalamic neurons and transported down axons of the posterior pituitary for secretion into blood. Oxytocin is also secreted from a few other tissues, including the ovaries and testes. Receptors are found in many limbic structures such as the amygdala and reward pathways (nucleus accumbens and ventral pallidum). Oxytocin has a genetic lineage extending millions of generations (Donaldson and Young, 2008) and is expressed in the brains of social organisms ranging from fish to humans (Carter and Porges, 2011). Moreover, it has been suggested that oxytocin is related to the phylogenetic emergence of distinct systems including the primitive immobilization system (the unmyelinated vagus), intermediate mobilization system (sympathetic system) and the most recently developed social engagement system (the myelinated vagus) (Porges, 1998).

Oxytocin was originally described within the context of mother-child interaction as this hormone is intricately involved in lactation and uterine contractions. Furthermore, oxytocin and the highly related neuropeptide vasopressin have been shown to be intricately involved in the social bonds of the monogamous prairie vole (Carter and Porges, 2011). For example, adult female prairie voles that over express oxytocin receptors within the nucleus accumbens display accelerated partner preference following interactions with a male (Ross et al., 2009).

Recently it has become apparent that oxytocin is involved in a myriad of social processes, including empathy and concern, that range beyond child-infant interactions. Indeed, while oxytocin and related neuropeptide systems are thought to have originally developed to facilitate basic maternal behavior, their function has been commandeered by various systems associated with the processing of complex social behaviors, including empathy (Hurlemann et al., 2010). Oxytocin seems to enable animals to overcome their natural avoidance of proximity and to inhibit defensive behavior, thereby facilitating approach behavior, which is critical to trigger empathy-related behaviors such as concern. Similar effects are have been documented in humans too. For instance, intranasal administration of oxytocin, compared to placebo, reduces emotional arousal to threatening human stimuli (Norman et al., 2011) and modulates the amygdala-brainstem coupling that is characteristic of automatic fear responses (Kirsch et al., 2005). Two studies showed that intranasally administered oxytocin increases the detection of subtle affective facial expressions (Domes et al., 2007) and improves empathic accuracy (Bartz et al., 2010). Furthermore, there is evidence that a naturally occurring genetic variation of the oxytocin receptor relates to perceived social isolation, empathy and stress profiles (Rodrigues et al., 2009; Lucht et al., 2009; Norman et al., 2012b). Similarly, a recent study suggests that variations in the human oxytocin receptor are related to general pro-social temperament in association with basic functional and structural alterations in limbic structures associated with motivated behavior and social interaction (Tost et al., 2010).

(Panksepp, 2011), which posits that similar to other mammalian species, human emotions may spread across conspecifics, and at times these shared emotions may facilitate empathic concern, which promotes pro-social behaviors and altruism. Primary emotional processes, where sources of empathy may arise (i.e., feeling what other organisms are feeling), coordinate with secondary-process learning and memory mechanisms (i.e., knowing what others are feeling). Both of these then interact with higher mental processes, which can exert a variety of top-down influences on the regulation of empathic tendencies (i.e., desires to respond compassionately to others' distress). Once the empathic capacity evolved, it came to be expressed outside the parental-care context

(De Waal, 2008). For instance, when people send money to distant earthquake victims in Haiti, or petition to support a bill that would contribute to curb the violence in Darfur, empathy reaches beyond its evolutionary origins, extending beyond inclusive fitness among kin and social group members. Along with enculturation, the development of empathy and caring is then further assisted by domain-general and high-level cognitive abilities such as executive functions, theory of mind, rational cognition, and language, which combine to expand the range and the scope of empathically driven behavior. Furthermore, the development of human empathy across history may have been facilitated by advancements and innovations from our past. Singer (1986) proposed that over the course of history, people have enlarged the range of beings whose interests they value as value their own. One of the mechanisms argued to contribute to the inflation of one's empathy circle is the expansion of literacy during the humanitarian revolution in the 18th century, where reading was increasingly used as a technology for perspective-taking (Pinker, 2011). Notably, Pinker puts forward this idea that in the epistolary novel, the story unfolds in a character's own words, exposing the character's thoughts and feelings in real time rather than describing them from the distancing perspective of a disembodied narrator.

Overall, the evolutionary conceptual view of empathy that we have developed in this paper is compatible with the hypothesis that advanced levels of social cognition have arisen as an emergent property of powerful executive functioning assisted by the representational properties of perspective taking, language, and executive functioning (Barrett et al., 2003). However, these cognitive functions are likely to rely and interact with pre-existing neural circuits already possessing suitable resources. Similar neurobiological mechanisms that regulate parental behavior, attachment, and affective processing in all mammals interact with newer cortical systems shaped by social, cultural and educational contexts to produce the flexible and generalized forms of nurturant care found among humans. These evolutionary newer developments help explain why humans care not only for their offspring but for strangers, and why they are motivated to uphold moral principles such as justice and fairness (Batson, 2011).

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