# Social Neuroscience: Complexities to Be Unravelled

*Donald Pfaff*[1] and *Ralph Adolphs*[2]

## Summary

The use of hormone actions to help unravel brain mechanisms for behavior has led to several striking successes in analyzing neural circuits and cellular mechanisms for social behaviors. This success has prompted us to look forward and speculate about the essential nature of the most complex social behaviors. We propose that there are several aspects that distinguish social neuroscience from neuroscience more generally. One notion is that the nature of human social behavior is qualitatively different from that of any other species and was perhaps a key driving force behind the evolution of the human mind and brain. Other speculations involve the normative aspects of social behaviors, both prosocial and antisocial. Bringing complex social behaviors into the laboratory for systematic analysis will pose one of the major challenges for experimenters in our field.

## Introduction

Science usually proceeds from the simple to the complex. In neuroscience, for example, some of the most brilliant forays of the last century involved discovering the stimulus properties of neuronal response requirements in the visual system, by David Hubel and Torsten Wiesel, and in the somatosensory system, by Vernon Mountcastle. On the subject of motor response regulation, the spinal cord reflexology of Charles Sherrington followed by the synaptologic analyses of John Eccles would provide two of the most famous illustrations. An extremely simple social behavior, lordosis behavior, was explainable both in terms of neural mechanisms and in terms of functional genomics, in part because of its hormonal dependency (Pfaff 1999). Then, without discarding any of these ambitions regarding stimulus processing and motor control, scientists have made considerable progress analyzing *states* of the CNS. Thus, mechanisms underlying stress (McEwen 2007), sleep/wake cycles (McCarley 2007), circadian biology (Young and Kay 2001) and fundamental brain arousal (Pfaff 2006) have been investigated. We note that these state changes are of considerable importance to medicine and public health, having implications for a variety of mood disorders and for cognitive functions

[1] The Rockefeller University Box 275, Department of Neurobiology and Behavior, 1230 York Avenue, NY 10021-6399 New York, USA, e-mail: pfaff@rockefeller.edu
[2] California Institute of Technology, 331B Baxter Hall, CA 91125 Pasadena, USA

Pfaff et al.
Hormones and Social Behavior

involving attention. In all these cases, wherever there is a hormone dependency, the use of our knowledge of the molecular mechanisms of hormone action makes progress easier.

Now, using the hormonal dependencies revealed by chemical endocrinology and molecular endocrinology whenever possible, neuroscientists are attacking problems having to do with complex social behaviors, that is, they are invading territory that formerly concerned social psychologists. In fact, a journal, Social, Cognitive and Affective Neuroscience (SCAN), is entirely devoted to such research. These scientific developments seem somewhat amazing because of the astounding complexity of such behaviors. Chains of responses by two animals might be represented by quantitative

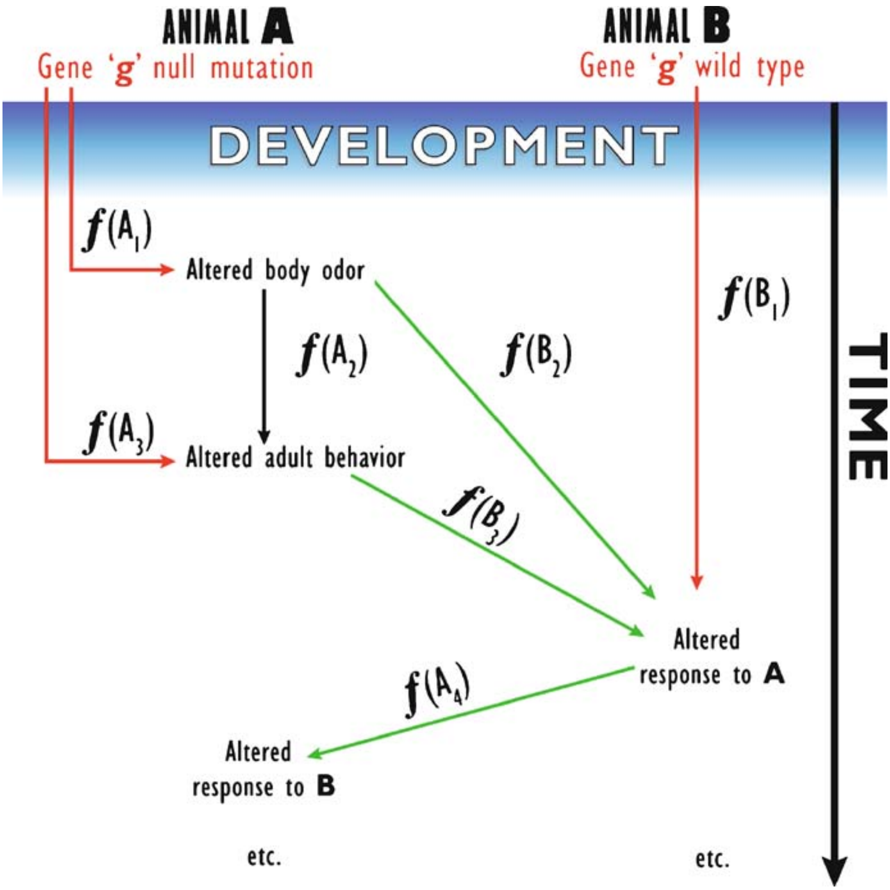


**Fig. 1.** Genomic effects on social behaviors are potentially complex in the extreme. If we think of just the fragment of an example sketched above quantitatively, as an equation, then it would be composed of at least seven functions, four for animal A and three for animal B. Are these functions multiplicative? Exponential? Note that Kavaliers et al. (2004) have shown that some of the behavioral dynamics of the estrogen receptor-alpha knockout mouse are due to its altered body odors – its properties as an olfactory stimulus to the other animal in the dyad

functions in which the two sets of behaviors are multiplicative or even exponential functions of each other. Indirect routes of causation abound. For example, when we talk about gene/behavior relations, we usually are considering that gene's impact on nerve cells in the relevant neural circuits of the very animal in which the gene has been altered. However, one recent paper (Kavaliers et al. 2004) indicates that removal of an estrogen receptor gene alters the stimulus properties (odors) of the knockout animal, thereby affecting the behavior of other mice (Fig. 1). Further aspects of the complexities of gene/behavior relations – applying to simple behaviors as well as to social behaviors – include pleitropy of gene action, redundancies of functions among different genes, and the incomplete penetrance of some dominant genes. These are illustrated in Fig. 2.

With respect to positively valenced social behaviors, we would stand, as did Claude Kordon (this volume), with the renowned evolutionary biologist Ernst Mayr, who considered sexual behavior to be at "the leading edge of evolutionary change." Mating behavior sets the *bauplan*, the initial organizing structure, for a variety of social behaviors and has been the subject of extensive neural, endocrine and genomic research (Pfaff 1999). With respect to negatively valenced behaviors, mechanisms for learned fear have been analyzed (LeDoux 2000) and have emphasized the crucial participation of nerve cells in the lateral amygdala.

In this brief chapter, we would like to take the opportunity to consider whether there are any unique, abstract issues that we will face, as special problems or opportunities, as we continue to study mechanisms for social behaviors in animals and humans. Is current work in social neuroscience just one more example of lab science pushing into domains that used to be part of the humanities or social sciences? We think not.

## The Social Brain

We propose that there are several very interesting aspects that distinguish social neuroscience from neuroscience more generally. One notion is that the nature of human social behavior is qualitatively different from that of any other species and was perhaps a key driving force behind the evolution of the human mind and brain; so, the social aspects might be a lot of what make humans different from other species.

The "social brain hypothesis" has argued that the expansion of the human brain and the cognitive capacities that have resulted were driven by the need to adapt to an environment that was becoming more socially complex (Byrne and Whiten 1988; Dunbar 1998; Dunbar and Shultz 2007a). Precisely what it is about social behavior that makes it more complex and in need of more substantial cognitive capacity, and what it is about the brain whose evolution can adapt to this challenge, are still matters of some debate (Healy and Rowe 2007). There is good evidence for a correlation between neocortex volume, in particular, and the size of social groups; but social group size has been argued, on the basis of detailed path analyses, to be a proxy for "social group complexity," which is defined as the number and kind of social relationships that an individual must keep track of to successfully negotiate social transactions in its group (Dunbar and Shultz 2007b). While it seems clear that many or most brain regions must evolve in tandem to support any increase in one region in particular, sectors of the prefrontal cortex have received the most attention, as that region of the brain has

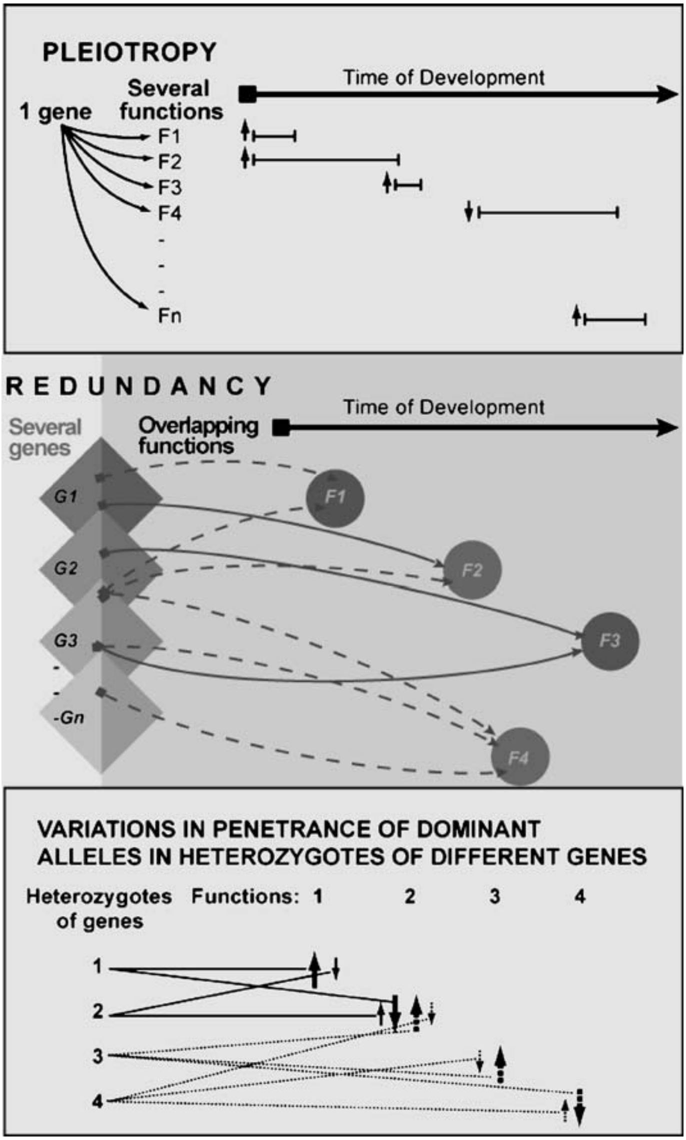


**Fig. 2.** Some of the reasons for complexity in gene/behavior relationships have to do with pleiotropy, redundancy and incomplete expression of dominant genes in heterozygotes (adapted from Pfaff 2001)

expanded the most specifically in human evolution. Prefrontal cortex as a whole is not larger in humans than it is in the great apes (relative to whole brain size; Semendeferi et al. 2002), but very anterior regions within it (Semendeferi et al. 2001), as well as white matter interconnecting its diverse sectors (Schoenemann et al. 2005) do seem to have expanded disproportionately in human evolution. Moreover, much of the expansion of the human brain has occurred quite recently in evolution. We assign importance to this expansion being coupled to the highly altricial (developing over a long period of time, and late developing) brain that human neonates have compared to those of other primate species (Coqueugnlot et al. 2004).

A related point of great public importance is that understanding the neural underpinnings of human social behavior has the potential to address what are arguably the most pressing issues for the future survival of our species. A pressing case concerns intergroup conflict. The most devastating examples would be instances of attempted genocide. Even during the relatively short time since the Holocaust, there have been five cases: Kosovo, Rwanda, Somalia, Cambodia and Darfur. Scientists may, in the future, be able to understand what is going on in such cases and may help in learning how to prevent such man-made disasters.

On the other hand, we all are aware of examples in which people have acted entirely unselfishly and helped others, at times with great danger or loss of life to themselves. In fact, one of us has argued that our brains are "wired for altruism" (Pfaff 2007). Such exemplary pro-social behavior appears to be exactly at the opposite end of the spectrum from the conflicts mentioned above that often make the headline news, but how can it be explained? Concerning perhaps one of the most exciting areas in social science and social neuroscience, several theoretical reasons have been given as to why non-reciprocally altruistic behaviors might evolve (Nowak and Sigmund 2005) and how the altruistic behaviors of even a small number of individuals could spread in a society and render it better adapted (Gintis et al. 2003). Aspects of prosocial behavior are now being investigated with techniques ranging from functioning neuroimaging (deQuervain et al. 2005) to pharmacology (Kosfeld et al. 2005). The mechanisms that would enable such behaviors are precisely the ones that would contribute to the "social complexity" factor we noted above and that would have contributed to the evolution of cognitive abilities and brain regions that could subserve them.

Social neuroscience looks at issues that are very important to us from a normative point of view, assigning positive or negative evaluations on any given set of acts. Since we are such an intensely social species, often living in crowded environments, the morality of our behaviors towards each other takes on overwhelming importance. One person living alone in a forest does not have such problems, but we presently are living in times when a very small number of people can do harm to a very large number of people. The psychological and neural underpinnings of moral judgment and moral reasoning are intense topics of recent research (Hauser 2006; Moll et al. 2005), as reviewed in Hauser's chapter in this volume. How to study actual moral behavior in an ecologically valid setting remains a challenge.

## Social Experience Driving High Levels of Self Awareness?

A final point would be very speculative: that ultimately an understanding of how social information is processed in the brain will also yield insight into the nature of conscious experience. At least it seems plausible that much of the nature of human conscious experience depends on being embedded in a complex social environment. Consider that the tremendous expansion of the human cerebral cortex permits a human to use large numbers of facial muscles to express emotions and to emit grammatical speech, and correspondingly our powerful cortex leads to the human receiver's ability to recognize emotional expressions and to understand speech. In these ways, our social communication is associated with our highest nervous and mental capacities. It is notable that neurologists use the ability of a patient to initiate social communication and to respond to social signals as a sign that the patient has emerged from a vegetative state into a conscious state (Posner et al. 2007; Schiff et al. 2007).

While conscious experience remains one of the most difficult phenomena to approach scientifically, amounting to one of the "hardest" problems in science, it is also true that we can observe intriguing correlations between the richness (or even the presence) of conscious experience and social behavior. To make any such correlations causal, we will need to know much more about the processes and the neural structures that underlie both conscious experience and social cognition. There are some leads. Consider, for instance, the finding that similar network of brain structure is engaged when we construct episodic thoughts (either about our autobiographical past or the imagined future) and when we engage in self-referential thinking of any kind (Buckner and Carroll 2007). This network is also likely engaged when we think about the minds of other people. One direction in which the causality could run is from social to conscious experience. This idea would propose that complex social behavior promoted the evolution of higher cognitive functions required for large and episodic memory stores, for counterfactual and recursive thinking, in short, for outsmarting others, and that this collection of cognitive abilities provided much of the content, if not the state/level, of human conscious experience. But one could also see the causal chain running in the other direction. One strategy by which it is thought that humans figure out what other people believe and intend to do is by simulating aspects of what is going on in their minds at a conscious level. "Simulation" theories of how we predict and interpret other people's behavior seem to put emphasis on the simulation engaging conscious experience (although this is usually not made explicit in the theories), for instance in the form of conscious experiences of emotion when we empathize with another person we observe to be in pain (Singer et al. 2004). In summary, social cognition may have enabled (aspects of) the nature of human conscious experience or conscious experience may have enabled (e.g., simulation aspects of) social cognition.

All of these issues are extremely "high-level" in the sense that they are difficult to investigate experimentally in the laboratory. Self awareness and consciousness are hard subjects. We can make a start by defining and assaying generalized CNS arousal and working on its cellular and molecular mechanisms (Pfaff 2006). Beyond this humble start, certainly, the more abstract among these questions are the ones that neuroscience is barely beginning to study. We feel, however, that eventually they will be seen to be grounded in, and require a detailed understanding of, neuroscientific mechanisms. We expect that these mechanisms serve the more basic aspects of emotional and social information processing in humans, as well as aspects of emotional and social information processing in other animals. Indeed, there are now a number of findings showing the effects of specific neurotransmitters on social cognition (Chiavegatto et al. 2001; Clarke et al. 2004; Harmer et al. 2003; Kosfeld et al. 2005), the engagement of structures involved in emotion and reward processing (deQuervain et al. 2005; Eisenberger et al. 2003; Singer et al. 2006), and even the influence of specific genes (Good et al. 2003; Pezawas et al. 2005). The key question will be how these more basic mechanisms, taken together, can add up to and explain the full richness of social cognition.

## Outlook

While some of the most solid work on mechanisms of social behaviors in animals and humans has made clever use of hormone actions on nerve cells, the very success of such neuroendocrine experiments on simple behaviors encourages speculations about the essential nature of still more complex social behaviors. As a result of such speculations, we do not consider that social neuroscience is just like neuroscience more generally, only more complex. Instead, it is distinguished qualitatively by giving special insight into how we (and other species) evolved, how we may survive as a species in the future, and how we experience the world. It remains an important challenge for future investigations to carve out precisely which domain, at the process level, is at the core of "social cognition," or which domains social cognition is most related to. There are certainly some abstract, and complex, operations that social cognition shares with other cognitive domains: for instance, recursion is a feature both of complex social interactions and language; causal reasoning may be related to complex tool use (Johnson-Frey 2003) and to counterfactual reasoning; and domains like language and social behavior may be related in other ways as well, such as that shared language influences social group membership (Kinzler et al. 2007). As we noted above, an intriguing recent observation is that there appears to be a common neutral substrate for self-reflective thought, for reasoning about other people's minds, and for retrospective and prospective episodic thinking (episodic memory and episodic future planning and anticipation; Buckner and Carroll 2007). All these abilities are certainly "complex" in some sense, requiring high-level inferential and counterfactual thinking (Gilbert and Wilson 2007), and it is intriguing to speculate that they might be related and perhaps driven by the need to be able to track and predict complex social interactions.

This book began at a high integrative level by considering prosocial, moral behavior as a natural product of the human mind and by presenting experimental data on trust and altruism shown by human subjects Then, brain mechanisms were analyzed in reductionistic experiments with animals, including hormones, neurotransmitters and neuropeptides. As far as antisocial behavior is concerned, we recognize that pathologies of social behavior abound. Some of the best-understood pathologies have to do with the human amygdala and the prefrontal cortex. We rush to acknowledge that not all causes of abnormal social behavior, such as violence are, ab initio, derived from the offender's central nervous system; humiliation of young men by huge disparities of wealth, mistreatment of children during critical periods such as the neonatal and pubertal periods, rendering children anonymous by virtue of overwhelmingly large schools and failing to provide children with positive visions of their roles in society all can play a part (Devine et al. 2004). This volume, however, is limited strictly to biological considerations, even while realizing that they are not the entire story. These chapters give multiple examples of the intimate relations between alterations in hormone levels and alterations in social behaviors.

In terms of public health, the most important aspects of hormones and social behaviors will deal with attempts to reduce the most damaging aspects of human behavior. Two structures linked to pathologies of social behavior, the amygdala and prefrontal cortex, are known to be involved in aspects of emotion processing: the amygdala in Pavlovian fear conditioning (LeDoux 2000) and in mediating emotional autonomic responses (Chapman et al. 1954) and the prefrontal cortex in aspects of autonomic response as well as in emotion regulation and self-control (Beauregard et al. 2001; Ochsner et al. 2002). There is even evidence at the circuit level implicating the prefrontal cortex in regulating the amygdala's participation in emotion processing (Jackson and Moghaddam 2001) as well as conversely (Garcia et al. 1999). Both structures are also well known to participate in social behavior. In the case of the prefrontal cortex, the classical case of Phineas Gage (Damasio et al. 1994) and modern lesion studies showing the critical role of this region in social decision-making (Damasio 1994) and moral judgment (Koenigs et al. 2007) are clear examples. In the case of the amygdala, the story is somewhat more subtle; it is clearest for recognizing social cues such as certain emotions ( Adolphs et al. 1994) or trustworthiness ( Adolphs et al. 1998) from viewing faces. It is interesting to note that, at least in the case of the amygdala, the basic mechanisms that seem to explain impaired social perception may not be specifically social at all but rather reflect more abstract attentional mechanisms. For instance, the amygdala's role in recognizing emotional facial expressions appears to result from its role in assigning saliency to particular features within faces, notably the eyes (Adolphs et al. 2005), and this attentional role appears to extend to processing unpredictable and potentially salient stimuli that are not in any way social or emotional, such as unpredictable sequences of tones (Herry et al. 2007). These findings provide substantial detail about the mechanisms whereby certain brain structures participate in social cognition, but they bring us back to some of the questions we raised earlier: what is left of the domain specificity of social cognition? Is it comprised entirely of a collection of non-social processing modules? These are important open questions for the future.

## References

Adolphs R, Tranel D, Damasio H, Damasio A (1994). Impaired recognition of emotion in facial expressions following bilateral damage to the human amygdala. Nature 372:669–672

Adolphs R, Tranel D, Damasio AR (1998) The human amygdala in social judgment. Nature 393:470–474

Adolphs R, Gosselin F, Buchanan TW, Tranel D, Schyns P, Damasio AR (2005). A mechanism for impaired fear recognition after amygdala damage. Nature 433:68–72

Beauregard M, Levesque J, Bourgouin P (2001) Neural correlates of conscious self-regulation of emotion. J Neurosci 21(RC165):RC1–6

Buckner RL, Carroll DC (2007) Self-projection and the brain. Trends Cogn Sci 11:49–57

Byrne R, Whiten A (eds) (1988) Machiavellian intelligence: social expertise and the evolution of intellect in monkeys, apes, and humans. Oxford, Clarendon

Chapman WP, Schroeder HR, Geyer G, Brazier MAB, Fager C, Poppen JL, Solomon HC, Yakovplev PI (1954) Physiological evidence concerning importance of the amygdaloid nuclear region in the integration of circulatory function and emotion in man. Science, 120:949–950

Chiavegatto S, Dawson VL. Mamounas LA, Koliatsos VE, Dawson TM, Nelson RJ (2001) Brain serotonin dysfunction accounts for aggression in male mice lacking neuronal nitric oxide synthase. Proc Natl Acad Sci USA 98:1277–1281

Clarke HF, Dalley JW, Crofts HS, Robbins TW, Roberts AC (2004) Cognitive inflexibility after prefrontal serotonin depletion. Science 304:878–880

Coqueugnlot H, Hublin J-J, Vellon F, Houet F, Jacob T (2004) Early brain growth in Homo erectus and implications for cognitive ability. Nature 431:299–232

Damasio AR (1994) Descartes' error: emotion, reason, and the human brain. New York, Grosset/Putnam

Damasio H, Grabowski T, Frank R, Galaburda AM, Damasio AR (1994) The return of Phineas Gage: clues about the brain from the skull of a famous patient. Science 264:1102–1104
de Quervain D-J, Fischbacher U, Treyer V, Schellhammer M, Schnyder U, Buck A, Fehr E (2005) The neural basis of altruistic punishment. Nature 305:1254–1258
Devine J, Gilligan J, Miczek K, Shaikh R, Pfaff D (eds) (2004) Scientific approaches to the prevention of youth violence. Ann NY Acad Sci 1036
Dunbar R (1998) The social brain hypothesis. Evol Anthropol 6:178–190
Dunbar RI, Shultz S (2007a) Evolution in the social brain. Science 317(5843):1344–1347
Dunbar RI, Shultz S (2007b) Understanding primate brain evolution. Philos Trans R Soc Lond B Biol Sci 362:649–658
Eisenberger NI, Lieberman MD, Williams KD (2003) Does rejection hurt? An fMRI study of social exclusion. Science 302:290–292
Garcia R, Vouimba R-M, Baudry M, Thompson RF (1999) The amgdala modulates prefrontal cortex activity relative to conditioned fear. Nature 402:294–296
Gilbert DT, Wilson TD (2007) Prospection: experiencing the future. Science 317:1351–1354
Gintis H, Bowles S, Boyd R, Fehr E (2003) Explaining altruistic behavior in humans. Evol Human Behav 24:153–172
Good CD, Lawrence K, Thomas NS, Price CJ, Ashburner J, Friston KJ, Frackowiak RS, Oreland L, Skuse DH (2003) Dosage-sensitive X-linked locus influences the development of amygdala and orbitofrontal cortex, and fear recognition in humans. Brain 126:2431–2446
Harmer CJ, Bhagwagar Z, Perrett DI, Vollm BA, Cowen PJ, Goodwin GM (2003) Acute SSRI administration affects the processing of social cues in healthy volunteers. Neuropsychopharmacology 28:148–152
Hauser MD (2006) Moral minds: how nature designed our universal sense of right and wrong. New York, Harper Collins
Healy SD, Rowe C (2007) A critique of comparative studies of brain size. Proc Roy Soc B 274:453–464
Herry C, Bach DR, Esposito F, DiSalle F, Perrig WJ, Scheffler K, Lüthi A, Seifritz E (2007) Processing of temporal unpredictability in human and animal amygdala. J Neurosci 27:5958–5966
Jackson ME, Moghaddam B (2001) Amygdala regulation of nucleus accumbens dopamine output is governed by the prefrontal cortex. J Neurosci 21:676–681
Johnson-Frey SH (2003) What's so special about human tool use? Neuron 39:201–204
Kavaliers M, Ågmo A, Choleris E, Gustafsson JA, Korach KS, Muglia LJ, Pfaff DW, Ogawa S (2004) Oxytocin and estrogen receptor alpha and beta knockout mice provide discriminably different odour cues in behavioural assays. Genes Brain Behav 3:189–195
Kinzler KD, Dupoux E, Spelke ES (2007) The native language of social cognition. Proc Natl Acd Sci USA 104:12577–12580
Koenigs M, Young L, Adolphs R, Tranel D, Cushman F, Hauser M, Damasio A (2007) Damage to the prefrontal cortex increases utilitarian moral judgments. Nature 446:908–911
Kosfeld M, Heinrichs M, Zak PJ, Fischbacher U, Fehr E (2005) Oxytocin increases trust in humans. Nature 435:673–676
LeDoux J (2000) Emotion circuits in the brain. Ann Rev Neurosci 23:155–184
McCarley R (2007) Neurobiology of REM and NREM sleep. Sleep Med 8:302–330
McEwen BS (2007) Stress; definitions and concepts. Encyclopedia of stress. Oxford, Elsevier
Moll J, Zahn R, de Oliveira-Souza R, Krueger F, Grafman J (2005) The neural basis of human moral cognition. Nature Rev Neurosci 6:799–809
Nowak MA, Sigmund K (2005) Evolution of indirect reciprocity. Nature 437:1291–1298
Ochsner K, Bunge SA, Gross JJ, Gabrieli JDE (2002) Rethinking feelings: an fMRI study of the cognitive regulation of emotion. J Cogn Neurosci 14:1215–1229
Pezawas L, Meyer-Lindenberg A, Drabant EM, Verchinski BA, Munoz KE, Kolachana BS, Egan MF, Mattay VS, Hariri AR, Weinberger DR (2005) 5-HTTLPR polymorphism impacts human cingulate-amygdala interactions: a genetic susceptibility mechanism for depression. Nature Neurosci 8:828–834

Pfaff D (1999) Drive. Cambridge, The M.I.T. Press
Pfaff D (2006) Brain arousal and information theory. Cambridge, Harvard University Press
Pfaff D (2007) The neuroscience of fair play. Washington, Dana Press
Posner J, Saper C, Schiff N, Plum F (2007) Plum and Posner's diagnosis of stupor and coma. 4th ed. Oxford, Oxford University Press
Schiff ND, Giacino JT, Kalmar K, Victor JD Baker K, Gerber M, Fritz B, Eisenberg B, O'Connor J, Kobylarz EJ, Farris S, Machado A, McCagg C, Plum F, Fins JJ, Rezai AR (2007) Behavioral improvements with thalamic stimulation after severe traumatic brain injury. Nature 448:600–603
Schoenemann PT, Sheehan MJ, Glotzer LD (2005). Prefrontal white matter volume is disproportionately larger in humans than in other primates. Nature Neurosci 8:242–252
Semendeferi K, Armstrong E, Schleicher A, Zilles K, Van Hoesen GW (2001). Prefrontal cortex in humans and apes: a comparative study of area 10. Am J Phys Anthropol 114:224–241
Semendeferi K, Lu A, Schenker N, Damasio H (2002) Humans and great apes share a large frontal cortex. Nature Neurosci 5:272–277
Singer T, Seymour B, O'Doherty J, Kaube H, Dolan RJ, Frith CD (2004) Empathy for pain involves the affective but not sensory components of pain. Science 303:1157–1162
Singer T, Seymour B, O'Doherty J, Stephan KE, Dolan RJ, Frith CD (2006) Empathic neural responses are modulated by the perceived fairness of others. Nature 439:466–469
Young MW, Kay SA (2001) Time zones: a comparative genetics of circadian clocks. Nature Rev Genet 2:702–15