BEHAVIOR

Empathy and the Laws of Affect

Can animal models provide insights into human empathy and promote nurturance?

Jaak Panksepp

There is a growing recognition of how animals respond to the affective states of other animals (*1*, *2*), including the show of empathy, a state once thought to be unique to primates. On page 1427 of this issue, Ben-Ami Bartal *et al*. (*3*) demonstrate that captive rats controlled experiments act prosocially to help other rats, even when they receive no explicit social rewards. This raises questions about the affective experiences of animals other than humans.

Ben-Ami Bartal *et al*. allowed rats to learn to free physically restrained cage-mates. This would have been less impressive if the rats' actions had just resulted in a social reward (*4*), such as gaining the opportunity to interact with the freed rats. However, the rats released their cage-mates even when further social contact was precluded, or when their preferred food items, such as chocolate, were shared (rather than hoarded) with those they had liberated.

A key question concerns the nature of the rats' motivations—the affective and cognitive underpinnings of their "empathy." It is unclear whether the rats sympathize with the distress of their cage-mates, or simply feel better as they alleviate the perceived distress of others. Nor is it known whether they perceive the freedom of another rat to be a positive affective resource. Such empathy could arise from cortical mirror-neuron systems that allow humans and animals to understand others' emotions (*5*), or it could arise from more primal neuronal networks that guide positive social relations (*6*). Also unclear is whether simpler processes such as nonempathic secondary social rewards (*4*) were ruled out by simply separating animals during the tests. Behaviorists may wonder whether such behavioral choices may even proceed "mindlessly," with no need to consider the role of neuro-affective processes.

Future research needs to untangle whether empathic responses in mammals arise more from higher cognitive or lower affective brain functions, or some combination of these (see the figure). Human brain imaging studies of empathy suggest both are involved (*7*, *8*), especially in coping with the distress of others (*9*, *10*). But solid neurobiologically based evolutionary evidence, both bottom-up and top-down, is so far lacking.

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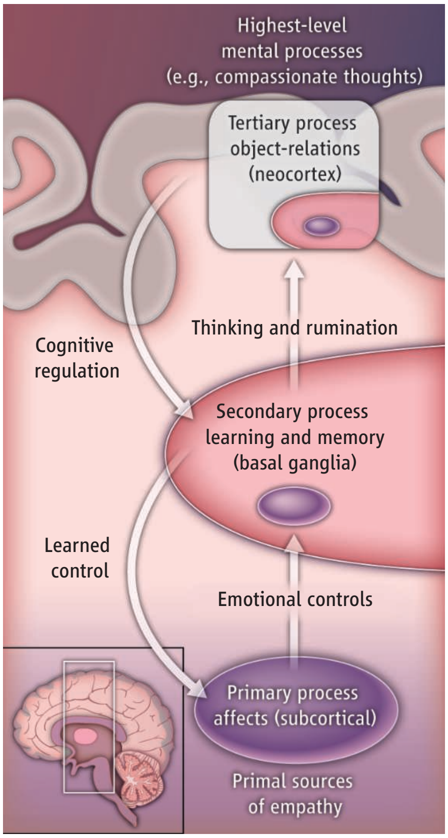

Nested brain-mind hierarchies. One concept of how mammalian brains generate empathic responses at different levels is shown. Primary emotional processes, where sources of empathy may arise (i.e., feeling what other organisms are feeling), coordinate with secondary-process learning and memory mechanisms (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).

To illuminate how empathy is constituted in mammalian brains requires understanding the affective infrastructure of animal minds (*6*). There remains a huge resistance against accepting that nonhuman animals have affective experiences, and that these can and should be studied in empirical ways (*6*, *11*). However, recent advances in cross-species functional neurosciences are allowing investigation of a variety of affective states that control learning, memory, and behavioral choices (*12*). Studies of empathy in mammals are among the most subtle exemplars of the changing zeitgeist (*1*–*3*), as prevailing attitudes are transformed by new evidence.

Behavioral scientists have long relied on the "law of effect" to describe how "rewards" and "punishments" control learning: Behaviors followed by rewards increase, whereas those followed by punishments decrease. But such rewards and punishments are more than objects in the outside world; they can change affective brain dynamics (*6*, *11*, *12*). Thus, we can envision "laws of affect" whereby primal "feeling networks" of the mammalian brain guide secondary-process associative learning and memory mechanisms. Perhaps changes in emotional states promote the functions of brain neurotransmitter receptors that transform "silent synapses" into fully responsive mediators of emotional learning.

The willingness of some mammals to help others might depend upon brain mechanisms that generate psychological pain engendered by perceiving the distress of others (*6*). Neurochemical candidates range from endogenous opioids to oxytocin (*4*, *6*). Empathic tendencies might be changed under the influences of such prosocial neurochemistries as well as various affectively negative neurochemicals, from cholecystokinin to corticotrophin releasing factor, that may also modulate the affects that underlie empathic urges.

The layering of evolutionary progressions is evident in the human brain (*6*, *12*). The deepest midbrain and hypothalamic regions mediate primary-process, instinctual affects. More recently evolved subcortical regions, among them basal ganglia, amygdala, and nucleus accumbens, help promote higher cognitive activities through learning and memory. Although we currently look to mirror-neuron zones of the neocortex for evidence of the highest mind functions such as compassion (*5*, *7*), empathic tendencies are surely also promoted by the more ancient primary-process emotional networks that are essential foundations for mental life. For example, a primal form of "empathy" is mothers' exquisite sensitivity to crying babies. Might crying access those systems in mothers' brains that are known to medi-

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ate separation anxiety in young animals (*6*)? Perhaps affective urges for maternal caregiving are triggered as mothers' brains experience psychological pain engendered by their infants' cries. It may be that empathic coordination of social motivations is mediated by emotional resonances among nearby animals, allowing receivers to experience the emotions of transmitters. At such deep affective levels, emotional states may reverberate among animals, with no need for learned re-representations arising from mirror neurons. Mammals may have intrinsic abilities to resonate with the pains and joys of nearby others through primal emotional contagion.

Much deep-brain research remains to be done to understand the degree to which mammalian empathy is achieved more through higher social-cognitive processes or primal affective processes in the brain. Simplified models of empathy, as in mice and rats, offer new inroads for understanding our own social-emotional nature and nurture. Such knowledge may eventually help us promote nurturant behaviors in humans.

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MATERIALS SCIENCE

Complex Colloidal Assembly

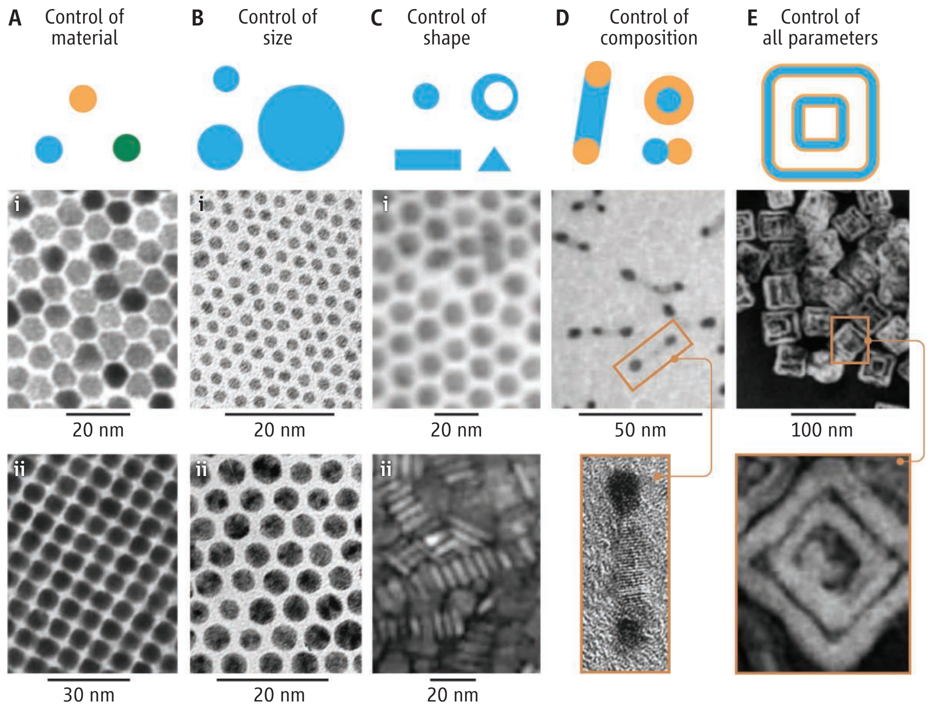
A colloidal chemistry approach is used to fabricate complex three-dimensional objects on the nanometer scale.

Wolfgang J. Parak

Since the popularization of nanotechnology almost two decades ago, the public has been fascinated by the prospect of a "nano-assembler" for the construction of complex three-dimensional (3D) objects. Such a device would assemble objects atom-by-atom or molecule-by-molecule. Indeed, small objects have been assembled on a 2D surface by picking up individual atoms and molecules with the tip of a scanning tunneling microscope or an atomic force microscope, respectively (*1*, *2*). However, it is not only the action of gripping an object that presents a challenge, but also its release at the designated position. The Nobel laureate Richard Smalley described this as a problem of "sticky fingers" (*3*). There is, however, an alternative approach for bottom-up assembly on the nanometer scale that originates from colloidal chemistry. On page 1377 of this issue, González *et al*. (*4*) report on the synthesis of complex 3D colloidal nanoparticles, a route that may circumvent the problem of the sticky nano-finger.

In colloidal chemistry, 3D objects are formed by self-assembly of atomic or molecular precursors (crystallization). Although this is a parallel approach that allows for producing many objects, the complexity of such objects so far has been limited; the degrees of freedom to design the structure and composition of the object were relatively low. In contrast, González *et al*. demonstrate the complexity with which colloidal nano-objects can be synthesized, how colloidal nanoparticles (NPs) are formed, and how their geometry and composition can be designed.

Colloidal NPs are self-assembled in solution by nucleation and further growth of atomic or molecular precursors. Different precursors will obviously lead to NPs made of different materials (see the figure, panel A). Size uniformity, achieved through the interplay of van der Waals forces and surface tension, can be externally controlled



Putting it together. **(A)** Nanoparticles (NPs) can be synthesized out of different materials, such as (i) CdSe (*10*) and (ii) FePt (*8*). **(B)** The size of the NPs can be controlled, such as for Au NPs with diameters of (i) 4.5 nm and (ii) 9.6 nm (*7*). **(C)** NPs can be made with different shapes, such as (i) disk-shaped and (ii) spherical Co NPs (*11*). **(D)** NPs can also be synthesized with defined domains of different materials, such as CdSe nanorods with spherical Au on their tips (*14*). **(E)** Control of all parameters leads to complex objects, such as the Ag/Au NP composites demonstrated by González *et al*.

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