

A Neurobiological Approach to Emotional Intelligence

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Emotions may be defined as states elicited by reinforcers (rewards and punishers). This approach helps with understanding the functions of emotion, classifying different emotions, and understanding *what* information processing systems in the brain are involved in emotion and *how* they are involved (Rolls, 2005, 2008). The theory is summarized that brains are designed around reward and punishment evaluation systems, because this is the way that genes can build a complex system that will produce appropriate but flexible behavior to increase their fitness. By specifying goals rather than particular behavioral patterns of responses, genes leave much more open the possible behavioral strategies that might be required to increase their fitness.

This approach leads to a framework for understanding brain systems involved in emotion, including how primary (unlearned) reinforcers are decoded; how associations are learned from previously neutral stimuli to primary reinforcers, and rapidly reversed; and how actions are learned to obtain the goals. This approach also leads to a framework for understanding emotional intelligence, in that the evolution of each of the gene-specified reinforcers (which are independent), and the systems that learn about stimulus-reinforcer associations and action-outcome associations, are likely to be independent in part of general cognition and intelligence. By focusing on the core capacities that are fundamental to emotion, it is possible to identify a set of competencies and processes that might be thought of as a basis for emotional intelligence.

In this chapter I first outline this neurobiological approach to emotion, discussing the theory of emotion, the functions of emotion, an evolutionary approach to emotion and brain design, and implicit versus explicit routes to action. This provides the basis for an approach to emotional intelligence, in which emotional competencies are emphasized as providing ways in which emotion-related processing can be different from that involved in general intelligence. We might characterize this as an emotional competencies approach to emotional intelligence.

A Theory of Emotion, and Some Definitions

What are emotions? Why do we have emotions? What are the rules by which emotion operates? What are the brain mechanisms of emotion, and how can disorders of emotion be understood? What motivates us to work for particular rewards such as food when we are hungry, or water when we are thirsty? How do these motivational control systems operate to ensure that we eat approximately the correct amount of food to maintain our body weight or to replenish our thirst? What factors account for the overeating and obesity that some humans show? Why is the brain built to have reward, and punishment, systems, rather than in some other way?

Emotions can usefully be defined as states elicited by rewards and punishers, including changes in rewards and punishers (Rolls, 1990, 1999, 2005). A reward is anything for which an animal will work. A punisher is anything that an animal will work to escape or avoid. An example of an emotion might thus be happiness produced by being given a reward, such as a pleasant touch, praise, or winning a large sum of money. Another example of an emotion might be fear produced by the sound of a rapidly approaching bus, or the sight of an angry expression on someone's face. We will work to avoid such stimuli. Another example would be frustration, anger, or sadness produced by the omission of an expected reward such as a prize, or the termination of a reward such as the death of a loved one. Another example would be relief produced by the omission or termination of a punisher such as the removal of a painful stimulus, or sailing out of danger.

These examples indicate how emotions can be produced by the delivery, omission, or termination of rewards or punishers, and go some way to indicate how different emotions could be produced and classified in terms of the rewards and punishers received, omitted, or terminated. A diagram summarizing some of the emotions associated with the delivery of a reward or punisher or a stimulus associated with them, or with the omission of a reward or punisher, is shown in Figure 3.1. It should be understood that this diagram summarizes the states that could be produced by manipulation of the reinforcement contingencies for any one reinforcer. The brain is built to have a large set of different primary reinforcers, and the reinforcer space is in this sense high dimensional.

Before accepting this approach, we should consider whether there are any exceptions to the proposed rule. Are any emotions caused by stimuli, events, or remembered events that are not rewarding or punishing? Do any rewarding or punishing stimuli not cause emotions? We will consider these questions in more detail below. The point is that if there are no major exceptions, or if any exceptions can be clearly encapsulated, then we may have a good working definition at least of what causes emotions, and this leads to principled ways for eliciting and studying emotion.

I next consider a slightly more formal definition than rewards or punishers in which the concept of reinforcers is introduced, and show how there has been a considerable history in the development of ideas along this line.

The proposal that emotions can be usefully seen as states produced by instrumental reinforcing stimuli follows earlier work by Weiskrantz (1968), Gray (1975, 1987), and

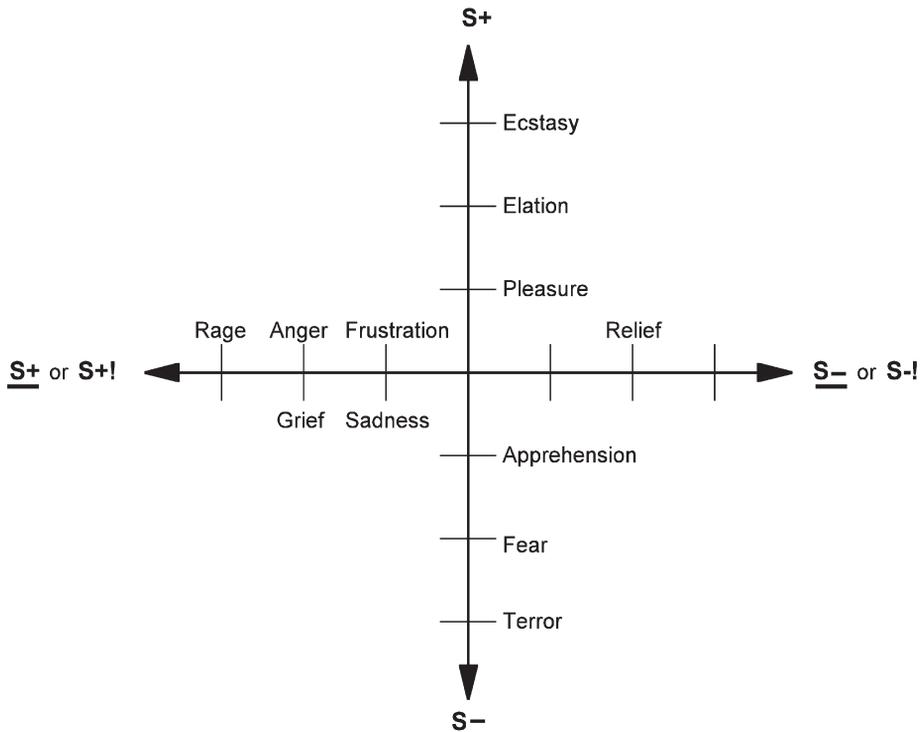


Figure 3.1. Some of the emotions associated with different reinforcement contingencies are indicated. Intensity increases away from the center of the diagram, on a continuous scale. The classification scheme created by the different reinforcement contingencies consists with respect to the action of (1) the delivery presentation of a reward (S+), (2) the presentation of a punisher (S-), (3) the omission of a reward (S+) (extinction) or the termination of a reward (S+!) (time out), and (4) the omission of a punisher (S-) (avoidance) or the termination of a punisher (S-!) (escape)

Rolls (1986a, 1986b, 1990).¹ My argument is that an affectively positive or “appetitive” stimulus (which produces a state of pleasure) acts operationally as a *reward*, which instrumentally when delivered acts as a positive reinforcer, or when not delivered (omitted or terminated) acts to decrease the probability of responses on which it is contingent. Conversely, I argue that an affectively negative or aversive stimulus (which produces an unpleasant state) acts operationally as a *punisher*, which instrumentally when delivered acts to decrease the probability of responses on which it is contingent, or when not delivered (escaped from or avoided) acts as a negative reinforcer.

The link between emotion and instrumental reinforcers being made is partly an operational link. Most people find that it is not easy to think of exceptions to the statements that emotions occur after rewards or punishers are given (sometimes continuing for long after the eliciting stimulus has ended, as in a mood state); or that rewards and punishers, but not other stimuli, produce emotional states. But the link is deeper than this, as we will see, in that the theory has been developed that genes specify primary reinforcers in

order to encourage the animal to perform arbitrary actions to seek particular goals, thus increasing the probability of their own (the genes') survival into the next generation (Rolls, 2005). The emotional states elicited by the reinforcers have a number of functions, described below, related to these processes.

This foundation has been developed (Rolls, 1990, 1999, 2005) to show how a very wide range of emotions can be accounted for, as a result of the operation of a number of factors, including the following, all of which can be manipulated to influence the elicitation of emotion:

1. The *reinforcement contingency* (e.g., whether reward or punishment is given or withheld; see Figure 3.1).
2. The *intensity* of the reinforcer (see Figure 3.1).
3. Any environmental stimulus might have a *number of different reinforcement associations*. (For example, a stimulus might be associated both with the presentation of a reward and of a punisher, allowing states such as conflict and guilt to arise.)
4. Emotions elicited by stimuli associated with *different primary reinforcers* will be different.
5. Emotions elicited by *different secondary reinforcing stimuli* will be different from each other (even if the primary reinforcer is similar). For example, if two different people were each associated with the same primary reinforcer, then the emotions would be different. This is in line with my hypothesis that emotions consist of states elicited by reinforcers, and that these states include whatever representations are needed for the eliciting stimulus, which could be cognitive, and the resulting mood change. Moods then may continue in the absence of the eliciting stimulus, or can be produced, as in depression, sometimes in the absence of an eliciting stimulus, perhaps due to dysregulation in the system that normally enables moods to be long lasting.
6. The emotion elicited can depend on whether an *active or passive behavioral response* is possible. (For example, if an active behavioral response can occur to the omission of a positive reinforcer, then anger—a state that tends to lead to action—might be produced, but if only passive behavior is possible; then sadness, depression or grief might occur.)

By combining these six factors, it is possible to account for, and also elicit, a very wide range of emotions (Rolls, 2005). Some examples follow. Fear is a state that might be produced by a stimulus that has become a secondary reinforcer by virtue of its learned association with a primary negative reinforcer such as pain (see Figure 3.1). Anger is a state that might be produced by the omission of an expected reward, frustrative nonreward, when an active behavioral response is possible (see Figure 3.1). (In particular, anger may occur if another individual prevents an expected reward from being obtained.) Guilt may arise when there is a conflict between an available reward and a rule or law of society.

Jealousy is an emotion that might be aroused in a male if the faithfulness of his partner seems to be threatened by her liaison (e.g., flirting) with another male. In

this case the reinforcement contingency that is operating is produced by a punisher, and it may be that males are specified genetically to find this punishing because it indicates a potential threat to their paternity and paternal investment (Rolls, 2005). Similarly, a female may become jealous if her partner has a liaison with another female, because the resources available to the “wife” useful to bring up her children are threatened. Again, the punisher here may be gene specified (Rolls, 2005). Envy or disappointment might be produced if a prize is obtained by a competitor. In this case, part of the way in which the frustrative nonreward is produced is by the cognitive understanding that this is a competition in which there will be a winner, and that the person has set himself or herself the goal of obtaining it. The partial list of primary reinforcers, shown in Table 3.1, should provide a foundation for starting to understand the rich classification scheme for different types of emotion that can be classified in this way.

TABLE 3.1. Some primary reinforcers, and the dimensions of the environment to which they are tuned.

<i>Taste</i>	
Salt taste	+ reinforcer in salt deficiency
Sweet	+ reinforcer in energy deficiency
Bitter	– reinforcer, indicator of possible poison
Sour	– reinforcer
Umami	+ reinforcer; indicator of protein; produced by monosodium glutamate and inosine monophosphate; see Rolls et al., 1996b
Tannic acid	– reinforcer; prevents absorption of protein; found in old leaves; probably somatosensory rather than strictly gustatory; see Critchley and Rolls, 1996c
<i>Odor</i>	
Putrefying odor	– reinforcer; hazard to health
Pheromones	+ reinforcer (depending on hormonal state)
<i>Somatosensory</i>	
Pain	– reinforcer
Touch	+ reinforcer
Grooming	+ reinforcer; to give grooming may also be a primary reinforcer
Washing	+ reinforcer
Temperature	+ reinforcer if tends to help maintain normal body temperature; otherwise –
<i>Visual</i>	
Snakes, etc.	– reinforcer for, e.g., primates
Youthfulness	+ reinforcer; associated with mate choice
Beauty	+ reinforcer
Secondary sexual characteristics	+ reinforcers
Face expression	+ (e.g., smile) and – (e.g., threat) reinforcer
Blue sky, cover, open space	+ reinforcer; indicator of safety

TABLE 3.1. (continued)

Flowers	+ reinforcer (indicator of fruit later in the season?)
<i>Auditory</i>	
Warning call	– reinforcer
Aggressive vocalization	– reinforcer
Soothing vocalization	+ reinforcer (part of the evolutionary history of music, which at least in its origins taps into the channels used for the communication of emotions)
<i>Reproduction</i>	
Courtship	+ reinforcer
Sexual behavior	+ reinforcer (a number of different reinforcers, including a low waist-to-hip ratio, and attractiveness influenced by symmetry and being found attractive by members of the other sex; discussed in Chapter 8)
Mate guarding	+ reinforcer for a male to protect his parental investment; jealousy results if his mate is courted by another male, because this may ruin his parental investment
Nest building	+ reinforcer (when expecting young)
Parental attachment	+ reinforcer
Infant attachment to parents	+ reinforcer
Infant crying	– reinforcer to parents; produced to promote successful development
<i>Other</i>	
Novel stimuli	+ reinforcers; encourage animals to investigate the full possibilities of the multidimensional space in which their genes are operating
Sleep	+ reinforcer; minimizes nutritional requirements and protects from danger
Altruism to genetically related individuals (kin altruism)	+ reinforcer
Altruism to other individuals (reciprocal altruism)	+ reinforcer when the altruism is reciprocated in a “tit-for-tat” reciprocation; – reinforcer when the altruism is not reciprocated
Group acceptance	+ reinforcer (social greeting might indicate this)
Control over actions	+ reinforcer
Play	+ reinforcer
Danger, stimulation, excitement	+ reinforcer if not too extreme (adaptive because practice?)
Exercise	+ reinforcer (keeps the body fit for action)
Mind reading	+ reinforcer; practice in reading others’ minds, which might be adaptive
Solving an intellectual problem	+ reinforcer (practice that might be adaptive)
Storing, collecting	+ reinforcer (e.g., food)
Habitat preference, home, territory	+ reinforcer
Some responses	+ reinforcer (e.g., pecking in chickens, pigeons; adaptive because it is a simple way in which eating grain can be programmed for a relatively fixed type of environmental stimulus)
Breathing	+ reinforcer

Many other similar examples can be surmised from the area of evolutionary psychology (Barratt, Dunbar, & Lycett, 2002; Buss, 1999; Ridley, 1993). For example, there may be a set of reinforcers that are genetically specified to help promote social cooperation and even reciprocal altruism. Such genes might specify that emotion should be elicited, and behavioral changes should occur, if a cooperating partner defects or “cheats.” Moreover, the genes may build brains with genetically specified rules that are useful heuristics for social cooperation, such as acting with a strategy of “generous tit-for-tat,” which can be more adaptive than strict “tit-for-tat,” in that being generous occasionally is a good strategy to help promote further cooperation that has failed when both partners defect in a strict “tit-for-tat” scenario (Ridley, 1993). Genes that specify good heuristics to promote social cooperation may thus underlie such complex emotional states as feeling forgiving. As in the other reinforcers specified by genes, genetic variation may lead to differences among individuals.

It is also worth noting that emotions can be elicited by the recall of reinforcing events as well as by external reinforcing stimuli; that cognitive processing (whether conscious or not) is important in many emotions, for very complex cognitive processing may be required to determine whether or not environmental events are reinforcing. Indeed, emotions normally consist of cognitive processing, which analyses the stimulus and then determines its reinforcing valence; and then an elicited mood change if the valence is positive or negative. In that an emotion is produced by a stimulus, philosophers say that emotions have an object in the world, and that emotional states are intentional, in that they are about something. We note that a mood or affective state may occur in the absence of an external stimulus, as in some types of depression, but that normally the mood or affective state is produced by an external stimulus, with the whole process of stimulus representation, evaluation in terms of reward or punishment, and the resulting mood or affect being referred to as emotion.

An external stimulus may be perceived consciously, but stimuli that are not perceived consciously may also produce emotion. Indeed, there may be separate routes to action for conscious and unconscious stimuli (Rolls, 2005). Further, emotional states (i.e., those elicited by reinforcers) have many functions (as described in the next section), and the implementations of only some of these functions by the brain are associated with emotional feelings, that is, with conscious emotional states (Rolls, 2005). There is, for example, evidence for interesting dissociations in some patients with brain damage between actions performed to reinforcing stimuli and what is subjectively reported. In this sense it is biologically and psychologically useful to consider emotional states to include more than those states associated with conscious feelings of emotion (Rolls, 2005).

The Functions of Emotion

The functions of emotion provide insight into the evolution of emotion and lead to the view that particular types of neural processing and brain systems may have evolved

for emotion, and thus that some factors involved in what might be termed emotional intelligence may be separable from some processes involved in other types of cognition and intelligence. These functions, described more fully elsewhere (Rolls, 2005), can be summarized as follows:

1. The *elicitation of autonomic responses* (e.g., a change in heart rate) and *endocrine responses* (e.g., the release of adrenaline).
2. *Flexibility of behavioral responses to reinforcing stimuli*. This is a crucial function of emotion in my evolutionary theory of why emotion is so important. Emotional (and motivational) states allow a simple interface between sensory inputs and action systems. The essence of this idea is that goals for behavior are specified by reward and punishment evaluation, and the innate goals are specified by genes. When an environmental stimulus has been decoded as a primary reward or punishment, or (after previous stimulus-reinforcer association learning) a secondary rewarding or punishing stimulus, then it becomes a goal for action. The animal can then perform any action (instrumental response) to obtain the reward, or to avoid the punisher. The instrumental action or “operant” is arbitrary, and could consist of a left turn, or a right turn, to obtain the goal.

It is in this sense that by specifying goals and not particular actions, the genes are specifying flexible routes to action. This is in contrast to specifying a reflex response, and is also in contrast to stimulus-response, or habit, learning in which a particular response to a particular stimulus is learned. It also contrasts with the elicitation of species-typical behavioral responses by sign-releasing stimuli (such as pecking at a spot on the beak of the parent herring gull in order to be fed [Tinbergen, 1951], in which there is inflexibility of the stimulus and the response, and which can be seen as a very limited type of brain solution to the elicitation of behavior). The emotional route to action is flexible not only because any action can be performed to obtain the reward or avoid the punishment, but also because the animal can learn in as little as one trial that a reward or punishment is associated with a particular stimulus, in what is termed “stimulus-reinforcer association learning.” It is because goals are specified by the genes, and not actions, that evolution has achieved a powerful way for genes to influence behavior without having to rather inflexibly specify particular responses.

An example of a goal might be a sweet taste when hunger is present. We know that particular genes specify the sweet taste receptors, and other genes must specify that only when there is a homeostatic need state for food that the sweet taste is rewarding (Rolls, 2005). Different goals or rewards, including social rewards, are specified by different genes, and each type of reward must not dominate the others if it is to succeed in the phenotype that carries the genes.

All of these gene-specified reinforcers are primary reinforcers. A preliminary list of these, which is subject to extension and revision, but which is intended to convey the types of stimuli that may be primary reinforcers, was shown in Table 3.1. Each of these genes may be thought of as specifying a different

type of emotional competence. To the extent that genes evolve independently, in competition, I thus argue that not only are there many partly independent emotional competencies, but also that they are likely to be partly independent of other types of cognitive processing and general intelligence. Thus the specialized genes for emotion, and the partly specialized brain systems such as the amygdala and orbitofrontal cortex that process the reinforcement-related information as specified by these genes, provide an “emotional competencies” approach to emotional intelligence that separates it in part from other cognitive functions and general intelligence.

Selecting between available rewards with their associated costs, and avoiding punishers with their associated costs, is a process that can take place both implicitly (unconsciously), and explicitly using a language system to enable long-term plans to be made and corrected (Rolls, 2005). These many different brain systems, some involving implicit evaluation of rewards, and others explicit, verbal, conscious, evaluation of rewards and planned long-term goals, must all enter into the selection systems for behavior (see Figure 3.2). These selector or decision systems are poorly understood, but might include a process of competition between all the competing calls on output, and might involve structures such as the cingulate cortex and basal ganglia in the brain, which receive from structures such as the orbitofrontal cortex and amygdala, which compute the rewards (see Figure 3.2 and Rolls, 2005). The decision-making process itself may involve biased competition, with the biasing inputs representing the rewards with their associated costs (Deco & Rolls, 2006).

3. Emotion is *motivating*, as just described. For example, fear learned by stimulus-reinforcement association provides the motivation for actions performed to avoid noxious stimuli. Genes that specify goals for action, for example, rewards, must as an intrinsic property make the animal motivated to obtain the reward, otherwise it would not be a reward. Thus no separate explanation of motivation is required.
4. *Communication*. Monkeys, for example, may communicate their emotional state to others by making an open-mouth threat to indicate the extent to which they are willing to compete for resources, and this may influence the behavior of other animals. This aspect of emotion was emphasized by Darwin (1872), and has been studied more recently by Ekman (1982, 1992). Ekman reviews evidence that humans can categorize facial expressions into the categories happy, sad, fearful, angry, surprised and disgusted, and that this categorization may operate similarly in different cultures. He also describes how the facial muscles produce different expressions. Many different types of gene-specified reward have been suggested by Rolls (2005; see Table 3.1), and include not only genes for kin altruism, but also genes to facilitate social interactions that may be to the advantage of those competent to cooperate, as in reciprocal altruism.
5. *Social bonding*. Examples of this are the emotions associated with the attachment of the parents to their young, and the attachment of the young to their

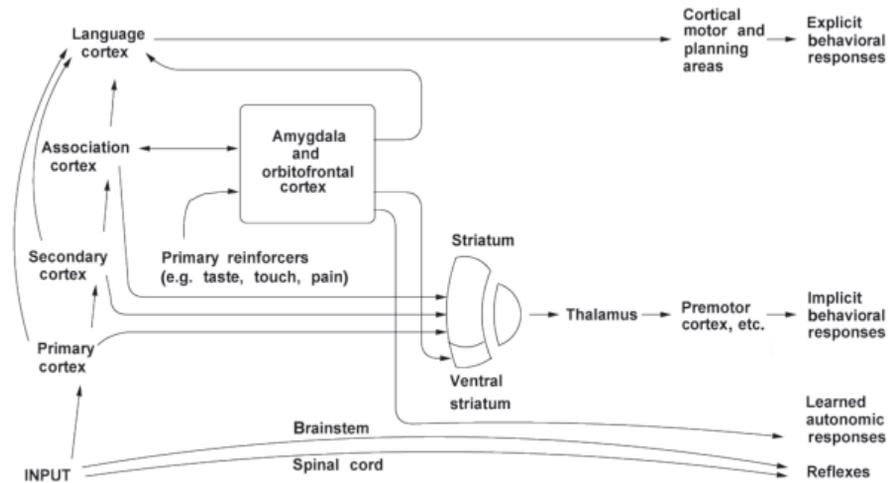


Figure 3.2. Dual routes to the initiation of action in response to rewarding and punishing stimuli. The inputs from different sensory systems to brain structures such as the orbitofrontal cortex and amygdala allow these brain structures to evaluate the reward- or punishment-related value of incoming stimuli, or of remembered stimuli. The different sensory inputs enable evaluations within the orbitofrontal cortex and amygdala based mainly on the primary (unlearned) reinforcement value for taste, touch, and olfactory stimuli, and on the secondary (learned) reinforcement value for visual and auditory stimuli. In the case of vision, the “association cortex,” which outputs representations of objects to the amygdala and orbitofrontal cortex, is the inferior temporal visual cortex. One route for the outputs from these evaluative brain structures is via projections directly to structures such as the basal ganglia (including the striatum and ventral striatum) to enable implicit, direct behavioral responses based on the reward- or punishment-related evaluation of the stimuli to be made. The second route is via the language systems of the brain, which allow explicit (verbalizable) decisions involving multistep syntactic planning to be implemented.

parents. The attachment of the parents to each other is also beneficial in species such as many birds, and humans, in which the offspring are more likely to survive if both parents are involved in the care (Rolls, 2005).

6. *The current mood state can affect the cognitive evaluation of events or memories* (Oatley & Jenkins, 1996). This may facilitate continuity in the interpretation of the reinforcing value of events in the environment. A hypothesis that back-projections from parts of the brain involved in emotion such as the orbitofrontal cortex and amygdala to higher perceptual and cognitive cortical areas implement this is described in *Emotion Explained* (Rolls, 2005), and is developed in a formal model of interacting attractor (short-term memory) networks (Rolls & Stringer, 2001). In this model, the weak back-projections from the “mood” attractor can, because of associative connections formed when the perceptual

and mood states were originally present, influence the states into which the perceptual or memory attractor falls.

7. Emotion may facilitate the *storage of memories*. One way this occurs is that episodic memory (i.e., one's memory of particular episodes) is facilitated by emotional states. This may be advantageous in that storing many details of the prevailing situation when a strong reinforcer is delivered may be useful in generating appropriate behavior in situations with some similarities in the future. This function may be implemented by the relatively nonspecific projecting systems to the cerebral cortex and hippocampus, including the cholinergic pathways in the basal forebrain and medial septum, and the ascending noradrenergic pathways (Rolls, 2005). A second way in which emotion may affect the storage of memories is that the current emotional state may be stored with episodic memories, providing a mechanism for the current emotional state to affect which memories are recalled. A third way that emotion may affect the storage of memories is by guiding the cerebral cortex in the representations of the world that are set up. For example, in the visual system it may be useful for perceptual representations or analyzers to be built that are different from each other if they are associated with different reinforcers, and for these to be less likely to be built if they have no association with reinforcement. Rolls and Treves (1998) and Rolls and Deco (2002) discuss ways in which back-projections from parts of the brain important in emotion (such as the amygdala) to parts of the cerebral cortex could perform this function.
8. Another function of emotion is that by enduring for minutes or longer after a reinforcing stimulus has occurred, it may help to produce *persistent and continuing motivation and direction of behavior* to help achieve a goal or goals.
9. Emotion may trigger the *recall of memories* stored in neocortical representations. Amygdala back-projections to the cortex could perform this for emotion in a way analogous to that in which the hippocampus could implement the retrieval in the neocortex of recent (episodic) memories (Rolls & Stringer, 2001; Rolls & Treves, 1998). This is one way in which the memories recalled can be biased by mood states.

Reward, Punishment and Emotion in Brain Design: An Evolutionary Approach

The implication of this approach to emotion and its evolution (Rolls, 2005) is that operation by animals using reward and punishment systems tuned to dimensions of the environment that increase fitness provides a mode of operation that can work in organisms that evolve by natural selection. It is clearly a natural outcome of Darwinian evolution to operate using reward and punishment systems tuned to fitness-related dimensions of the environment, if arbitrary responses are to be made by the animals, rather than just preprogrammed movements such as taxes and reflexes. Is there any alternative to such

a reward/punishment based system in this evolution by natural selection situation? It is not clear that there is, if the genes are efficiently to control behavior by specifying the goals for actions. The argument is that genes can specify actions that will increase their fitness if they specify the goals for action. It would be very difficult for them in general to specify in advance the particular responses to be made to each of a myriad of different stimuli. This may be why we are built to work for rewards, avoid punishers, and to have emotions and needs (motivational states). This view of brain design in terms of reward and punishment systems built by genes that gain their adaptive value by being tuned to a goal for action (Rolls, 2005) offers, I believe, a deep insight into how natural selection has shaped many brain systems, and is a fascinating outcome of Darwinian thought. It also shows how these reinforcer-processing systems could be used to define brain processing for different types of emotional competencies, and how these competencies could be different from other types of cognitive processing and general intelligence.

Dual Routes to Action

It is suggested (Rolls, 1999, 2005) that there are two types of route to action performed in relation to reward or punishment in humans. Examples of such actions include emotional and motivational behavior.

The first (implicit) route is via the brain systems that have been present in nonhuman primates such as monkeys, and to some extent in other mammals, for millions of years. These systems include the amygdala and, particularly well developed in primates, the orbitofrontal cortex. These systems control behavior in relation to previous associations of stimuli with reinforcement. The computation that controls the action thus involves assessment of the reinforcement-related value of a stimulus.

This assessment may be based on a number of different factors. One is the previous reinforcement history, which involves stimulus-reinforcement association learning using the amygdala, and its rapid updating especially in primates using the orbitofrontal cortex. This stimulus-reinforcement association learning may involve quite specific information about a stimulus, for example, of the energy associated with each type of food, by the process of conditioned appetite and satiety. A second is the current motivational state, for example, whether hunger is present, whether other needs are satisfied, and so forth.

A third factor that affects the computed reward value of the stimulus is whether that reward has been received recently. If it has been received recently but in small quantity, this may increase the reward value of the stimulus. This is known as incentive motivation or the “salted nut” phenomenon. The adaptive value of such a process is that this positive feedback of reward value in the early stages of working for a particular reward tends to lock the organism onto behavior being performed for that reward. This means that animals that are, for example, almost equally hungry and thirsty will show hysteresis in their choice of action, rather than continually switching from eating to drinking and back with each mouthful of water or food. This introduction of hysteresis into the reward evaluation system makes action selection a much more efficient process

in a natural environment, for constantly switching between different types of behavior would be very costly if all the different rewards were not available in the same place at the same time. (For example, walking half a mile between a site where water was available and a site where food was available after every mouthful would be very inefficient.) The amygdala is one structure that may be involved in this increase in the reward value of stimuli early on in a series of presentations, in that lesions of the amygdala (in rats) abolish the expression of this reward-incrementing process, which is normally evident in the increasing rate of working for a food reward early on in a meal, and amygdala lesions do impair the hysteresis normally built in to the food-water switching mechanism (Rolls, 2005).

A fourth factor is the computed absolute value of the reward or punishment expected or being obtained from a stimulus, e.g., the sweetness of the stimulus (set by evolution so that sweet stimuli will tend to be rewarding, because they are generally associated with energy sources), or the pleasantness of touch (set by evolution to be pleasant according to the extent to which it brings animals together [e.g., for sexual reproduction, for maternal behavior, and for grooming], and depending on the investment in time that the partner is willing to put into making the touch pleasurable, a sign that indicates the commitment and value for the partner of the relationship). After the reward value of the stimulus has been assessed in these ways, behavior is then initiated based on approach toward or withdrawal from the stimulus. A critical aspect of the behavior produced by this type of system is that it is aimed directly toward obtaining a sensed or expected reward, by virtue of connections to brain systems such as the basal ganglia, which are concerned with the initiation of actions (see Figure 3.2). The expectation may of course involve behavior to obtain stimuli associated with reward, which might even be present in a chain. This expectation is built by stimulus-reinforcement association learning in the amygdala and orbitofrontal cortex, reversed by learning in the orbitofrontal cortex, from where signals may reach the dopamine system (Rolls, 2005).

Now part of the way in which the behavior is controlled with this first (implicit) route is according to the reward value of the outcome. At the same time, the animal may only work for the reward if the cost is not too high. Indeed, in the field of behavioral ecology, animals are often thought of as performing optimally on some cost-benefit curve (see, e.g., Krebs & Kacelnik, 1991). This does not at all mean that the animal thinks about the rewards and performs a cost-benefit analysis using a lot of thoughts about the costs, other rewards available and their costs, and so forth. Instead, it should be taken to mean that in evolution, the system has evolved in such a way that the manner in which the reward varies with the different energy densities or amounts of food and the delay before it is received, can be used as part of the input to a mechanism that has also been built to track the costs of obtaining the food (e.g., energy loss in obtaining it, risk of predation), and to then select given many such types of reward and the associated cost, the current behavior that provides the most “net reward.” Part of the value of having the computation expressed in this reward-minus-cost form is that there is then a suitable “currency,” or net reward value, to enable the animal

to select the behavior with currently the most net reward gain (or minimal aversive outcome).

The second (explicit) route in humans involves a computation with many “if... then” statements, to implement a plan to obtain a reward. In this case, the reward may actually be *deferred* as part of the plan, which might involve working first to obtain one reward, and only then to work for a second more highly valued reward, if this was thought to be overall an optimal strategy in terms of resource usage (e.g., time). In this case, syntax is required, because the many symbols (e.g., names of people) that are part of the plan must be correctly linked or bound. Such linking might be of the form: “if A does this, then B is likely to do this, and this will cause C to do this...” The requirement of syntax for this type of planning implies that an output to language systems that at least can implement syntax in the brain is required for this type of planning (Rolls, 2004b; see Figure 3.2). Thus the explicit language system in humans may allow working for deferred rewards by enabling use of a one-off, individual, plan appropriate for each situation. Another building block for such planning operations in the brain may be the type of short-term memory in which the prefrontal cortex is involved. This short-term memory may be, for example, in nonhuman primates of where in space a response has just been made. A development of this type of short-term response memory system in humans to enable multiple short-term memories to be held in place correctly, preferably with the temporal order of the different items in the short-term memory coded correctly, may be another building block for the multiple step “if... then” type of computation in order to form a multiple step plan. Such short-term memories are implemented in the (dorsolateral and inferior convexity) prefrontal cortex of nonhuman primates and humans and may be part of the reason prefrontal cortex damage impairs planning and the selection of action (Deco & Rolls, 2005a; Goldman-Rakic, 1996; Rolls & Deco, 2002).

Of these two routes (see Figure 3.2), it is the second, involving syntax and higher order thoughts, that I have suggested above is related to consciousness (Rolls, 2004b, 2005). This second route, with multistep plans, and thoughts about thoughts, may be related to some aspects of general intelligence, and to the extent that this second route can be used for both emotional and nonemotional processing, this aspect of emotional intelligence and general intelligence may be difficult to separate. This type of ability may underlie what contributes to emotional understanding in the sense in which it is used in the context of emotional intelligence (Mayer, Salovey, Caruso, & Sitarenios, 2001).

The question then arises of how decisions are made in animals such as humans, who have both the implicit, direct reward-based, and the explicit, rational, planning systems (see Figure 3.2). One particular situation in which the first, implicit, system may be especially important is when rapid reactions to stimuli with reward or punishment value must be made, for then the direct connections from structures such as the orbitofrontal cortex to the basal ganglia may allow rapid actions. Another is when there may be too many factors to be taken into account easily by the explicit, rational, planning system, when the implicit system may be used to guide action. In contrast, when the implicit

system continually makes errors, it would then be beneficial for the organism to switch from automatic, direct action based on obtaining what the orbitofrontal cortex system decodes as being the most positively reinforcing choice currently available, to the explicit conscious control system that can evaluate with its long-term planning algorithms what action should be performed next. Indeed, it would be adaptive for the explicit system to regularly be assessing performance by the more automatic system, and to switch itself in to control behavior quite frequently, as otherwise the adaptive value of having the explicit system would be less than optimal.

Another factor that may influence the balance between control by the implicit and explicit systems is the presence of pharmacological agents such as alcohol, which may alter the balance toward control by the implicit system, allow the implicit system to influence more the explanations made by the explicit system, and within the explicit system alter the relative value it places on caution and restraint versus commitment to a risky action or plan.

There may also be a flow of influence from the explicit, verbal system to the implicit system, in that the explicit system may decide on a plan of action or strategy and exert an influence on the implicit system that will alter the reinforcement evaluations made by and the signals produced by the implicit system. An example of this might be that if a pregnant woman feels that she would like to escape a cruel mate, but is aware that she may not survive in the jungle, then it would be adaptive if the explicit system could suppress some aspects of her implicit behavior toward her mate, so that she does not give signals that she is displeased with her situation.

Another example might be that the explicit system might, because of its long-term plans, influence the implicit system to increase its response to a positive reinforcer. One way in which the explicit system might influence the implicit system is by setting up the conditions in which, when a given stimulus (e.g., person) is present, positive reinforcers are given to facilitate stimulus-reinforcement association learning by the implicit system of the person receiving the positive reinforcers. Conversely, the implicit system may influence the explicit system, for example, by highlighting certain stimuli in the environment that are currently associated with reward to guide the attention of the explicit system to such stimuli.

However, it may be expected that there is often a conflict between these systems, in that the first, implicit, system is able to guide behavior particularly to obtain the greatest immediate reinforcement, whereas the explicit system can potentially enable immediate rewards to be deferred, and longer term, multistep plans to be formed. This type of conflict will occur in animals with a syntactic planning ability (as described above) that is in humans and any other animals that have the ability to process a series of “if . . . then” stages of planning. This is a property of the human language system, and the extent to which it is a property of nonhuman primates is not yet fully clear. In any case, such conflict may be an important aspect of the operation of at least the human mind, because it is so essential for humans to correctly decide, at every moment, whether to invest in a relationship or a group that may offer long-term benefits, or whether to directly pursue immediate benefits.

A Neurobiological Approach to Emotional Intelligence

Within the framework described above, we now consider whether during evolution special neurobiological systems have been shaped to implement the types of processing involved in emotion. To the extent that they are special and independent of some other brain systems involved in other types of computation, we might have a new approach to understanding how competencies that might underlie emotional intelligence might be separate from other types of intelligence. In the approach described here, *emotional intelligence* would be defined in terms of the special competencies elucidated within the above framework that provide the reinforcer-related processing capacities involved in emotion. These competencies might involve, for example, the ability to respond to a small change of facial expression, and to adjust one's social and emotional behavior accordingly (Kringelbach & Rolls, 2003; Rolls, 2005). A new approach to understanding and even defining emotional intelligence may be particularly useful in view of the evidence that it is difficult to separate current concepts of emotional intelligence (Goleman, 1996; Mayer et al., 2001) from other types of intelligence including general intelligence, and from other constructs (Matthews et al., 2002, 2004).

The concept in the literature of emotional intelligence envisages four processes (Matthews et al., 2002, 2004; Mayer et al., 2001). The first is *emotion perception*. To the extent that this is perception of emotion in others, what I describe in this chapter and elsewhere (Rolls, 2005) related to decoding primary reinforcers such as facial expression and performing stimulus-reinforcer association learning and reversal based on, for example a facial expression associated with subsequent reinforcers, is relevant.

The second is *emotion understanding*. To the extent that this involves emotions produced by external stimuli or events, what I describe in this chapter and elsewhere (Rolls, 2005) about decoding primary reinforcers and stimulus-reinforcer learning is fundamental. These processes correspond in part to primary appraisal in appraisal theory and involve assessing the rewards and punishers that are present (Oatley & Jenkins, 1996). To the extent that emotion understanding might involve thoughts about emotions, this would be part of the higher order syntactic thought system described above under dual routes to action.

The third process is *emotion assimilation*, which involves incorporating one's current emotional circumstances into one's mental life, and this would also seem to involve higher order thoughts and planning for future actions given the emotional context.

The fourth process involves *emotion regulation*, and this could cover a whole host of processes, from autonomic responses through instrumental actions to obtain goals using action-outcome learning, to multistep action planning requiring syntax, and benefiting from higher order thoughts in order to correct the plans. The fourth process, and to some extent the third, may correspond in part to secondary appraisal in appraisal theory. In the next subsections, I describe some of the functions that are involved in emotion when a neurobiological perspective is taken (Rolls, 2005) and show how these functions lead to a new approach to emotional intelligence.

Decoding Primary Reinforcers

A crucial aspect of emotion according to Rolls' theory of emotion (Rolls, 2005) is the ability to respond to primary (unlearned) reinforcers and to treat these as goals for action. There are many emotional competencies of this type. To respond to primary reinforcers, the brain builds special systems that represent different types of reinforcers in terms of their reinforcement value, and this is what I mean by decoding reinforcers.

The concept can be made clear by considering sweet taste. The reward or reinforcing value of the sweet taste is independent of the quality or intensity of the taste, in that the reward value can decrease to zero after eating sucrose to satiety, yet it still tastes as sweet as before feeding to satiety (Rolls, Rolls, & Rowe, 1983). The intensity of the taste is represented in the primary taste cortex in the anterior insula, and the reward value or pleasantness in the secondary taste cortex in the orbitofrontal cortex (Rolls, 2005). Sensory-specific satiety, the process by which the reward value of a particular stimulus consumed to satiety or received for a period in the order of a number of minutes, may decrease relative to other stimuli but independently of the perceived intensity of the stimulus appears to be a general property of reward systems that has the important adaptive function of promoting a variety of goals (Rolls, 2005).

These points, and much other evidence, show that the reward value of different primary reinforcers must be regulated independently (Rolls, 2005). This occurs both on the short timescale of minutes, but also in evolutionary time in the sense that different genes determine which stimuli in the environment are primary reinforcers, and the genes can be seen as promoting their own fitness independently of each other by (selfish) competition (Dawkins, 1986, 1989), but also to some extent by cooperating, in that no one reinforcement system must become so rewarding that it always wins the competition against the other reward systems, as this would be highly maladaptive (Rolls, 2005).

Given that there are specialized systems for decoding primary reinforcers, and that they are genetically, functionally, and in terms of their neural implementation, partly separate, this provides one basis for different processing relevant to emotions to be separable from other types of processing, such as spatial navigation and spatial ability. This is one sense in which some aspects of "emotional intelligence" by virtue of these emotional competencies could be different from other types of intelligence.

Some of the types of primary reinforcers that are relevant were depicted earlier in Table 3.1. They include homeostatically relevant primary reinforcers such as food when hungry, and water when thirsty. They also include specialized perceptual systems for decoding facial expression, which is an important signal in regulation emotion and emotional behavior. The systems involved include specialized temporal lobe visual cortical areas with neuronal responses to facial expressions but not facial identity (Hasselmo, Rolls, & Baylis, 1989; Rolls, 2007b), and orbitofrontal cortex regions with selective responses to faces (Rolls, Critchley, Browning, & Inoue, 2006), which if damaged lead to difficulties in recognizing facial (and/or vocal) expressions (Hornak et al., 2003).

The primary reinforcers will also include systems relevant to identifying kin (based perhaps on sensory cues and also on learning) that will be important in kin altruism,

and there could be gene-based differences in the extent to which individuals invest in their kin and show family attachment, which could make a contribution to differences in emotional intelligence. They will also include systems relevant to reciprocal altruism, such as being sensitive to whether a particular individual is cooperating or defecting. There appear to be specialized systems important in risk taking and sensation seeking (Zuckerman, 1994; Zuckerman & Kuhlman, 2000), promiscuity (Hamer & Copeland, 1998), and impulsiveness with an implementation in the orbitofrontal cortex (Berlin, Rolls, & Iversen, 2005; Berlin, Rolls, & Kischka, 2004). There may also be more general systems related to personality that reflect sensitivity to punishers including nonreward versus rewards (Gray, 1979, 1987; Matthews & Gilliland, 1999; Matthews et al., 2002).

Concepts of emotional intelligence (Goleman, 1996; Mayer et al., 2001) tend to focus on social reinforcers, but these are just part of the range of reinforcers that contribute to defining emotion and affect (Rolls, 2005).

Learning and Reversing Associations to Primary Reinforcers

Given the importance of rewards and punishers in emotion, the learning of associations from previously neutral stimuli to primary reinforcers is the type of learning that is fundamental in emotion, and that is another type of emotional competency. It is also very important that such associations can be rapidly and flexibly reversed. For example, in social interactions, even a short change in a facial expression may indicate that a change of behavior to the person is appropriate. The processes that underlie this type of associative learning, which is stimulus-stimulus (in that the primary reinforcer is a stimulus), are therefore of considerable interest as emotional competencies and are also of clinical relevance.

It appears that different brain systems, especially the amygdala and orbitofrontal cortex, make different types of contribution to this learning with, as described next, the amygdala playing a special role in learning these associations, and the orbitofrontal cortex in rapidly reversing them. Given that these are systems that are at least partially separate and have evolved differently, with the amygdala present in fish and reptiles, and the orbitofrontal cortex appearing in mammals but developing greatly in primates including humans, it is possible that genetic variation can occur to some extent independently for these systems. This, it is suggested, could lead individuals to differ in their emotional learning and in their ability to respond rapidly to changes in reinforcement contingency, and it is therefore suggested that these could be part of a new neurobiologically based approach to emotional intelligence.

Given the anatomical connections shown in Figure 3.3, there would not seem to be the basis in the high order visual cortical areas, such as the inferior temporal visual cortex, for associations between visual stimuli and primary reinforcers to be learned, in that taste and somatosensory stimuli do not reach these cortical areas. This has been directly demonstrated, in that when the reward that is normally obtained if the monkey

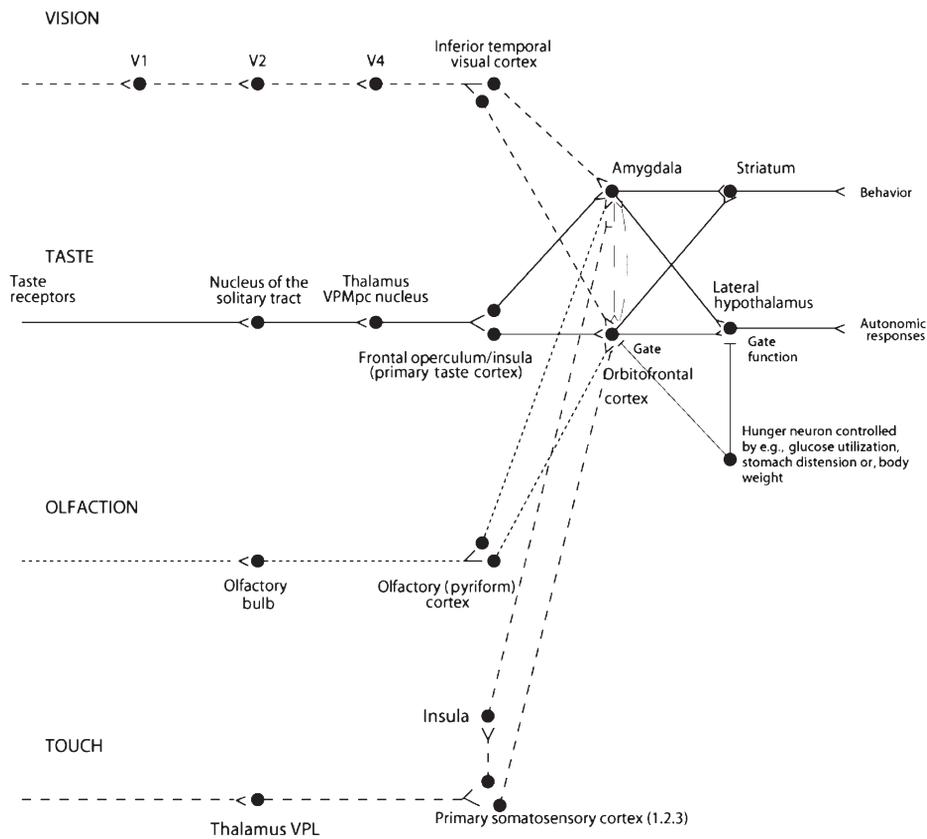


Figure 3.3. Schematic diagram showing some of the gustatory, olfactory, visual, and somatosensory pathways to the orbitofrontal cortex and amygdala, and some of the outputs of the orbitofrontal cortex and amygdala. The secondary taste cortex, and the secondary olfactory cortex, are within the orbitofrontal cortex. V1 = primary visual cortex; V4 = visual cortical area V4

licks to a visual stimulus is altered in a visual discrimination task so that after reversal the monkey would obtain aversive salt if he licked, there is no alteration of the responses of inferior temporal cortex neurons, which continue to fire to the physical stimulus to which they respond, independently of its affective significance (Rolls, Aggelopoulos, & Zheng, 2003; Rolls, Judge, & Sanghera, 1977).

In contrast, some neurons in the macaque orbitofrontal cortex learn in as little as one trial to respond to a visual stimulus associated with a taste reward, and can reverse this response when the reinforcement contingencies are reversed (Rolls, Critchley, Mason, & Wakeman, 1996; Thorpe, Rolls, & Maddison, 1983). These neurons reflect the reward (or affective) value of the visual stimulus, in that they stop responding to the visual stimulus gradually as the monkey is fed to satiety (Critchley & Rolls, 1996). Also consistent with this, lesions of the macaque orbitofrontal cortex impair stimulus-reward reversal learning and extinction (see Rolls, 2005), and deficits in this type of learning

are also found in humans after orbitofrontal cortex lesions (Hornak et al., 2004; Rolls, Hornak, Wade, & McGrath 1994).

In humans, activation of the orbitofrontal cortex can reflect quite abstract rewards, though in the end may be associated with primary reinforcers, such as monetary reward (medially) and loss (laterally; O'Doherty, Kringelbach, Rolls, Hornak, & Andrews, 2001). A probabilistic presentation of the magnitude of reward was used in this investigation, and a complementary investigation with the same task in patients with lesions of the orbitofrontal cortex (Hornak et al., 2004) so that the magnitude of the brain activation could be correlated in a single-event fMRI design with the amount of monetary reward or loss on each trial, and to minimize the use of verbal strategies and encourage the use of implicit associative emotional learning processes.

The special role of the orbitofrontal cortex in rapid reversal of stimulus-reinforcement associations is expressed also in the presence in the orbitofrontal cortex of neurons that respond when an expected reward is not obtained (Thorpe et al., 1983), and these can be called reward error neurons or frustrative nonreward neurons. They may have a special role in reversal (Deco & Rolls, 2005b; Rolls, 2004a, 2005). Consistent with this evidence in macaques, Kringelbach and Rolls (2003, 2004) found activation of a lateral part of the human orbitofrontal cortex specifically when a changed facial expression was used as a cue to signal reversal in a visual discrimination task.

The amygdala receives information about primary reinforcers (such as taste and touch), and also information about visual and auditory stimuli from higher cortical areas (such as the inferior temporal cortex) that can be associated by learning with primary reinforcers (Figure 3.3). Bilateral removal of the amygdala in monkeys produces tameness, a lack of emotional responsiveness, excessive examination of objects, often with the mouth, and eating of previously rejected items such as meat (the Kluver-Bucy syndrome). In analyses of the bases of these behavioral changes, it has been observed that there are deficits in learning to associate stimuli with primary reinforcement, including both punishments and rewards (Rolls, 2005). The association learning deficit is present when the associations must be learned from a previously neutral stimulus (e.g., the sight of an object) to a primary reinforcing stimulus (such as the taste of food).

Further evidence linking the amygdala to reinforcement mechanisms is that monkeys will work in order to obtain electrical stimulation of the amygdala, that single neurons in the amygdala are activated by brain-stimulation reward of a number of different sites, and that some amygdala neurons respond mainly to rewarding stimuli, and others to punishing stimuli (Rolls, 2005). The association learning in the amygdala may be implemented by associatively modifiable synapses from visual and auditory neurons onto neurons receiving inputs from taste, olfactory, or somatosensory primary reinforcers (LeDoux, 2000).

Consistent with this, Davis (2001) has found that at least one type of associative learning in the amygdala can be blocked by local application to the amygdala of a NMDA receptor blocker, which blocks long-term potentiation (LTP), which is a model of the synaptic changes that underlie learning (Rolls & Deco, 2002; Rolls & Treves, 1998). Davis used a fear-potentiated startle response as a measure of the conditioned

fear. Consistent with the hypothesis that the learned incentive (conditioned reinforcing) effects of previously neutral stimuli paired with rewards are mediated by the amygdala acting through the ventral striatum, amphetamine injections into the ventral striatum enhanced the effects of a conditioned reinforcing stimulus only if the amygdala was intact (Cardinal, Parkinson, Hall, & Everitt, 2002).

In an imaging study in humans, Ploghaus et al. (2000) showed that fear conditioning produced activation of the amygdala. A difference between the amygdala and orbitofrontal cortex in stimulus-reinforcement association learning may be that the rapid reversal of the associations may require the orbitofrontal cortex (Rolls, 2005), which may implement this rapid reversal at the neuronal level more efficiently, perhaps because it has rule-based attractor networks that can be rapidly switched by nonreward (Deco & Rolls, 2005b).

Individual variation in the functioning of the orbitofrontal cortex and amygdala could thus result in individuals having different capacities for emotional learning, and in sensitivity to change in reinforcement contingency. This in turn is likely to have implications for personality (Matthews & Gilliland, 1999; Rolls, 2005). Consistent with this, after damage to the human orbitofrontal cortex, there are many changes in emotion (Hornak, Rolls, & Wade, 1996; Hornak et al., 2003; Rolls et al., 1994), and also in impulsiveness, and the impulsiveness is also present in people with borderline personality disorder (Berlin et al., 2004, 2005). It must also be said that the changes in emotion that are produced by bilateral amygdala damage in humans are relatively subtle, with few changes very apparent in their everyday behavior, though there are some deficits in skin conductance response conditioning (Phelps, 2004) and in recognizing fear facial expressions because the eyes are not looked at (Adolphs et al., 2005). It thus appears to be unlikely that the amygdala dominates or controls the orbitofrontal cortex (Goleman, 1996).

Performing Actions to Obtain Emotion-Related Goals—"Emotional Regulation"

As described above, there is evidence for dual routes to action, implicit and explicit. The inherent processes are quite different, and different individuals might be predisposed to utilize these two approaches to different extents. There has to be a decision-making process between the implicit and explicit systems, and this could be biased one way or the other by the relative strengths of the biasing inputs (Deco & Rolls, 2007b) in different individuals. Relevant factors that could be related to this are the relative values of short-term versus long-term rewards. The explicit system may enable one to forgo a short-term reward in order to obtain a better outcome in the long term, but this has to depend on the relative values that are placed on short-term versus long-term, discounted, rewards (Rolls, 2005, pp. 441–443). Impulsiveness may increase the value placed on short-term rewards (Rolls, 2005).

When multistep syntactic planning is being used in the explicit system, then this planning and executive function may utilize brain regions such as the dorsolateral prefrontal cortex (McClure, Laibson, Loewenstein, & Cohen, 2004; Rolls, 2005; Shallice &

Burgess, 1996). To the extent that holding and manipulating many items in short-term memory, and syntactic operations (such as “if...then”) on them, are required for this rational decision making, then these capacities could in principle be used when making both this type of emotional decision and nonemotional explicit decisions, and we might expect that this aspect of emotional intelligence, and nonemotional intelligence, might operate similarly within an individual. Similarly, theory of mind capability may be very useful, but not for emotion only (Bird, Castelli, Malik, Frith, & Husain, 2004).

When implicit decisions are being taken, instrumental learning of the actions required to obtain a goal is required. There are multiple aspects and processes involved in such instrumental learning, each involving somewhat separate neural systems (Rolls, 2005), and, given that they are separate neural systems, there is presumably the opportunity for variation between individuals, and this variation could allow this neurobiologically defined type of emotional competence or intelligence to differ among individuals. The processes involved in instrumental learning include learning the instrumental contingency between the action and a particular outcome (action-outcome contingency), which can be signaled by a learned discriminative stimulus; and a representation of the outcome as a goal (Cardinal et al., 2002; Rolls, 2005). The representation of the outcome as a goal may involve the orbitofrontal cortex, and this may be related to hedonic assessment (Rolls, 2005). Learning action-outcome associations may involve the anterior cingulate cortex. If the behavior becomes overlearned, it may become implemented by stimulus-response habit learning, implemented in the basal ganglia (Rolls, 2005). These types of processes thus involve different brain systems from those involved in explicit reasoning and planning, and thus some emotional competencies that are part of the new concept of emotional intelligence described here may vary independently of reasoning and general intelligence.

In addition to the systems for instrumental action, there are also multiple neural systems (in the amygdala and orbitofrontal cortex) involved in autonomic responses to learned emotion-provoking stimuli (Rolls, 2005). Differing responsiveness among different individuals might produce variation in the emotional competencies, in that some people might be more sensitive to the autonomic consequences of emotional states. This can occur in people subject to panic attacks.

Alexithymia and Emotional Intelligence

When Daniel Goleman (1996) popularized the concept of emotional intelligence, the rather sweeping definition given was “Emotional intelligence [includes] abilities such as being able to motivate oneself and persist in the face of frustrations, to control impulse and delay gratification; to regulate one’s moods and keep distress from swamping the ability to think; to empathize and to hope” (p. 34).

One potential problem with this definition of emotional intelligence as an ability is that different aspects within this definition (such as impulse control and hope) may be unrelated, so a unitary ability described in this way seems unlikely. A critical evaluation of the concept has been produced by Matthews et al. (2002). They note (p. 368) that

in a rough and ready way, one might identify personality traits of emotional stability (low neuroticism), extraversion, agreeableness, and conscientiousness/self-control as dispositions that tend to facilitate everyday social interaction and to promote more positive emotion. (Indeed, one measure of emotional intelligence, the EQ-i, has high correlations with some of the Big Five personality traits, especially, negatively, with neuroticism, and the EQ-i may reflect three constructs: self-esteem, empathy, and impulse control [Matthews et al., 2002].) But these personality traits are supposed to be independent, so linking them to a single ability of emotional intelligence is inconsistent. Moreover, this combination of personality traits might well not be adaptive in many circumstances, so the concept of this combination as an “ability” is inappropriate (pp. 368–370).

However, the concept of emotional intelligence does appear to be related in a general way to the usage of the (mainly clinical) term *alexithymia*, in a sense the opposite, which includes the following components: (a) difficulty in identifying and describing emotions and distinguishing between feelings and the bodily sensations of arousal, (b) difficulty in ascribing feelings to other people, (c) constricted imaginal processes, as evidenced by a paucity of fantasies, and (d) a stimulus-bound externally oriented cognitive style, as evidenced by preoccupation with the details of external events rather than inner emotional experiences (Matthews et al., 2002; Taylor & Bagby, 2004). In terms of personality, alexithymia converges with the first three dimensions of the five-factor model of personality (FFM, the Big Five model), with high N (vulnerability to emotional distress), low E (low positive emotionality), and low O (a limited range of imagination; Matthews et al., 2002). Indeed, alexithymia is strongly inversely correlated with measures of emotional intelligence, suggesting that emotional intelligence may be in part a new term that encompasses much of the opposite of what has been the important concept of alexithymia in the clinical literature for more than 20 years (Matthews et al., 2002).

People diagnosed with alexithymia have difficulties in identifying facial expressions (Lane et al., 1996), suggesting some impairments in the fundamental processing of emotion-related information, in particular capacities known to require the orbitofrontal and anterior cingulate cortices (Hornak et al., 2003) and the amygdala (Adolphs et al., 2005). Consistently, it has been found that anterior cingulate cortex activation is correlated across individuals with their ability to recognize and describe emotions induced either by films or by the recall of personal experiences (Lane et al., 1998). Thus, some aspects of alexithymia, and hence of emotional intelligence, may be related to the emotional competencies approach to emotional intelligence developed in this chapter and elsewhere (Rolls, 2005).

Brain Systems Underlying Emotion

The brain systems underlying emotions have been described elsewhere (Rolls, 2005). Some of functions of the amygdala in emotion have been summarized above, and include a role in conditioned emotional responses. The orbitofrontal cortex, in addition to its

functions in stimulus-reinforcer learning and reversal, is also important in representing many primary reinforcers, including taste and somatosensory reinforcers. It also represents olfactory, facial expression, visual, monetary, and social reinforcers (Rolls, 2005). Damage to the orbitofrontal cortex, and/or to the anterior cingulate cortex, can impair many aspects of emotional behavior. As noted above, the anterior cingulate cortex may be involved in action-outcome learning and thus in implicit emotional behavior, and the basal ganglia in stimulus-response learning. All of these processes may contribute to emotional competencies, including emotional identification and expression and the elicitation of frequently implicit emotional responses. These processes may be relatively independent of general intelligence, and thus we can propose that there is a neurobiological basis for what we might call emotional competencies as a part of emotional intelligence that is separate from general intelligence.

When it comes to using rational, syntactic processing for multistep planning, the emotional system may be able to use the explicit route to action, but in this case it is likely that the system being used is very similar to the planning system that contributes to general intelligence. Thus this explicit, multistep planning, part of emotional intelligence may be difficult to separate from general intelligence.

The Implications for Emotional Intelligence of This Neurobiological Approach to Emotion

1. *How should EI be conceptualized: as a competence, a skill, an adaptive outcome, a set of cultural beliefs or some other construct?* The neurobiological approach proposed here implies that emotional intelligence is a set of competencies that center on abilities to respond to different rewards and punishers. Within this domain, a first issue is that there are many competencies that are to some extent independent, in that different genes specify different primary reinforcers or goals for action, and the genes operate to some extent independently, in competition with each other. The implication is that gene variation across a population will lead to different patterns of competencies in different individuals.

A second issue is that the competencies to learn different reinforcement contingencies (e.g., that a stimulus is associated with reward vs. that a stimulus is no longer associated with reward; see Figure 3.1) may have a different neurobiological basis. The implication is that the competencies in different individuals may vary in ways that may result in different degrees of sensitivity to reward versus nonreward, to punishment versus nonpunishment, and so forth, in different individuals, leading to, for example, different extents of emotional inhibition versus disinhibition, impulsiveness, and so forth, in different individuals.

A third issue, I have argued, is that there are two main routes to action for emotion, the implicit and explicit (Rolls, 2007a). Much of the reward- and punishment-related processing may take place in the brain by systems specialized for such processing (such as the orbitofrontal cortex and amygdala) and may be separable from other

types of cognitive processing (such as spatial ability, multistep planning, and general intelligence), and at least part of this processing is implicit. I have argued that some of the processing in the explicit system is involved with multistep planning, the ability to defer immediate rewards, and so forth, and this type of processing may be useful for both emotional intelligence and general intelligence, and therefore this aspect of emotional intelligence may be difficult to separate from general intelligence.

2. Is the concept of EI compatible with existing theories of emotion and of cognitive intelligence? The approach described here has the implications described in question 1. The approach to EI described in this chapter is consistent with Rolls' theory of emotion (Rolls, 2005), and suggests that future work in the area of EI might take into account both the basic emotion competencies described here, which would be expected to show individual variation, and also the explicit multistep planning type of computation which may be more closely related to general intelligence. It is also of interest that maximizing sensitivity to all emotion competencies might not lead to an animal that had optimal survival fitness. Instead, we might consider that each phenotype contains a unique set of values for the different emotion competencies, and that natural selection operating in a particular environment may favor certain combinations of emotion competencies in which each competency is not set to its maximal value. This is neither a Galtonian position (that more is better), nor an Aristotelian position (that there is an optimum intermediate level), but instead a Darwinian position. The position I propose also suggests that there may not be a general EI (apart from the ability to perform multistep planning, which may not be separable from general intelligence), but that instead emotional competencies may exist in a high dimensional space of competencies, which need not have high correlations between different competencies. That is, this is a multifactorial approach.

3. What are the key components, facets or branches of EI? The approach described here has the implications described in questions 1 and 2.

4. How is EI distinct from existing personality and ability constructs? Could a multistratum psychometric model integrate a dimension or dimensions of EI with existing personality and ability constructs? The approach to emotional intelligence described here is different from existing personality and ability constructs, in that it includes a whole set of emotional competencies that may influence emotional behavior in many ways.

5. How does EI change over the life span, quantitatively and qualitatively? The basic sensitivity to different reinforcers is likely to be relatively constant over the life span. Learned associations of previously neutral stimuli to primary reinforcers are likely to change regularly during life, and may even reverse on a single trial, after one pairing. The ability to use planning to help find multistep solutions with the explicit system is likely to be a skill that can develop continuously, though the ability of different individuals to utilize this aspect of emotional intelligence may be different, and may covary with general intelligence in so far as this reflects multistep planning ability.

6. How might EI contribute to adaptation to real-world social environments? Competencies such as one-trial stimulus-reward reversal learning provide a mechanism for

continually updating one's social responses (Kringelbach & Rolls, 2003; Rolls, 2005). Competencies such as the abilities involved in reciprocal altruism, tit-for-tat game playing and more efficient strategies, defection detection, and face and voice emotional expression recognition will also be important in real-world social adaptation (Rolls, 2005). Multistep planning, with the ability to correct plans using higher order thoughts, will also make important contributions to adaptation to real-world social environments (Rolls, 2004b, 2005, 2007a).

Note

The author has worked on some of the experiments described here with I. de Araujo, G. C. Baylis, L. L. Baylis, M. J. Burton, H. C. Critchley, M. E. Hasselmo, J. Hornak, M. Kringelbach, C. M. Leonard, F. Mora, J. O' Doherty, D. I. Perrett, M. K. Sanghera, T. R. Scott, S. J. Thorpe, and F. A. W. Wilson, and their collaboration, and helpful discussions with or communications from M. Davies (Corpus Christi College, Oxford), D. Rosenthal, and M. S. Dawkins, are sincerely acknowledged. Some of the research described was supported by the Medical Research Council. The author is grateful to Moshe Zeidner for comments on an earlier version of this chapter.

1. Instrumental reinforcers are stimuli that, if their occurrence, termination, or omission is made contingent upon the making of an action, alter the probability of the future emission of that action. Rewards and punishers are instrumental reinforcing stimuli. The notion of an action here is that an arbitrary action, for example, turning right versus turning left will be performed in order to obtain the reward or avoid the punisher, so that there is no prewired connection between the response and the reinforcer. Some stimuli are primary (unlearned) reinforcers (e.g., the taste of food if the animal is hungry, or pain); whereas others may become reinforcing by learning, because of their association with such primary reinforcers, thereby becoming "secondary reinforcers."

This type of learning may thus be called "stimulus-reinforcement association," and occurs via an associative learning process. A positive reinforcer (such as food) increases the probability of emission of a response on which it is contingent; the process is termed positive reinforcement, and the outcome is a reward (such as food). A punisher (such as a painful stimulus) can increase the probability of emission of a response, which causes the negative reinforcer to be omitted (as in active avoidance) or terminated (as in escape), and then acts as a positive reinforcer (Rolls, 2005). If a punisher decreases the probability of omission of a response (as in passive avoidance), then the punisher acts as a negative reinforcer. (Negative reinforcement may also be the result produced by the omission or termination of a reward ["extinction" and "time out" respectively], in that both may decrease the probability of responses [Rolls, 2005].)

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