Reviews in the Neurosciences, 14, 303-316 (2003)

The Human Amygdala: An Evolved System for Relevance Detection

David Sander[1], Jordan Grafman[2] and Tiziana Zalla[3]

[1]*Geneva Emotion Research Group, Psychology Section, University of Geneva, Geneva, Switzerland,*
[2]*Cognitive Neuroscience Section, NINDS, National Institutes of Health, Bethesda, MD, USA and*
[3]*Institut des Sciences Cognitives, Bron, France*

SYNOPSIS

Evidence from pioneering animal research has suggested that the amygdala is involved in the processing of aversive stimuli, particularly fear-related information. Fear is central in the evolution of the mammalian brain: it is automatically and rapidly elicited by potentially dangerous and deadly events. The view that the amygdala shares the main characteristics of modular systems, e.g. domain specificity, automaticity, and cognitive impenetrability, has become popular in neuroscience. Because of its computational properties, it has been proposed to implement a rapid-response 'fear module'. In this article, we review recent patient and neuroimaging data of the human brain and argue that the fundamental criteria for the amygdala to be a modular system are not met. We propose a different computational view and suggest the notion of a specific involvement of the human amygdala in the appraisal of relevant events that include, but are not restricted to, fear-related stimuli. Considering the amygdala as a 'relevance detector' would integrate the 'fear module' hypothesis with the concept of an evolved neural system devoted to the processing of a broader category of biologically relevant stimuli. In primates, socially relevant events appear to have become, through evolution, the dominant elements of the amygdala's domain of specificity.

Accepted: 8 May, 2003

Reprint address:
Tiziana Zalla
Institut des Sciences Cognitives
67, boulevard Pinel
69675 Bron cedex, France
e-mail: zalla@isc.cnrs.fr

KEY WORDS

social cognition, emotion, appraisal, evolutionary psychology, temporal lobe, human brain

PURPOSE AND OVERVIEW

The study of the functions of the amygdala has exploded during the so-called 'decade of the brain'. During this period many new anatomical and functional findings about the amygdala have been obtained (see /10,11/). A marker of this interest is that numerous reviews on the amygdala have been published; these articles include reviews highlighting the amygdala's contributions to emotion /3,27,73/, vigilance-emotion relationships /34,100/, memory /46,63,76/, attention /51/, fear conditioning /26/, reward-based learning /18/ and social cognition /2,4,13/. In the present review, we challenge one of the major features of the current theories of the human amygdala by proposing a different hypothesis about its computational profile and domain of specificity. In order to do so, we adopt a perspective that takes into account data from cognitive neuropsychology and functional brain imaging in humans. After a short presentation of the dual route architecture in which the amygdala is involved, we show that the definition of the amygdala's specific domain of processing is highly controversial and propose a perspective that may help to resolve this debate.

A DUAL ROUTE ARCHITECTURE TO THE AMYGDALA

Pioneering animal studies have provided an important contribution to the understanding of the anatomical and functional structure of the amygdala. The primate amygdala is an almond-shaped

nuclear complex composed of at least 13 nuclei located in the anterior part of the medial temporal lobe in the limbic system /12/. These nuclei are heterogeneous and do not constitute an integrated functional system /97/. However, the basolateral amygdala, which is composed of lateral, basal and accessory basal nuclei, seems to constitute a system of this kind; it was even proposed "*to think of the amygdala as the 'basolateral amygdala'*" /34/. In the primate, the latter set of nuclei receives information from the thalamus and all sensory cortices /12/. Moreover, amygdalofugal projections to sensory-related cortices are massive, and an analysis of connectivity suggested that the amygdala makes output projections to all but eight of the cortical areas in the macaque /109/. The complexity of the amygdala itself and its widespread connections with other structures are a function of evolution and vary considerably from one species to another /17,40/. Nevertheless, anatomical and functional evidence suggests that a dual route architecture involving the amygdala is conserved amongst vertebrate species. This architecture consists of a direct subcortical pathway and an indirect cortical pathway to the amygdala.

Experiments of auditory fear conditioning in rats have shown the existence of a direct subcortical pathway from the auditory thalamus to the amygdala /61/. Brain imaging studies (e.g. /32/; see 26/) and patient data /21/ confirmed a role of the human amygdala in fear conditioning. Critical results were obtained by Morris, Öhman, and Dolan /70/ (see also /67/) who showed that regions of the pulvinar and superior colliculus covaried positively with amygdala activation during masked visual presentations of conditioned faces. These results led the authors to the conclusion that the emotional value of visual stimuli could be detected by a colliculo-pulvinar-amygdala pathway. Results from de Gelder and colleagues /35,36/ showing that recognition of emotional stimuli is possible in a blindsight patient also suggest that this pathway exists in humans. The existence of projections from the pulvinar to the amygdala in primates /53/ is consistent with this observation.

The connections from the cortex conveying complex cognitive information to the amygdala /12/ constitute the indirect pathway /61/. Brain imaging studies highlighted the importance of this route from the thalamus through the cortex to the amygdala. Pessoa and colleagues /77/ suggested that the critical pathway for the evaluation of emotional expression proceeds from the primary visual cortex to extrastriate areas, including fusiform and superior temporal sulcus, and then to the amygdala. Moreover, using an instructed fear paradigm in which an event is associated with an aversive outcome through verbal communication only, Phelps and colleagues /80/ suggested that when a frightening stimulus is encountered, the cortical representation of fear is conveyed to the amygdala through the insular cortex, leading to the expression of fear.

A major functional difference between these two pathways is that the lower-order direct pathway provides the amygdala with rapid and coarse representations while cortical inputs inform the amygdala with a slower and refined top-down message. On the basis of this functional difference, constraints on the character of emotional processes can be formulated. Indeed, the subcortical pathway would implement processes that require neither intention nor attention and may be defined as automatic, while the cortical, more indirect, pathway would compute cognitively integrated information.

THE AMYGDALA AND THE DOMAIN-SPECIFICITY HYPOTHESIS

From an evolutionary perspective, cognitive functions are often described as functionally independent modules rather than in terms of general-purpose mechanisms /33/. Modules are rapid, automatic, domain-specific cognitive systems designed by evolution to solve specific adaptive problems encountered recurrently in the environment. According to evolutionary neuroscience, the amygdala constitutes the central structure of a modular system in the mammalian brain shaped by evolution to respond to potentially fearful and threatening stimuli. Kjelstrup and colleagues /57/ recently introduced their article by stating that "*The experience of anxiety and fear is controlled by a modular neural system (...). The amygdala plays a pivotal role in this system.*" Similarly, Öhman and Mineka /74/ argued that "*The amygdala is a fear*

module...having an ancient evolutionary origin and it served animals with primitive brains long before more recent biological families with more well developed cortices emerged...Basically, the fear module is a device for activating defensive behaviour and associated psychophysiological responses and emotional feelings to threatening stimuli."

The majority of animal studies support the view that the amygdala is part of a system specialised for rapidly triggering physiological states related to threat or danger, e.g., a snake or an unfamiliar adult male monkey. Temporal lobe lesions including the amygdala produce extensive behavioural, social and emotional changes in non-human primates. As expressed in the Klüver-Bucy syndrome, primates show enhanced approach behaviour, hyperorality and hypersexuality as well as reduced fear /58,99/. In this syndrome, stimuli are still perceived as objects, but they no longer elicit normal affective responses /13/. The Klüver-Bucy syndrome generally ascribed to amygdala lesions is in fact likely caused by damage to the fibres of passage coursing through the amygdala. For example, Meunier and colleagues /64/ showed that selective neurotoxic bilateral amygdala lesions sparing efferent projection fibres to the temporal pole, the entorhinal and perirhinal areas, induce inadequate and inappropriate emotional responses to social stimuli, such as enhanced submission and approach behaviour or reduced fear and aggression.

As largely documented by patient studies /8,9, 25,27,28,96,108/, bilateral damage to the amygdala may impair the processing of fear expressed by the face. Moreover, several neuroimaging studies have confirmed the role of the amygdala in the processing of fearful faces /24,29,68,69,77,81,83,98, 101,105/ and in fear conditioning /26/. A less robust finding is the one showing that patients with an amygdala lesion are impaired in the processing of fear expressed by voice. A lesion study /93/ reported impaired recognition of non-verbal vocal signals of fear in a patient with bilateral amygdala damage. Conversely, Anderson and Phelps /14/ as well as Adolphs and Tranel /5/ failed to observe such an impairment in the auditory domain. Nevertheless, Phillips and colleagues /82/ showed that non-verbal vocal fear-related stimuli activate the amygdala. Moreover, the findings from a functional magnetic resonance imaging (fMRI) study /37/ suggest that the amygdala plays an integrative role during cross-modal emotional processing of fear expressed simultaneously by voice and face. Clearly, further experiments are necessary in order to conclude whether the amygdala processes both visual and auditory emotional information in the same way.

The amygdala is also necessary in learning to associate neutral stimuli with fear responses, as consistently revealed by conditioning experiments in animals and humans /26,61/. This means that although the amygdala may be genetically programmed to detect evolutionary salient fear-related stimuli, it allows, through associative learning processes, a wider range of stimuli and situations to activate fear responses.

So far, a vast corpus of evidence shows that the amygdala is involved in fear processing, supporting the notion that fear-related stimuli constitute *the amygdala's domain of specificity*. However, the fact that a given brain region is consistently involved in the processing of a specific category of stimuli does not necessarily mean that this brain region is selectively dedicated to that domain of stimuli. As discussed by Carmel and Bentin /31/, clear criteria are needed to verify any hypothesis about the functional specificity of brain activity and its link to a particular cognitive mechanism. From an experimental perspective, a key criterion is to show that differences in the activation of a brain region obtained for the proposed domain of specificity cannot be found across domains for which the particular brain response is not supposed to be specific. For instance, consider the hypothesis that measures of amygdala activity reflect amygdala specificity in the processing of fear-related stimuli. In this case, a key criterion to verify this hypothesis would be to show that the differences obtained in amygdala activation for the processing of fear-related versus neutral stimuli are never found when comparing amygdala activation for the processing of non-fear-related versus neutral stimuli. Two lines of research, described below, refute the view of the amygdala as a fear module.

The first line of research shows that fear is not the only negative emotion that is subserved by the

amygdala. Although a deficit in recognition of fearful faces is often observed in patients with amygdala deficits, it is now well documented that recognition of other negative emotions, such as anger and sadness, can also be defective /42,85/. As shown by fMRI studies, the processing of faces expressing sadness /22/ and of disgusting pictures /90/, as well as the subjective experience of negative emotions /62,91/, activate the amygdala. Other aversive, but not specifically fear-related stimuli, such as olfactory stimuli /87,110/, gustatory stimuli /111/, visually presented words /49/, and complex visual scenes /52/, were also shown to evoke amygdala response. Sustained amygdala activity was shown in response to negative (but not specifically fear-related) information in depressed individuals /94/. Scott and colleagues /93/ reported the case of a patient with bilateral amygdala damage who showed impaired recognition of anger from both facial and vocal stimuli. Moreover, two recent fMRI studies reported amygdala activation in response to schematic /106/ and real /107/ angry faces.

From the 'fear module' hypothesis, one can formulate the following operational prediction: the more a visual stimulus induces fear in an observer, the more the amygdala should be activated. Consider now the logical proposal that an angry face looking at an observer should make him/her more frightened than a fearful face. This proposal is based on the reasoning that an angry face with a direct gaze is a threat that should induce the fear of being attacked, whereas a fearful face with a direct gaze by itself does not constitute a threat. Hence, according to the 'fear module' hypothesis, an angry face with a direct gaze would produce stronger amygdala activation than a fearful face with a direct gaze, simply because the former is more frightening than the latter (see also /100/). Contrary to this prediction, Whalen and colleagues /102/ found that the amygdala responds less to faces expressing anger than to faces expressing fear. Interestingly, Phan and colleagues /78/ reported amygdala activation only when subjective ratings were incorporated in the analysis of brain activation as individualised regressors. This finding clearly indicates that activation of this structure is associated with subjective arousal and that individual variability between and within participants enhances the sensitivity for detecting amygdala responsiveness.

In the attempt to account for the large corpus of data demonstrating that the amygdala is not only associated with the processing of fear-related stimuli, it has been argued that the amygdala's domain of specificity is composed of a wider range of *unpleasant* stimuli. According to Paradiso and colleagues /75/, it would be implicated in the processing of highly arousing negative emotions, but not in the evaluation of positive events.

The next line of research that we review refutes both the 'fear module' view and the 'arousing negative emotions' view. As also documented by a large body of evidence, the amygdala's domain of computation is far from being restricted to negative emotions. In animals, the amygdala is implicated in learning and processing the rewarding values of events (for review see /18/). In humans, Bechara and colleagues /20/ showed that patients with bilateral lesions of the amygdala exhibited abnormal skin conductance responses following both positive and negative reinforcement (gaining or losing money in a gambling task). Critically, human brain imaging studies support this view. In Table 1, we present human neuroimaging studies showing that the amygdala's domain of computation is not restricted to stimuli eliciting *negative* emotions. Indeed, amygdala activation is also correlated with the processing of *positive* events, such as happy faces /24,29,45,59,77,106,107/, positive words /49/, positive pictures /30,43,47,48/, pleasant tastes /72/ or expectation of pleasant tastes /71/, erotic film excerpts /19,55,86/, amusement-inducing films /1, 86/, and reward /95,112/. In an fMRI study performed by two of the present authors /112/, regional brain activity was investigated when healthy human participants were given feedback on their performance during a simple response time task in a fictitious competitive tournament. In this study, changes in the frequency of rewarding ('win') or aversive ('lose') words used as feedback resulted in a modulation of amygdala activation. Specifically, increased winning was associated with left amygdala activation, whereas increased losing was associated with right amygdala activation. In this study, it clearly appeared that the amygdala is

activated by both negative and positive reinforcements conveyed by lexical stimuli. Two other brain imaging reports that used stimuli whose emotional value varied according to participants' internal state provide evidence that amygdala function is not specifically tuned to negative contexts /60,66/. LaBar and colleagues /60/ showed that the amygdala was more activated by the visual presentation of food-related stimuli when participants were in a hungry state than when they were in a satiated state. Morris and Dolan /66/ observed that amygdala activation was positively correlated with recognition memory scores for food items and that participants showed enhanced recognition of food stimuli (relative to non-food) in a fasting state. This enhanced recognition for food stimuli was significantly reduced when participants were in a satiated state.

Amygdala activation was also revealed by experiments that did not manipulate the emotional value of stimuli but still used biologically relevant information. In particular, the amygdala was recruited when participants were required to attribute mental states to other individuals /15/, to process unknown faces /38/ or direct gaze /44, 103/, to discriminate gaze direction /56/ and to process racial outgroup faces /50,79/. Interestingly, an fMRI study /104/ replicated patient data /7/ by showing an involvement of the amygdala in response to untrustworthy faces. This example is of particular interest for two reasons. First, it is a clear case showing that highly consistent findings can be obtained from the behavioural study of brain-damaged patients and from imaging of the normal human brain. Second, these findings strongly suggest that the amygdala is necessary for evaluating socially relevant information. Adolphs and colleagues /7/ tested patients with amygdala lesions and showed that they were impaired in judging the trustworthiness of individuals from viewing their neutral faces. More recently, Winston and colleagues /104/ asked participants to explicitly assess the trustworthiness of neutral faces and found that trustworthiness ratings, as provided by the participants themselves, correlated with BOLD signal changes in the amygdala. When participants were requested to assess the age of the very same neutral faces, trustworthiness ratings also correlated with amygdala activity. Taken together, these findings reveal that the amygdala is involved in both explicit and implicit assessment of the social value of a neutral face and that amygdala dysfunction impairs social evaluation (see also /4/).

Activation of the amygdala was clearly found in processing point-light sequences simulating meaningful body motion versus non-biological movement /23/. Greater activation of the amygdala was also observed when hearing one's own name, as compared to a beep, during sleep than during a wakeful state /84/. In a more recent study, Hamann and colleagues /48/ showed that the amygdala was activated by the processing of highly interesting and unusual pictures even when they were emotionally neutral. In conclusion, this body of literature provides convincing evidence of the theoretical insufficiency of the 'negative emotions' view.

THE AMYGDALA: RELEVANCE AND EMOTION

An important contribution of evolutionary psychology to cognitive neuroscience is to promote the view that evolution improved the performance of the cognitive modules constituting the human brain by restricting their domain of specificity /39/. From an evolutionary perspective, certain biological stimuli acquired the property of eliciting emotions because of their adaptive values /41/. In particular, fear reactions are preferentially activated by potentially aversive stimuli in order to promote escape and avoidance. Hence, the view emerged that the amygdala's domain of specificity is restricted to 'evolutionary salient fear-related stimuli' /74/. However, the recent patient and brain imaging data reviewed in the present article strongly suggest that the amygdala is neither a *fear module* nor a *negative-emotions-dedicated subsystem.* Indeed, differences in measures assumed to reflect amygdala functions obtained for the 'fear' domain and the 'negative emotions' domain were also found across domains for which the amygdala response was not supposed to be specific (see Table 1). On the basis of this evidence, it is legitimate to offer an alternative conceptual framework. Here, we present two classes of plausible explanations for the functions of the amygdala.

TABLE 1

Brain imaging studies showing amygdala involvement in the processing of non-negative events

Study	Amygdala activation
Aalto *et al.* (2002) /1/	Passive viewing of amusement-inducing vs neutral films
Baron-Cohen *et al.* (1999) /15/	A theory of mind task* vs a gender decision task on photographs of eyes *In the theory of mind task, participants were to decide for each stimulus which of two simultaneously presented words best describes what the person in the photograph was feeling or thinking.
Beauregard *et al.* (2001) /19/	Passive viewing of erotic vs neutral film excerpts
Bonda *et al.* (1996) /23/	Looking carefully at point-light sequences simulating meaningful biological body movement vs random motion
Breiter *et al.* (1996) /24/	Passive viewing of happy vs neutral faces
Canli *et al.* (2002) /29/	Gender decision on happy vs neutral faces (amygdala activation correlated with the degree of participants extraversion)
Canli *et al.* (2001) /30/	Correlation between extraversion and amygdala activation to passive viewing of positive vs negative pictures
Dubois *et al.* (1999) /38/	Gender decision on unknown vs known neutral faces
Garavan *et al.* (2001) /43/	Passive viewing of positive (both low and high in arousal) vs neutral pictures
George *et al.* (2001) /44/	Specific coupling between the fusiform gyrus and the amygdala, for direct vs averted gaze during a gender decision task
Gorno-Tempini *et al.* (2001) /45/	Explicit categorization of facial expressions on happy faces vs a control task** Gender decision task on happy faces vs a control task** **In the control task, participants were requested to detect a white square in a greyscale mosaic stimulus.
Hamann *et al.* (1999) /47/	Correlation of amygdala activity with memory enhancement for positive vs interesting neutral pictures
Hamann *et al.* (2002) /48/	Positive pictures vs neutral stimuli High-interest, unusual neutral pictures vs neutral stimuli
Hamann & Mao (2002) /49/	Passive viewing of positive vs neutral words
Hart *et al.* (2000) /50/	Gender decision task on racial outgroup vs ingroup neutral faces*** ***Black or White participants were presented with neutral faces of Black or White individuals. The reported amygdala activation was observed only during later stimulus presentation.
Karama *et al.* (2002) /55/	Passive viewing of erotic vs neutral film excerpts

Table 1 cont.

Study	Amygdala activation
Kawashima *et al.* (1999) /56/	Discriminating the gaze direction (upwards or downwards) of neutral faces vs deciding whether the left or right eye blinked
Kosaka *et al.* (2002) /59/	Judging among a happy and a neutral face which face was emotional vs a control condition**** ****In the control condition, the participants were instructed to discriminate the size of two rectangles and indicate which one was larger.
LaBar *et al.* (2001) /60/	Viewing of food stimuli by participants in a hungry vs satiated state (the task was to press a button whenever one of the objects blinked)
Morris & Dolan (2001) /66/	Positive covariation with recognition memory for food items (Participants showed enhanced recognition of food stimuli relative to non-food in the fasting state. Satiation significantly reduced the memory advantage for food.)
O'Doherty *et al.* (2002) /71/	Anticipation of positive vs negative taste
O'Doherty *et al.* (2001) /72/	Receipt of sweet taste (1 M glucose) vs tasteless solution
Pessoa *et al.* (2002) /77/	Processing of neutral faces vs scrambled stimuli Gender decision task on happy vs neutral faces Processing of neutral faces in an attended vs unattended to faces condition***** Processing of happy faces in an attended vs unattended to faces condition***** *****In attended trials, participants performed a gender decision task. In unattended trials, participants indicated whether two bars above the faces were of similar or dissimilar orientations.
Phelps *et al.* (2000) /79/	Viewing of unfamiliar Black vs White faces by White participants
Portas *et al.* (2000) /84/	Hearing one's own name (compared with hearing a beep) during sleep vs hearing one's own name (compared with hearing a beep) while awake
Redouté *et al.* (2000) /86/	Passive viewing of sexually explicit vs neutral film excerpts Passive viewing of humorous vs neutral film excerpts
Schneider *et al.* (1997) /91/	Happy mood vs neutral induction
Schwartz *et al.* (2002) /92/	Increased functional connectivity between the amygdala and the visual cortex in a new untrained condition of visual texture discrimination
Wicker (2003) /103/	Processing of direct vs averted gaze in non-emotional faces
Wright *et al.* (2002) /106/	Passive viewing of happy vs neutral schematic faces
Yang *et al.* (2002) /107/	Gender decision task on happy vs neutral faces
Zalla *et al.* (2000) /112/	Increased presentation rate of the word «WIN»

The first kind of explanation argues that the amygdala implements *as many processes as those that are directly suggested by the variety of experimental results*. According to this view, a subregion of the amygdala can still be considered as implementing a *fear module*, but other parts of the amygdala subserve processes that can hardly be explained by the 'fear module' hypothesis. On the basis of fMRI results, Canli and colleagues /29/ suggested the existence of two basic processes within the amygdaloid structure. According to these authors, the first process would be engaged consistently across people in response to fearful expressions and may reflect the importance of detecting cues to potentially dangerous situations. The second process would be engaged variably across people, as a function of extraversion, in response to happy expressions. It is true that the amygdala is composed of different nuclei that play distinct roles in animal behaviour /34,97/. However, remarkable results obtained by Barton and colleagues /17/ in three separate groups of mammals suggested that evolutionary changes in the volumes of amygdala components are strongly correlated. This suggests that the amygdala should be viewed as a structural and a functional unit. Unfortunately, it is not possible to draw straightforward conclusions about the functional specialisation of the human amygdala nuclei from either lesion or brain imaging studies. Indeed, to our knowledge, no study on patients with a restricted amygdala nucleus lesion has been reported in the literature. Moreover, the spatial resolution of brain imaging techniques does not allow for a clear assessment of nuclei functions in human (see /65, 102/).

Another argument that also speaks in favour of the 'multi-processes' explanation is the existence of the dual route to the amygdala described earlier. The fact that the amygdala receives projections from the subcortical and the cortical pathways suggests that different processes may be engaged depending on the type of information. Further experiments that investigate the differential role of both the colliculo-pulvinar-amygdala and the insular-amygdala pathways (see /70,80/) will help to clarify the debate about the domain specificity of the amygdala. However, the theoretical limitation of this 'multi-processes' explanation is that it appears implausible to explain the variety of results by a one-to-one matching between *each* type of result and *each* amygdalar nucleus or pathway. Therefore, at some point, a common process that explains different classes of results should be proposed.

The second kind of explanation argues that an extensive analysis of the types of stimuli and tasks associated with amygdala activation should help delineate a *common computational profile*. Whalen /100/ linked emotion to vigilance by proposing that the amygdala may be especially involved in increasing vigilance and attention based on stimulus ambiguity. According to this view, ambiguous stimuli require more information to be gathered in order for the organism to decide the appropriate behaviour to engage in. Increased vigilance was then defined as potentiated neuronal responsiveness in sensory systems receiving inputs from the amygdala /34,100,102/. Unlike angry faces, fearful faces are both negative and ambiguous stimuli because they signal an increased probability of threat without providing clear information about its source. In accordance with Whalen's proposal, Yang and colleagues /107/ predicted that facial expressions other than fear, that might be interpreted as ambiguous, should also activate the amygdala (e.g., when neither the source of sadness nor happiness is present in facial stimuli). These authors observed the amygdala activation in response to happy, angry, sad, and fearful faces compared to neutral faces and suggested that the amygdala is implicated in processing biologically relevant stimuli that have some presently unclear predictive value. Similarly, Wright and colleagues /106/ observed such an activation by using schematic stimuli. Therefore, although angry faces are not as ambiguous as fearful faces, they still have the property to activate the amygdala but do so to a lesser extent than fearful faces /102/.

The appraisal theories of emotion can enlighten the contribution of the human amygdala to emotion processing. The central proposal of these theories is that the specificity and the differentiation of an emotion mostly relies upon the cognitive evaluation of the meaning and the consequences of a relevant external event, within a specific context and relationship to one's own goals. The detection of

relevance can be considered as the essential phase of this evaluative process /89/. Substantial evidence provided by several recent neuroimaging studies, reviewed in this paper, strongly supports the view that the computational profile of the amygdala meets the psychological concept of a relevance detector. An event is relevant for an organism if it can significantly influence (positively or negatively) the attainment of his or her goals, the satisfaction of his or her needs, the maintenance of his or her own well-being, and the well-being of his or her species. According to this view, fearful and angry faces represent relevant information because they potentially obstruct one's goal and signal the presence of a danger for the organism and his or her con-specifics.

An operational hypothesis can be formulated on the basis of this proposal. We can hypothesise, for example, that the facial expression of anger is more threatening for the observer if the gaze is directed to him/her rather than being averted, since this could signify the danger of being attacked. In other words, an angry face is more *relevant* if the gaze is directed to the observer than averted. Therefore, an angry face should elicit greater amygdala activation in a direct than an averted gaze condition. Similarly, in the case of facial expression of happiness, we can hypothesize that a social message is probably signalled to the observer by a direct, as compared to an averted, gaze and should elicit greater amygdala activation. However, in the case of the facial expression of fear, a threat event is more significant to the observer when signalled by an averted, as compared to a direct, gaze since this might indicate the presence of a threat next to the observer and should elicit greater amygdala activation. We also propose that in the fear conditioning paradigms, the neutral stimulus associated with the fear event activates the amygdala not because it *has acquired* a frightening meaning, but because it becomes, as the conditioned stimulus, highly *relevant* in signalling the presence of a potential threat. The result from Winston and colleagues /104/ showing that the amygdala increased its activity in response to untrustworthy faces is also consistent with the 'relevance hypothesis'. Using a game-like paradigm, Kahn and collaborators /54/ suggested that the amygdala is active both in appraisal of inherent value of choice and in warning about prospective negative outcomes. Furthermore, positive stimuli, such as happy faces, amusement-inducing and erotic pictures or movies, can also be relevant because of their intrinsic pleasantness inviting the organism to engage the event. From this perspective, some experimental data can be differently analysed. For example, the Canli and colleagues /29/ findings discussed above might be interpreted not as revealing *two different processes* but as reflecting the *relevance* of fearful faces. Perhaps the more extraverted people are, the more that happy faces are *relevant* to their goals and needs. Results showing that the amygdala response to food-related stimuli varies according to the internal state (hungry versus satiated) of participants /60,66/ is in accordance with this proposal. Indeed, the relevance value of food increases significantly whenever participants desire it to satisfy their needs. Consistently, in animals, the amygdala responds to rewards such as the taste or sight of food (see /18,71/).

Social events are also particularly relevant within primate societies. As a result of the increase of human social complexity, the amygdala's domain of specificity would have been enlarged to include a broader category of relevant stimuli allowing the expression of more complex emotional responses and social skills. As shown by a large corpus of data, social signals, *a priori* non-emotionally laden, such as gaze direction, intentions, group adherence, trustworthiness and facial familiarity, can activate the amygdala /15,23,38,44,50,56,79,84/.

The experimental evidence reviewed in the present paper suggests that the appropriate level of analysis to determine the amygdala's computational profile should transcend the so-called 'basic emotions' level, according to which basic emotions (e.g., fear, anger, sadness, disgust, and happiness) each relies on specific brain and physiological mechanisms. Indeed, both the brain-damaged and the brain imaging data suggest that the human amygdala is involved in the processing of events that are related to several basic and complex emotions presumably subserved by a common set of neural subsystems /88/.

CONCLUSION

Substantial evidence in non-primate animals has underlined the crucial role of the amygdala in processing fearful information. Although originally shaped by evolutionary contingencies to respond to specific stimuli, such as fear, to solve a restricted set of problems, i.e., adopting defensive behaviour, the primate amygdala may have evolved into a less specialised system in order to cope with new environmental problems. In this review, we argued that a broader theoretical perspective that includes a larger category of eliciting stimuli can account for the critical adaptive role of the amygdala. The debate regarding the functional specificity of the amygdala is not resolved, but the data from human studies suggest that the amygdala is concerned with processing and labelling *relevant* stimuli that include, but are not restricted to, fear-related stimuli. Anatomically, the amygdala is ideally located in the brain to act as a relevance detector. The large variety of cortical and subcortical projections to and from the amygdala provide it with information about the properties of the stimulus as well as the ongoing goals/needs of the organism. Although studies from animals have substantially contributed to our understanding of the amygdala, the study of emotions through lesion and neuroimaging studies in humans has led to additional findings that have modified the interpretation of the evolved role of the amygdala in human behaviour. A better understanding of the computational profile of the human amygdala will constitute the foundation of an emergent cognitive neuroscience of appraisal and decision-making.

ACKNOWLEDGEMENT

The authors wish to thank Olivier Koenig, Didier Grandjean, and Klaus R. Scherer for stimulating discussions.

REFERENCES

1. Aalto S, Naatanen P, Wallius E, Metsahonkala L, Stenman H, Niem PM, Karlsson H. Neuroanatomical substrata of amusement and sadness: a PET activation study using film stimuli. NeuroReport 2002; 13: 67-73.
2. Adolphs R. The neurobiology of social cognition. Curr Opin Neurobiol 2001; 11: 231-239.
3. Adolphs R. Neural systems for recognizing emotion. Curr Opin Neurobiol 2002; 12: 169-177.
4. Adolphs R. Cognitive neuroscience of human social behaviour. Nat Rev Neurosci 2003; 4: 165-178.
5. Adolphs R, Tranel D. Intact recognition of emotional prosody following amygdala damage. Neuropsychologia 1999; 37: 1285-1292.
6. Adolphs R, Tranel D. Emotion recognition and the human amygdala. In: Aggleton JP, ed. The Amygdala: A Functional Analysis. Oxford: Oxford University Press, 2000; 587-630.
7. Adolphs R, Tranel D, Damasio AR. The human amygdala in social judgment. Nature 1998; 393: 470-474.
8. Adolphs R, Tranel D, Damasio H, Damasio A. Impaired recognition of emotion in facial expressions following bilateral damage to the human amygdala. Nature 1994; 372: 669-672.
9. Adolphs R, Tranel D, Damasio H, Damasio AR. Fear and the human amygdala. J Neurosci 1995; 15: 5879-5891.
10. Aggleton JP. The Amygdala: Neurobiological Aspects of Emotion, Memory and Mental Dysfunction. New York: Wiley-Liss, 1992.
11. Aggleton JP. The Amygdala: A Functional Analysis, 2nd Ed. Oxford: Oxford University Press, 2000.
12. Amaral DG, Price JL, Pitkänen A, Carmichael ST. Anatomical organization of the primate amygdaloid complex. In: Aggleton JP, ed. The Amygdala: Neurobiological Aspects of Emotion, Memory and Mental Dysfunction. New York: Wiley-Liss, 1992; 1-66.
13. Amaral DG. The primate amygdala and the neurobiology of social behavior: implications for understanding social anxiety. Biol Psychiatry 2002; 51: 11-17.
14. Anderson AK, Phelps EA. Intact recognition of vocal expressions of fear following bilateral lesions of the human amygdala. NeuroReport 1998; 9: 3607-3613.
15. Baron-Cohen S, Ring HA, Wheelwright S, Bullmore ET, Brammer MJ, Simmons A, Williams SCR. Social intelligence in the normal and autistic brain: an fMRI study. Eur J Neurosci 1999; 11: 1891-1898.
16. Barton RA, Aggleton JP. Primate evolution and the amygdala. In: Aggleton JP, ed. The Amygdala: A Functional Analysis. Oxford: Oxford University Press, 2000; 479-508.
17. Barton RA, Aggleton JP, Grenyer R. Evolutionary coherence of the mammalian amygdala. Proc R Soc Lond B Biol Sci 2003; 270: 539-543.
18. Baxter MG, Murray EA. The amygdala and reward. Nat Rev Neurosci 2002; 3: 563-573.
19. Beauregard M, Lévesque J, Bourgouin P. Neural correlates of conscious self-regulation of emotion. J Neurosci 2001; 21: RC165 (1-6).

20. Bechara A, Damasio H, Damasio AR, Lee GP. Different contributions of the human amygdala and ventromedial prefrontal cortex to decision-making. J Neurosci 1999; 19: 5473-5481.
21. Bechara A, Tranel D, Damasio H, Adolphs R, Rockland C, Damasio AR. Double dissociation of conditioning and declarative knowledge relative to the amygdala and hippocampus in humans. Science 1995; 269: 1115-1118.
22. Blair RJR, Morris JS, Frith CD, Perret DI, Dolan RJ. Dissociable neural responses to facial expressions of sadness and anger. Brain 1999; 122: 883-893.
23. Bonda E, Petrides M, Ostry D, Evans A. Specific involvement of human parietal systems and the amygdala in the perception of biological motion. J Neurosci 1996; 16: 3737-3744.
24. Breiter HC, Etcoff NL, Whalen PJ, Kennedy WA, Rauch SL, Buckner RL, Strauss MM, Hyman SE, Rosen BR. Response and habituation of the human amygdala during visual processing of facial expression. Neuron 1996; 17: 875-887.
25. Broks P, Young AW, Maratos EJ, Coffey PJ, Calder AJ, Isaac C, Mayes AR, Hodges JR, Montaldi D, Cezayirli E, Roberts N, Hadley D. Face processing impairments after encephalitis: amygdala damage and recognition of fear. Neuropsychologia 1998; 36: 59-70.
26. Büchel C, Dolan RJ. Classical fear conditioning in functional neuroimaging. Curr Opin Neurobiol 2000; 10: 219-223.
27. Calder AJ, Lawrence AD, Young AW. Neuropsychology of fear and loathing. Nat Rev Neurosci 2001; 2: 352-363.
28. Calder AJ, Young AW, Rowland D, Perrett DI, Hodges JR, Etcoff NL. Facial emotion recognition after bilateral amygdala damage: differentially severe impairment of fear. Cogn Neuropsychol 1996; 13: 699-745.
29. Canli T, Sivers H, Whitfield SL, Gotlib IH, Gabrieli JDE. Amygdala response to happy faces as a function of extraversion. Science 2002; 296: 2191.
30. Canli T, Zhao Z, Desmond JE, Kang E, Gross J, Gabrieli JDE. An fMRI study of personality influences on brain reactivity to emotional stimuli. Behav Neurosci 2001; 115: 33-42.
31. Carmel D, Bentin S. Domain specificity and expertise: factors influencing distinct processing of faces. Cognition 2002; 83: 1-29.
32. Cheng DT, Knight DC, Smith CN, Stein EA, Helmstetter FJ. Functional MRI of human amygdala activity during Pavlovian fear conditioning: stimulus processing versus response expression. Behav Neurosci 2003; 117: 3-10.
33. Cosmides L, Tooby J. Origins of domain specificity: the evolution of functional organization. In: Hirschfeld LA, Gelman SA, eds. Mapping the Mind. Domain Specificity in Cognition and Culture. Cambridge: Cambridge University Press, 1994; 85-116.
34. Davis M, Whalen PJ. The amygdala: vigilance and emotion. Mol Psychiatry 2001; 6: 13-34.
35. de Gelder B, Vroomen J, Pourtois G, Weiskrantz L. Non-conscious recognition of affect in the absence of the striate cortex. NeuroReport 1999; 10: 3759-3763.
36. de Gelder B, Pourtois G, Weiskrantz L. Fear recognition in the voice is modulated by unconsciously recognized facial expressions but not by unconsciously recognized affective pictures. Proc Natl Acad Sci USA 2002; 99: 4121-4126.
37. Dolan RJ, Morris JS, de Gelder B. Crossmodal binding of fear in voice and face. Proc Natl Acad Sci USA 2001; 98: 10006-10010.
38. Dubois S, Rossion B, Schiltz C, Bodart JM, Michel C, Bruyer R, Crommelinck M. Effect of familiarity on the processing of human faces. Neuroimage 1999; 9: 278-289.
39. Duchaine B, Cosmides L, Tooby J. Evolutionary psychology and the brain. Curr Opin Neurobiol 2001; 11: 225-230.
40. Dumont EC, Martina M, Samson RD, Drolet G, Paré D. Physiological properties of central amygdala neurons: species differences. Eur J Neurosci 2002; 15: 545-552.
41. Ekman P. Basic emotions. In: Dalgleish T, Power M, eds. Handbook of Cognition and Emotion. Chichester: John Wiley & Sons, Ltd., 1999.
42. Fine C, Blair RJR. The cognitive and emotional effects of amygdala damage. NeuroReport 2000; 6: 435-450.
43. Garavan H, Pendergrass JC, Ross TJ, Stein EA, Risinger RC. Amygdala response to both positively and negatively valenced stimuli. NeuroReport 2001; 12: 2779-2783.
44. George N, Driver J, Dolan RJ. Seen gaze-direction modulates fusiform activity and its coupling with other brain areas during face processing. Neuroimage 2001; 13: 1102-1112.
45. Gorno-Tempini ML, Pradelli S, Serafini M, Pagnoni G, Baraldi P, Porro C, Nicoletti R, Umita C, Nichelli P. Explicit and incidental facial expression processing: an fMRI study. Neuroimage 2001; 14: 465-473.
46. Hamann S. Cognitive and neural mechanisms of emotional memory. Trends Cogn Sci 2001; 5: 394-400.
47. Hamann SB, Ely TD, Grafton ST, Kilts CD. Amygdala activity related to enhanced memory for pleasant and aversive stimuli. Nat Neurosci 1999; 2: 289-293.
48. Hamann SB, Ely TD, Hoffman JM, Kilts CD. Ecstasy and agony: activation of the human amygdala in positive and negative emotion. Psychol Sci 2002; 13: 135-141.
49. Hamann S, Mao H. Positive and negative emotional verbal stimuli elicit activity in the left amygdala. NeuroReport 2002; 13: 15-19.
50. Hart AJ, Whalen PJ, Shin LM, McInerney SC, Fischer H, Rauch SL. Differential response in the human amygdala to racial outgroup vs ingroup face stimuli. NeuroReport 2000; 11: 2351-2355.

51. Holland PC, Gallagher M. Amygdala circuitry in attentional and representational processes. Trends Cogn Sci 1999; 3: 65-73.
52. Irwin W, Davidson RJ, Lowe MJ, Mock BJ, Sorenson JA, Turski PA. Human amygdala activation detected with echo-planar functional magnetic resonance imaging. NeuroReport 1996; 7: 1765-1769.
53. Jones EG, Burton H. A projection from the medial pulvinar to the amygdala in primates. Brain Res 1976; 104: 142-147.
54. Kahn I, Yeshurun Y, Rotshtein P, Fried I, Ben-Bashat D, Hendler T. The role of the amygdala in signaling prospective outcome of choice. Neuron 2002; 33: 983-994.
55. Karama S, Lecours AR, Leroux J-M, Bourgouin P, Beaudoin G, Joubert S, Beauregard M. Areas of brain activation in males and females during viewing of erotic film excerpts. Hum Brain Mapp 2002; 16: 1-13.
56. Kawashima R, Sugiura M, Kato T, Nakamura A, Hatano K, Ito K, Fukuda H, Kojima S, Nakamura K. The human amygdala plays an important role in gaze monitoring. A PET study. Brain 1999; 122: 779-783.
57. Kjelstrup KG, Tuvnes FA, Steffenach HA, Murison R, Moser EI, Moser M-B. Reduced fear expression after lesions of the ventral hippocampus. Proc Natl Acad Sci USA 2002; 99: 10825-10830.
58. Klüver H, Bucy PC. An analysis of functions of the temporal lobes in monkeys, with special reference to «psychic blindness». J Psychol 1938; 5: 33-54.
59. Kosaka H, Omori M, Murata T, Iidaka T, Yamada H, Okada T, Takahashi T, Sadato N, Itoh H, Yonekura Y, Wada Y. Differential amygdala response during facial recognition in patients with schizophrenia: an fMRI study. Schizophr Res 2002; 7: 87-95.
60. LaBar KS, Gitelman DR, Parrish TB, Kim Y-H, Nobre A, Mesulam M-M. Hunger selectivity modulates corticolimbic activation to food stimuli in humans. Behav Neurosci 2001; 115: 493-500.
61. LeDoux JE. The Emotional Brain. London: Weidenfeld & Nicolson, 1996.
62. Levesque J, Eugene F, Joanette Y, Paquette V, Mensour B, Beaudoin G, Leroux JM, Bourgouin P, Beauregard M. Neural circuitry underlying voluntary suppression of sadness. Biol Psychiatry 2003; 53: 502-510.
63. McGaugh JL. Memory consolidation and the amygdala: a systems perspective. Trends Neurosci 2002; 25: 456-461.
64. Meunier M, Bachevalier J, Murray EA, Malkova L, Mishkin M. Effects of aspiration versus neurotoxic lesions of the amygdala on emotional responses in rhesus monkeys. Eur J Neurosci 1999; 11: 4403-4418.
65. Morris JS, Büchel C, Dolan RJ. Parallel neural responses in amygdala subregions and sensory cortex during implicit fear conditioning. Neuroimage 2001; 13: 1044-1052.
66. Morris JS, Dolan RJ. Involvement of human amygdala and orbitofrontal cortex in hunger-enhanced memory for food stimuli. J Neurosci 2001; 21: 5304-5310.
67. Morris JS, de Gelder B, Weiskrantz L, Dolan RJ. Differential extrageniculostriate and amygdala responses to presentation of emotional faces in a cortically blind field. Brain 2001; 124: 1241-1252.
68. Morris JS, Frith CD, Perret DI, Rowland D, Young AW, Calder AJ, Dolan RJ. A differential neural response in the human amygdalia to fearful and happy facial expressions. Nature 1996; 383: 812-815.
69. Morris JS, Öhman A, Dolan RJ. Conscious and unconscious emotional learning in the amygdala. Nature 1998; 393: 467-470.
70. Morris JS, Öhman A, Dolan RJ. A subcortical pathway to the right amygdala mediating «unseen» fear. Proc Natl Acad Sci USA 1999; 96: 1680-1685.
71. O'Doherty JP, Deichmann R, Critchley HD, Dolan RJ. Neural responses during anticipation of a primary taste reward. Neuron 2002; 33: 815-826.
72. O'Doherty J, Rolls ET, Francis S, Bowtell R, McGlone F. Representation of pleasant and aversive taste in the human brain. J Neurophysiol 2001; 85: 1315-1321.
73. Öhman A. Automaticity and the amygdala: nonconscious responses to emotional faces. Curr Directions Psychol Sci 2002; 11: 62-66.
74. Öhman A, Mineka S. Fears, phobias, and preparedness: toward an evolved module of fear and fear learning. Psychol Rev 2001; 108: 483-522.
75. Paradiso S, Johnson DL, Andreasen NC, O'Leary DS, Watkins GL, Boles Ponto LL, Hichwa RD. Cerebral blood flow changes associated with attribution of emotional valence to pleasant, unpleasant, and neutral visual stimuli in a PET study of normal subjects. Am J Psychiatry 1999; 156: 1618-1629.
76. Paré D, Collins DR, Pelletier JG. Amygdala oscillations and the consolidation of emotional memories. Trends Cogn Sci 2002; 6: 306-314.
77. Pessoa L, McKenna M, Gutierrez E, Ungerleider LG. Neural processing of emotional faces requires attention. Proc Natl Acad Sci USA 2002; 99: 11458-11463.
78. Phan KL, Taylor SF, Welsh RC, Decker LR, Noll DC, Nichols TE, Britton JC, Liberzon I. Activation of the medial prefrontal cortex and extended amygdala by individual ratings of emotional arousal: a fMRI study. Biol Psychiatry 2003; 53: 211-215.
79. Phelps EA, O'Connor KJ, Cunningham WA, Sumie Funayama E, Gatenby JC, Gore JC, Banaji MR. Performance on indirect measures of race evaluation predicts amygdala activation. J Cogn Neurosci 2000; 12: 729-738.
80. Phelps EA, O'Connor KJ, Gatenby JC, Gore JC, Grillon C, Davis M. Activation of the left amygdala to a cognitive representation of fear. Nat Neurosci 2001; 4: 437-441.
81. Phillips ML, Medford N, Young AW, Williams L, Williams SCR, Bullmore ET, Gray JA, Brammer MJ.

Time courses of left and right amygdalar responses to fearful facial expressions. Hum Brain Mapp 2001; 12: 193-202.
82. Phillips ML, Young AW, Scott SK, Calder AJ, Andrew C, Giampietro V, Williams SCR, Bullmore ET, Brammer M, Gray JA. Neural responses to facial and vocal expressions of fear and disgust. Proc R Soc Lond B Biol Sci 1998; 265: 1809-1817.
83. Phillips ML, Young AW, Senior C, Brammer M, Andrew C, Calder AJ, Bullmore ET, Perett DI, Rowland D, Williams SCR, Gray JA, David AS. A specific neural substrate for perceiving facial expressions of disgust. Nature 1997; 389: 495-498.
84. Portas CM, Krakow K, Allen P, Josephs O, Armony JL, Frith CD. Auditory processing across the sleep-wake cycle: simultaneous EEG and fMRI monitoring in humans. Neuron 2000; 28: 991-999.
85. Rapcsak SZ, Galper SR, Comer JF, Reminger SL, Nielsen L, Kaszniak AW, Verfaellie M, Laguna JF, Labiner DM, Cohen RA. Fear recognition deficits after focal brain damage. Neurology 2000; 54: 575-581.
86. Redouté J, Stoléru S, Grégoire M-C, Costes N, Cinotti L, Lavenne F, Le Bars D, Forest MG, Pujol JF. Brain processing of visual sexual stimuli in human males. Hum Brain Mapp 2000; 11: 162-177.
87. Royet J-P, Zald D, Versace R, Costes N, Lavenne F, Koenig O, Gervais R. Emotional responses to pleasant and unpleasant olfactory, visual, and auditory stimuli: a positron emission tomography study. J Neurosci 2000; 20: 7752-7759.
88. Sander D, Koenig O. No inferiority complex in the study of emotion complexity: a cognitive neuroscience computational architecture of emotion. Cogn Sci Q 2002; 2: 249-272.
89. Scherer KR, Schorr A, Johnstone T. Appraisal Processes in Emotion: Theory, Methods, Research. New York: Oxford University Press, 2001.
90. Schienle A, Stark R, Walter B, Blecker C, Ott U, Kirsch P, Sammer G, Vaitl D. The insula is not specifically involved in disgust processing: an fMRI study. NeuroReport 2002; 13: 2023-2026.
91. Schneider F, Habel U, Kessler C, Salloum JB, Posse S. Gender differences in regional cerebral activity during sadness. Hum Brain Mapp 2000; 9: 226-238.
92. Schwartz S, Maquet P, Frith C. Neural correlates of perceptual learning: a functional MRI study of visual texture discrimination. Proc Natl Acad Sci USA 2002; 99: 17137-17142.
93. Scott SK, Young AW, Calder AJ, Hellawell DJ, Aggleton JP, Johnson M. Impaired auditory recognition of fear and anger following bilateral amygdala lesions. Nature 1997; 385: 254-257.
94. Siegle GJ, Steinhauer SR, Thase ME, Stenger VA, Carter CS. Can't shake that feeling: event-related fMRI assessment of sustained amygdala activity in response to emotional information in depressed individuals. Biol Psychiatry 2002; 51: 693-707.
95. Small DM. Toward an understanding of the brain substrates of reward in humans. Neuron 2002; 33: 668-671.
96. Sprengelmeyer R, Young AW, Schroeder U, Grossenbacher PG, Federlein J, Büttner T, Przuntek H. Knowing no fear. Proc R Soc Lond B Biol Sci 1999; 266: 2451-2456.
97. Swanson LW, Petrovich GD. What is the amygdala? Trends Neurosci 1998; 21: 323-331.
98. Vuilleumier P, Armony JL, Driver J, Dolan, RJ. Effects of attention and emotion on face processing in the human brain: an event-related fMRI study. Neuron 2001; 3: 829-841.
99. Weiskrantz L. Behavioral changes associated with ablation of the amygdaloid complex in monkeys. J Comp Psychol 1956; 49: 381-391.
100. Whalen PJ. Fear, vigilance and ambiguity: initial neuroimaging studies of the human amygdala. Curr Directions Psychol Sci 1998; 7: 177-187.
101. Whalen PJ, Rauch LS, Etcoff NL, McInerney SC, Lee MB, Jenike MA. Masked presentations of emotional facial expressions modulate amygdala activity without explicit knowledge. J Neurosci 1998; 18: 411-418.
102. Whalen PJ, Shin LM, McInerney SC, Fischer H, Wright CI, Rauch SL. A functional MRI study of human amygdala responses to facial expressions of fear versus anger. Emotion 2001; 1: 70-83.
103. Wicker B, Perrett DI, Baron-Cohen S, Decety J. Being the target of another's emotion: a PET study. Neuropsychologia 2003; 41: 139-146.
104. Winston JS, Strange BA, O'Doherty J, Dolan RJ. Automatic and intentional brain responses during evaluation of trustworthiness of faces, Nat Neurosci 2002; 5: 277-283.
105. Wright CI, Fischer H, Whalen PJ, McInerney SC, Shin LM, Rauch SL. Differential prefrontal cortex and amygdala habituation to repeatedly presented emotional stimuli. NeuroReport 2001; 12: 379-383.
106. Wright CI, Martis B, Shin LM, Fischer H, Rauch SL. Enhanced amygdala responses to emotional versus neutral schematic facial expressions. NeuroReport 2002; 13: 785-790.
107. Yang TT, Menon V, Eliez S, Blasey C, White CD, Reid AJ, Gotlib IH, Reiss AL. Amygdalar activation associated with positive and negative facial expressions. NeuroReport 2002; 13: 1737-1741.
108. Young AW, Aggleton JP, Hellawell DJ, Johnson M, Broks P, Hanley JR. Face processing impairments after amygdalectomy. Brain 1995; 118: 15-24.
109. Young MP, Scannel JW, Burns GAPC, Blakemore C. Analysis of connectivity: neural systems in the cerebral cortex. Rev Neurosci 1994; 5: 227-249.
110. Zald D, Pardo JV. Emotion, olfaction, and the human amygdalia: amygdala activation during aversive olfactory stimulation. Proc Natl Acad Sci USA 1997; 94: 4119-4124.
111. Zald D, Lee JT, Fluegel KW, Pardo JV. Aversive

gustatory stimulation activates limbic structures in humans. Brain 1998; 121: 1143-1154.
112. Zalla T, Koechlin E, Pietrini P, Basso G, Aquino P, Sirigu A, Grafman J. Differential amygdala responses to winning and losing: a functional magnetic resonance imaging study in humans. Eur J Neurosci 2000; 12: 1764-1770.