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The X- and C-systems:

The neural basis of automatic and controlled social cognition

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## The X- and C-Systems: The neural basis of automatic and controlled social cognition.

The distinction between automatic and controlled processing is one of the most important theoretical distinctions made in social cognition. Our understanding on stereotyping (Banaji & Hardin, 1996; Devine, 1989; Macrae, Milne, & Bodenhausen, 1994), attitudes (Wilson, Lindsey, & Schooler, 2000), persuasion (Chaiken, Liberman, & Eagly, 1989; Petty & Cacioppo, 1986), person perception (Gilbert, 1989; Trope, 1986), self-regulation (Wegner, 1994), mood effects (Bless & Schwarz, 1999; Forgas, 1995) have been transformed through the use of cognitive measures to assess automaticity and control. These measures have included reaction time measures, manipulating interstimulus intervals, introducing cognitive load, subliminal priming versus drawing attention to the possible consequences of priming, sequential priming, memory clustering and word stem completion among others (Bargh & Chartrand, 2000). But as with all measures, these have their limits. In this chapter, I hope to suggest that social cognitive neuroscience (Ochsner & Lieberman, 2001) offers additional theoretical and methodological tools that can be marshaled in the effort to better understand the automatic and controlled bases of social cognition.

One of the most fundamental limitations of the dual-process literature (Chaiken & Trope, 1999) is that automaticity and control are defined as opposing anchors on a number of dimensions. Controlled processes are those that score high on dimensions of awareness, effort, intention, and inefficiency (Bargh, 1996). Automatic processes are those that score low on at least one and preferably most of these dimensions. Unfortunately, this mostly paints a picture of what automaticity is not, rather than focusing on what automaticity is.

Still, whether automatic and controlled processes are endpoints on a continuum or qualitatively distinct processes is an empirical question. However, the traditional measures available to assess automaticity and control do not address the question, instead assuming a dimensional approach from the start. For instance, adding a secondary task (i.e., a cognitive load manipulation) to be performed

concurrently with the process of interest allows for the assessment of efficiency. Processes that are more affected by the secondary task are less efficient and therefore more controlled than processes that are less affected. This analysis only provides relative positioning on the dimension of efficiency, but does not and cannot qualitatively identify or even posit boundaries between automaticity and control. However, one can imagine very different accounts of efficiency differences. On the one hand, some task which is performed with great efficiency may have become more automatic over time moving from one end of the continuum towards the other, with the process's internal structure becoming solidified and more efficient. Alternatively, there may be different processes simultaneously supporting the task when the task is performed at different degrees of efficiency. Some processes may be specialized for performing new tasks, but never with great efficiency. Other processes may operate very efficiently, but require a great deal of task experience until they develop to the point of being able to support task performance alone.

At root, this latter account allows for the possibility that qualitatively distinct processes could be at work without easily being identified as such with current measures (cf. Logan, 1988). Moreover, on many cognitive measures a person who is impulsive because of heightened automatic impulsives would be indistinguishable from someone who is impulsive because of deficient controlled processes. In both cases, one would conclude that the individual's cognitive activity is more automatic than controlled, but the causes would be qualitatively different in the two cases, as would the treatments.

If automatic and controlled components of social cognition can be studied separately from one another it may help address numerous questions such as: What is the representational structure of each type of process? Why do attempts at self-control often have paradoxical effects? Why do automatic processes appear to be both rigid (Kawakami et al., 2000) and flexible (Lowery, Hardin & Sinclair, 2001; Mitchell, Nosek, & Banaji, 2003)? How can controlled processes interfere with automatic processes?

## **Cognitive neuroscience revolution**

The issue of whether the differences between automatic and controlled social cognition should be conceived quantitatively or qualitatively is no different than many of the interpretive problems that have faced cognitive scientists for decades. Cognitive psychologists noted long ago that data from cognitive measures will always be consistent with multiple, and potentially infinite, theories or models (Anderson, 1978). Gilbert (1999) made the same assessment of dual-process models of social cognition and concluded that we may be limited to ruling out particular models without ever being able to determine the truth of the matter. Cognitive science's response to this limitation of cognitive measures provides hope. Starting in the 1980s, cognitive scientists began turning to brain data on a regular basis to contrast models of cognition and created the field of cognitive neuroscience in the process. In a longstanding debate over whether memory should be characterized as one or several systems, Schacter (1992) demonstrated with neuropsychological data, and later with neuroimaging data, that there are multiple memory systems. In another debate over whether visual imagery relies on the same or different processes as visual perception, Kosslyn (1994) used neuroimaging techniques to show that the same brain regions are involved in both and therefore that visual imagery recruits perceptual processes.

It is my hope that the study of automatic and controlled social cognition would similarly benefit from incorporating cognitive neuroscience approaches. To begin this process, my collaborators and I have developed a model of the neural bases of automatic and controlled social cognition (Lieberman, 2003; Lieberman, Gaunt, Gilbert, & Trope, 2002; Lieberman, Jarcho, & Satpute, 2005; Lieberman, Schreiber, & Ochsner, 2003). Our model starts from an assumption that automatic and controlled processes are qualitatively distinct, separately evolved, and functionally intertwined mechanisms. Importantly, this assumption is falsifiable and thus is a starting point rather than an ending point.

## The X- and C-systems

In characterizing what we believe to be the two neural systems responsible for automatic and controlled social cognition, we named one system the *X-system*, named for the ‘x’ in reflexive, and the other the *C-system*, named for the ‘c’ in reflective (Lieberman et al., 2002). Because the derivation of these two systems came from cognitive, phenomenological, and neural sources there are many ways in which these systems are not simply automaticity and control with new names (for a review, see Lieberman et al., 2002). Nevertheless, it is fair to say that the X-system is largely responsible for social processes that would be designated as automatic and the C-system is largely responsible for social processes that would be designated as controlled. For the purposes of this chapter, I will be highlighting the similarities more than the differences.

It is worth noting that the word “system” is being used in a loose rather than a strict sense here. That is to say, the X- and C-systems do not differ as much, are not as discrete, and are not as independent as, for instance, the visual system and the digestive system. The X- and C-systems are not conceived as hermetically sealed Fodorian modules. Both the X- and C-systems function to process socioemotional information and these two systems often work hand in hand to achieve socioemotional goals. However, each system has a collection of qualities that are relatively absent in the other system and for the most part, the subregions of each system tend to co-activate when one system’s particular qualities are most adapted to current demands.

In this section, I will be reviewing the brain regions nominated to each system and the original rationale for including them. On a personal note, I must admit that there was a certain degree of exploration in the conceptual development of these systems because cognitive neuroscience had not yet shown much of an interest in social cognition. I asked researchers where we might expect to find activations associated with schemas, implicit prejudice, self-focused attention, and intuitive processing and discovered that these were largely unexplored issues in brain research. As a result, I have assumed that the early proposals for the X- and C-systems would seem incomplete, inaccurate, and probably

naive through the eyes of history. However, the distinction between automaticity and control is so crucial to social cognition that it seemed imperative to map out this distinction as well as possible and then update it as required by the data.

*The X-system.* The main criteria for a system to be nominated for inclusion in the X-system were that it was activated under conditions that promote automatic, implicit, or nonconscious processing of social information. These structures also tend to be phylogenetically older than structures in the C-system and are more conserved across species. According to these criteria, the X-system (see Figure 1) is composed of the amygdala, basal ganglia, lateral temporal cortex (LTC), ventromedial prefrontal cortex (VMPFC), and dorsal anterior cingulate cortex (dACC). The dACC is a recent addition to the X-system (Eisenberger & Lieberman, 2004; Lieberman & Eisenberger, 2005) and will be discussed in some detail later in the chapter as it was originally included in the C-system, although always with certain caveats.

The amygdala are almond-shaped subcortical structures located within the poles of each of the temporal lobes. There is ongoing debate about the amygdala's function, however, it does appear to be sensitive to novel and emotionally evocative stimuli (LeDoux, 1996; Wright et al., 2001). A recent meta-analysis suggests that it responds more to stimuli that are negatively, than positively, valenced (Wager, Phan, Liberzon, & Taylor, 2003). It is critical to fear conditioning in animals (Fanselow & LeDoux, 1999). Additionally, for individuals who have amygdala lesions, there can be major disturbances of automatic social cognition (Heberlein, & Adolphs, 2004). This region projects to various other regions that allow it to serve as something of an alarm, triggering top down controlled processes in prefrontal cortex and autonomic nervous system responses that shift energy resources in the body to prepare for fight or flight. Most relevant to the X-system, however, are the numerous studies have demonstrated that the amygdala responds to subliminal and unseen presentations of threatening images (Cunningham et al., 2004; Liddell et al., 2005; Morris, Ohman, & Dolan, 1999; Pasley, Mayes & Schultz, 2004; Whalen et al., 1998).

The basal ganglia are curved horn-like subcortical structures that appear to be involved in the automatic components of affect, cognition, and behavior. The basal ganglia are best known for their central role in movement disorders such as Parkinson's disease and Huntington's disease, however, these disorders also lead to various social and affective deficits, including deficits in nonverbal communication (Lieberman, 2000). In the past decade, a number of neuropsychological and neuroimaging studies have established that the caudate, a substructure within the basal ganglia is involved in implicit learning of abstract sequential patterns that may subserve human intuition (Knowlton, Mangels & Squire, 1996; Lieberman, Chang, Chiao, Bookheimer, & Knowlton, 2004). Finally, the ventral striatum, another subregion of the basal ganglia, has been linked to positive affective responses to stimuli ranging from drugs, to money, to pictures of romantic partners (Bartels & Zeki, 2000; Breiter et al., 1997; Zalla et al., 2000).

Ventromedial prefrontal cortex (VMPFC) is the region of cortex at the intersection of the medial wall of prefrontal cortex and the orbital or bottom surface of prefrontal cortex. The damage to the famous patient Phineas Gage was primarily in VMPFC and Gage's deficits in social cognition are well known (Damasio, 1994). It is only in the past decade, however, that data is beginning to demonstrate that the deficits associated with VMPFC damage are more automatic in nature. Damasio and colleagues (Bechara, Damasio, Tranel, & Damasio, 1997) have suggested that this region is involved in social intuition because it is critical to learning the long-term value of different alternatives in a gambling paradigm. For those that have VMPFC intact, accurate intuitions are formed about the different alternatives prior to when explanations can be generated for why some alternatives are better than others. Thus the learning appears to be implicit, as in the basal ganglia, at least for some period of time. Milne and Grafman (2001) have also observed that patients with VMPFC damage do not show evidence of implicit gender stereotyping on the implicit association test (Greenwald, McGhee, & Schwartz, 1998). Most recently, Deppe et al. (2005) demonstrated that susceptibility to framing effects is positively related to activity in VMPFC. Framing effects have been considered a consequence of

capitalizing on operational properties of intuitive over deductive reasoning (Kahneman, 2003), further supporting the role of VMPFC in conjunction with the basal ganglia in the formation of automatic intuitions. Finally, a recent ERP study (Carretie, Hinojosa, Mercado, & Tapia, 2005) localized early responses (~150ms) to subliminally presented threat stimuli to VMPFC meeting two criteria of the X-system in sensitivity of subliminal presentations and speed of response.

Unlike the other regions of the X-system, lateral temporal cortex (LTC), consisting of the lateral and inferior portions of the temporal lobes, as well as the temporal poles, are primarily associated with semantic rather than affective processes. A degenerative brain disorder called semantic dementia (or the temporal variant of frontotemporal dementia) selectively affects LTC and produces major deficits in semantic knowledge while largely sparing memory for particular episodes (Garrard & Hodges, 2000; Mummery et al., 2000). A number of studies have now observed LTC activations associated with implicit semantic processing (Crinion, Lambon-Ralph, Warburton, Howard, & Wise, 2003; Mummery, Shallice, & Price, 1999; Rissman, Eliassen, & Blumstein, 2003; Rossell, Bullmore, Williams, & David, 2001) and have found that explicit or intentional semantic processes recruit lateral prefrontal cortex in addition to LTC (Lee, Robbins, Graham, & Own, 2002; Xu et al., 2002). Additionally, the multi-staged pathway from visual cortex to the temporal poles is massively parallel (Suzuki, Saleem, & Tanaka, 2000; Vogels, 1999), an architecture that appears to promote efficient but non-symbolic processes (Smolensky, 1988). Lastly, the superior temporal sulcus, a subregion of LTC, is critical to nonverbal decoding of facial expressions a process that is probably automatic given how little effort or intention is applied in determining the implication of most facial expressions (Ambady & Rosenthal, 1992).

*The C-system.* Nominating brain regions for the C-system required much less of an exploratory approach (guesswork) than the X-system because cognitive neuroscientists were already examining various networks relevant to controlled processing in their study of conflict detection, working memory, and episodic memory. From these lines of research, the C-system was posited to consist of anterior cingulate cortex (ACC), lateral prefrontal cortex (LPFC), posterior parietal cortex (PPC), and the

hippocampus and surrounding medial temporal lobe region (MTL). In the current formulation, only the rostral anterior cingulate cortex (rACC) is included in the C-system as will be discussed in the next section. Medial prefrontal cortex (MPFC), particularly the medial portion of Brodmann's area 10 may be another good candidate region for the C-system as it appears to be involved in self-focused attention (Gusnard, Akbudak, Shulman, & Raichle, 2001) and it is a region that is unusually larger in humans than other animals (Semendeferi, Schleicher, Zilles, Armstrong, & Van Hoesen, 2001).

Lateral prefrontal cortex (LPFC) is the heart of the C-system as it is involved in numerous higher cognitive processes that are experienced as intentional and effortful including working memory, implementation of top-down goals and plans, episodic retrieval, inhibition, and self-control (Cabeza & Nyberg, 2000). Though only rarely linked experimentally, working memory processes and controlled processes operate under similar constraints functioning serially, rather than in parallel, operating on discrete symbolic representations and propositions, and limited by motivation, intention, and effort (Baddeley, 1986). While X-system processes may be linked to our ongoing experience of the world, coloring in the semantic and affective aspects of the stream of consciousness, the C-system, and LPFC in particular, appears to be linked to our experience of responding to the world and our own impulses with our freely exerted "will" (Lau, Rogers, Ramnani, & Passingham, 2004).

Lateral posterior parietal cortex (LPPC) is thought to support many of the same functions attributed to LPFC including working memory, controlled processing, and logic (Cabeza & Nyberg, 2000). A number of recent neuroimaging studies also suggest that medial PPC is involved in self-focused attention (Gusnard et al., 2001; Kelly, Macrae, Wyland, Caglar, Inati, & Heatherton, 2002, Lieberman & Pfeifer, 2005) as well as distinguishing one's own perspective from that of another (Ruby & Decety, 2001), both tasks that require effort and symbolic representations.

The hippocampus and surrounding medial temporal lobe (MTL) are included in C-system because of their role in supporting episodic memory and the relation of episodic memory to controlled processing. One of the general functions of the frontal lobe and controlled processing is to exert control

and override the X-system (and other habit-based processes such as motor functions) when the habits and impulses of the X-system are insufficient or contextually inappropriate (McClelland, McNaughton, & O'Reilly, 1995; Miller & Cohen, 2001; Sloman, 1996). While the C-system is enormously flexible in its ability to create and implement new symbolic solutions in these situations, the C-system is also fragile because it processes information serially which limits its speed and the number of problems that can be handled simultaneously. Additionally, there is growing evidence to suggest that controlled processes are analogous to muscles in that they can tire with continuous or intense use (Baumeister et al., 1998).

One way to greatly enhance the efficiency of the C-system would be to keep a repository of memories for the different times that the C-system was invoked to override the X-system. Such a repository would be called upon when the same situation was encountered again allowing the C-system to focus on implementing a plan rather than having to first deliberate to generate the plan anew. If a situation is encountered frequently enough, the X-system will change its habits to accommodate the situation, but the X-system is very slow to change and thus these C-system memories would be very useful in the interim. Episodic memory can be characterized, in part, as a storehouse of memories for specific episodes when the C-system was engaged because things were running counter to expectations and one's habits were insufficient to guide behavior in a particular situation.

Since the 1970s, cognitive psychologists have known that 'depth of processing' correlated with the strength of episodic memories; the more cognitive elaboration performed, the more likely the episodic memory will be successfully retrieved later ( Craik & Tulving, 1975). The studies of patients like H.M. who are amnesic because of lesions to MTL have suggested that MTL serves as the representational storehouse for episodic memories. Recent neuroimaging research has demonstrated that the success of episodic retrieval is predicted by the amount of activity in MTL as well as LPFC (Brewer et al., 1998; Wagner et al., 1998). Moreover, the link between depth of processing and subsequent encoding has been tied to processing in the medial temporal lobe and other regions of the C-system

(Fujii et al., 2002). It appears then, that the more work that is performed by LPFC to override X-system habits, the better the long-term episodic memory for that information.

*Dorsal and Rostral ACC.* In previous discussions of the X- and C-systems, the anterior cingulate cortex (ACC) was included as a C-system structure, but always with caveats. The ACC functions, in part, as a conflict monitor detecting when expectations are violated or contextually-inappropriate responses might be made (Botvinick, Braver, Barch, Carter, & Cohen, 2001). As such, the ACC is something of an alarm system triggering controlled processes, particularly in LPFC, to override contextually-inappropriate responses. The prototypical example of ACC function is demonstrated in the Stroop task when, for instance, one is required to say the ink color of a word ('blue') when the word itself spells out another color ('R-E-D'). The ACC is thought to be critical in notifying LPFC that it needs to override the prepotent word reading response. As the starting point in detecting the need for and triggering many controlled processes, it seemed appropriate to include the ACC in the C-system. However, part of the elegance of the connectionist models of ACC function is that the models explain how the ACC can detect conflict automatically, without having to posit an autonomous homunculus inside the ACC that guides the ACC through symbolic decision processes. One of the natural outputs of connectionist architectures is a tension parameter that reflects the total amount of tension in the system (Cohen, Dunbar, & McClelland, 1990; Hopfield, 1982).

More recently, Eisenberger and Lieberman (2004; Lieberman and Eisenberger, 2005) have suggested that the dACC should be identified as an X-system structure, whereas the rACC should remain as part of the C-system. Eisenberger and Lieberman reviewed a number of cognition, affect, and pain studies and found that in each of these domains, dACC activations were associated with processes that could be characterized by non-symbolic tension processes, whereas rACC activations were associated with processes for which a symbolic representation of what would or did constitute expectancy violations was explicitly held in mind. For instance, unexpected pain stimulation tends to activate dACC whereas anticipation of pain activates rACC (Ploghaus, Becerra, Borras, & Borsook,

2003). Similarly, negative emotions, which are focused on a specific object or outcome, tend to activate rACC, whereas anxiety, which has been defined as similar to fear but without explicit focus on a specific object or outcome, tends to activate dACC. Additionally, Smith (1945) observed that in macaques, the entire ACC was morphologically analogous to human dACC. In other words, in primates that lack the capacity for true symbolic processing (Thompson & Oden, 2000), there is no rACC. More recent evidence points to “spindle cells” (Nimchinsky et al., 1999) that appear in rACC, but not dACC, and are present in diminishing densities in the ACC of children and other primates paralleling the diminished symbolic capacities in these groups (Craig, 2004).

### **Evidence for independence of the systems**

The data used to nominate the brain regions to the X- and C-systems was largely done by considering the properties of each system separately. A number of more recent studies have specifically examined how neural activity in these systems changes as processing conditions are altered to favor automatic or controlled processing. By and large, these studies suggest that conditions favoring automatic processing tend to promote X-system activation with little C-system activation, whereas conditions favoring controlled processing tend to promote C-system activation with little X-system activation. It should be remembered that while experimental tasks can be created to emphasize the processes of one system or the other, in everyday life, these two systems are often working together and simultaneously.

*Category Learning.* In one early study, Grafton, Hazeltine, and Ivry (1995) had subjects perform a sequence learning task in which cues appeared in a non-random sequence of locations on the screen and subjects produced location specific responses as quickly as possible. Approximately half of the subjects reported becoming aware of the pattern. Both aware and unaware subjects showed evidence of sequence learning, as indicated by slowed reaction times when the learned sequence was replaced by a random sequence, however the brain activations were different for subjects who were aware or unaware.

Subjects who were unaware activated the basal ganglia in the X-system during task performance, whereas subjects who were aware of the sequence did not activate the basal ganglia and instead activated LPFC in the C-system.

In a similar study, Aizenstein et al. (2000) has subjects perform a pattern learning task. In the first half of the study, subjects were unaware that the dot arrays presented were all variations on a never presented prototype (Posner & Keele, 1968). In this condition, implicit learning was associated with activation of the LTC in the X-system. Subsequently, subjects were run through another block of trials but this time were informed that there was a pattern to be learned. Under these explicit learning conditions, the LTC activation disappeared and was replaced by C-system activations in LPFC, MTL, and PPC.

*Attitudinal Prejudice.* A number of fMRI studies have looked at the neural underpinnings of race-related processes. The general finding across these studies is greater amygdala activity to African-American (AA) faces than to Caucasian-American (CA) faces (Hart, Whalen, Shin, McInerney, Fischer, & Rauch, 2000; Cunningham et al., 2004; Lieberman, Hariri, Jarcho, Eisenberger, & Bookheimer, 2005; Phelps et al., 2000) which is consistent with the negative stereotype of African-Americans and the amygdala's responsiveness to negative or threatening stimuli. Several findings suggest that the amygdala's response to AA faces reflects an automatic rather than a controlled process. First, Phelps et al. (2000) observed that the magnitude of the amygdala response to AA faces varied as a function of implicit, but not explicit, attitudes towards African-Americans. Additionally, Cunningham et al. (2004) found that subliminal presentation of AA faces produced greater amygdala activity than supraliminal presentation of AA faces. This is similar to the effect seen with the mere exposure effect paradigm and is one of the gold standards of automatic processes. Finally, Lieberman, Hariri, et al. (2005) found that African-American participants also showed greater amygdala activity in response to AA faces than CA faces. This is consistent with the behavioral research showing that African-Americans have negative

implicit attitudes, but positive explicit attitudes, towards African-Americans (Nosek, Banaji, & Greenwald, 2002).

Alternatively, when negative stereotypes and attitude objects were processed verbally there is enhanced activity in right LPFC and no significant activity in amygdala. Cunningham et al. (2003) found that judging the attitudinal valence of infamous names such as Adolph Hitler produced right LPFC activity, however, judging whether these were the names of living or dead individuals did not produce this activity. That this effect only emerged when judging valence is important because it indicates that the LPFC activity was dependent on explicit consideration of one's attitudes towards the targets, rather than a simple result of reading the names which would produce implicit effects as well. In the Lieberman, Hariri, et al. (2004) study of race-related processing, a second condition required subjects to categorize faces according to race using verbal labels. In this condition, there was activity in right LPFC very close to the region found in the Cunningham et al., (2003) study during verbal categorization of AA faces compared to EA faces. Finally, in a neuroimaging study of automatic behavior (Lieberman, Eisenberger, & Crockett, under review), the processing of words related to the negative stereotype of the elderly produced greater right LPFC activity in the same region seen in the previous studies when compared to the processing of words related to the relatively positive stereotype of intelligence.

*Self-knowledge.* Another area for which a significant amount of social cognitive neuroscience research has been conducted is the domain of self-knowledge (for review see Lieberman & Eisenberger, 2004; Lieberman & Pfeifer, 2005). The most reliable findings are that self-judgments tend to be associated with MPFC and medial PPC. Given that these are the same regions that tend to be observed in studies of self-focused attention (Eisenberger, Lieberman, & Satpute, 2004; Gusnard et al., 2001) it is unclear whether these activations are associated with self-knowledge per se or the retrieval of self-knowledge through self-focused processing.

Lieberman, Jarcho, & Satpute (2004) recently conducted an fMRI study in which self-knowledge judgments in high-experience and low-experience domains were compared. Our assumption was that actors would tend to be schematic for actor-relevant words and non-schematic for athlete-relevant words, whereas athletes would tend to show the opposite relationship (Markus, 1977). In other words, we expected each group to process high-experience words more automatically than low-experience words and indeed reaction time data bore out this assumption. Additionally, high-experience self-judgments activated VMPFC, basal ganglia, amygdala, and LTC in the X-system along with PPC in the C-system. Alternatively, low-experience judgments produced only a C-system activation in LPFC.

Further inspection of the reaction time data in this study indicated that approximately half of our subjects did not show evidence of schematicity in their high-experience domain. Even though we selected people who clearly have much more experience in one domain than the other, some simply may not have had or used schemas in their high experience domain. Thus these nonschematics, in contrast to schematics would be expected to recruit more C-system structures in making high-experience self-judgments given the greater number of episodic memories available in this domain. Consequently, all of the data were reanalyzed separately for schematics and nonschematics. When schematics made high-experience self-judgments they produced increased activity in VMPFC, basal ganglia, amygdala, LTC, and PPC and decreased activity in MTL and MPFC. Thus, schematics tended to activate X-system structures and deactivate C-system structures when they made high-experience self-judgments. Nonschematics show nearly the opposite pattern when they made high-experience self-judgments. Nonschematics produced increased activity in MTL, LPFC, MPFC, PPC and LTC along with no increases in X-system activity.

The results of this study are strong evidence that automatic processes are not merely faster, quieter versions of controlled processes. If the representations used during automatic and controlled processes were the same, then one might expect controlled processing regions to show decreases for high-experience judgments without any concomitant increases elsewhere. In fact, some non-social

forms of automaticity seem to follow this pattern (Jansma, Ramsey, Slagter, & Kahn, 2001). However, in our study, C-system decreases were matched by X-system increases suggesting that there are two separate systems that actively process social information under different conditions.

*Personality.* Extraversion has been frequently associated with positive affect and happiness whereas neuroticism has been associated with negative affect and anxiety. There is also some evidence to suggest that extraverts and neurotics tend to differ with respect to automatic and controlled processing. Across several studies, extraverts were found to have greater working memory efficiency than introverts, and thus were better able to handle multiple social interaction goals simultaneously (Lieberman, 2000b; Lieberman & Rosenthal, 2001; Oya, Manalo, & Greenwood, 2004). Alternatively, trait anxiety, which is a construct similar to neuroticism, has been associated with greater automatic interference effects (Egloff & Hock, 2001) and diminished working memory efficiency (Darke, 1988).

Eisenberger, Lieberman, and Satpute (2005) examined the neural reactivities associated with neuroticism and extraversion in an oddball task that combined conflict detection with exerting control through response inhibition. As described earlier, we believe dACC and rACC to be involved in non-symbolic and symbolic conflict detection, respectively, whereas LPFC is involved in response inhibition. In this study, neuroticism was positively correlated with the dACC response to conflict detection and negatively correlated with the rACC response to conflict detection. In contrast, extraversion was negatively correlated with the dACC response to conflict detection, but positively correlated with the rACC, LPFC, and PPC responses to conflict detection. These results approximately replicate Gray and Braver (2002) who found similar personality correlations with dACC and rACC. Together, these results suggest that extraverts tend to emphasize C-system processing, whereas neurotics tend to emphasize components of X-system processing, particularly those involved in automatic detection of threats and conflict.

## **Evidence for C-system regulation of the X-system**

The previous section reviewed research that suggests that during different kinds of social cognition, structures associated with the X- and C-systems tend to co-activate more with other structures from the same system than with structures from the other system. Additionally, these studies show that under processing conditions that favor automatic processing, X-system structures tend to be more active than C-system structures, whereas during conditions that favor controlled processing, C-system structures tend to be more active than X-system structures. This data suggests that there are qualitatively distinct systems supporting automatic and controlled social cognition. Although the conditions that are typically associated with eliciting automatic or controlled processing tend to vary in terms of awareness of stimuli and cognitive load, a central component of the X- and C-system's model is that the C-system is largely evolved to override the X-system when the habits and impulses of the X-system are contextually inappropriate. In this section, I will review studies that not only demonstrate that the C-system is activated under different conditions than the X-system, but that the magnitude of C-system activity in these conditions is negatively correlated with X-system activity. In other words, these studies suggest that C-system activity can inhibit X-system activity.

*Emotion regulation.* A number of recent studies have looked at intentional attempts at emotion regulation in neuroimaging paradigms (Beauregard, Levesque, Bourgouin, 2001; Levesque et al., 2003; Ochsner et al., 2004; Schaefer et al., 2003; Small et al., 2001). In general, these studies show the same pattern of X- and C-system activity as reviewed above with greater amygdala activity during passive viewing of emotionally evocative images and greater LPFC during attempts at emotion regulation by way of reappraisal or suppression (Gross, 1998). One of these studies has looked at the relationship between X- and C-system regions during reappraisal attempts at emotion regulation. Ochsner and colleagues (Ochsner et al., 2002) asked participants to passively view negatively valenced images in one condition and observed activation in the amygdala and VMPFC. However, in a second condition, participants were asked to reappraise each image by reinterpreting “the photo so that it no longer elicited

a negative response” (p. 1225). In this condition, LPFC was active, but neither of the amygdala or VMPFC activations observed in the passive viewing condition were present.

In subsequent functional connectivity analyses, Ochsner et al. (2002), examined the between subject differences in the C- and X-system activity during reappraisal. Ochsner et al. found that the greater the magnitude of the LPFC response during reappraisal, the smaller the magnitude of the amygdala and VMPFC responses during reappraisal. In other words, during reappraisal, some subjects activated the LPFC a lot and others just a little. The more any subject activated LPFC, the greater the reduction in the X-system regions. This analysis suggests that the C-system isn't merely 'speaking more loudly' than the X-system. Rather, it appears that while the C-system is speaking up it is also taking away the X-system's 'microphone' such that its volume is diminished.

Another set of studies have examined the effects of affective labeling on the amygdala's response to negatively valenced images (Hariri, Bookheimer, & Mazziotta, 2000; Hariri et al., 2003; Lange et al., 2003; Taylor et al., 2003). Philosophers have long suggested that thinking explicitly about one's affect can dampen the affect that is being reflected upon (James, 1890; Spinoza, 1650). Although thinking about or labeling one's affect is not an emotion regulation strategy, per se, it may be a mechanism by which other emotion regulation strategies have their effect. In other words, part of reappraisal's effectiveness may be due to the fact that it involves linguistic processing of affective stimuli and thus recruits the brain regions involved in affective labeling (for an account of why the brain may have evolved to inhibit the amygdala in response to affect labeling, see Lieberman, 2003; Lieberman, Jarcho et al., 2004).

*Affect labeling.* Similar to the studies of overt emotion regulation, these studies of linguistic regulation of emotion tend to find amygdala activity present during passive viewing of negatively valenced images, but this activity is absent or attenuated during explicit or linguistic processing of the images' affective content. In the latter condition, the amygdala activity is replaced by either bilateral or right LPFC. In two of these studies (Hariri et al., 2000, 2003), functional connectivity between LPFC

and amygdala during affect labeling was assessed and found to be significantly negative; the greater the LPFC activity during labeling, the weaker the amygdala activity. These data suggest that merely activating this C-system region is sufficient to downregulate X-system activity, even in the absence of any explicit intention at self-regulation.

*Attitudinal prejudice.* Some of the previously described studies of attitudes also examined functional connectivity. In each of the studies, during controlled processing of attitudinal objects, LPFC activity was negatively correlated with amygdala activity. Cunningham et al., (in press) found that in response to supraliminal, but not subliminal, presentations of AA faces, increases in dorsal LPFC predicted reductions in the magnitude of amygdala response. Lieberman, Hariri, et al. (2005) observed that right ventral LPFC activity while linguistically labeling the race of AA faces was negatively correlated with amygdala activity. Finally, in Lieberman, Eisenberger, and Crockett's (under review) study of automatic behavior, right ventral LPFC activity during linguistic processing of the elderly stereotype was negatively correlated with amygdala activity. This pattern was not observed when participants processed words related to the intelligence stereotype again suggesting that this effect may be specific to negatively valenced language.

It should also be noted that this study used the sentence unscrambling task (Bargh, Chen, & Burrows, 1996) that requires linguistic processing of stereotypes without bringing the relevance of the stereotype to mind for participants. Thus, there is no reason to assume participants were engaged in any kind of intentional emotion regulation. Rather, these results suggest that humans are hardwired such that the C-system regions that are recruited to process negatively valenced language can inhibit the amygdala when activated.

*Implicit learning.* Although research on the neural correlates of implicit learning has been decidedly non-social in nature, the implications for social psychology are substantial (Lewicki, 1986; Lieberman, 2000a). It is then of interest that a number of studies, neuroimaging studies in humans and lesion studies in rodents, have suggested that the basal ganglia and MTL function competitively

(Poldrack & Packard, 2003). Packard, Hirsch, and White (1989) lesioned either the basal ganglia or the MTL in rodents and then had the rodents perform tasks that depend on one or the other of these brain regions. Not surprisingly, basal ganglia lesion rats performed poorly on the basal ganglia specific task and MTL lesion rats performed poorly on the MTL specific task. What was surprising is that the basal ganglia lesion rats performed *better than normal* on the MTL specific task and the MTL lesion rats performed better than normal on the basal ganglia specific task. In other words, the presence of a normal functioning MTL tends to interfere with performance on tasks that strongly rely on the basal ganglia and thus performance on these tasks are enhanced when the MTL is removed.

Poldrack et al. (2001) found negative functional connectivity between the basal ganglia and MTL in humans during a category learning task that involves both explicit and implicit learning to some extent such that the participants who activated MTL more during this task activated the basal ganglia less. Lieberman, Chang, Chiao, Bookheimer, & Knowlton (2004) extended this finding by using a paradigm for which trials promoting the use of implicit and explicitly learned cues were distinguishable and could be compared. On trials for which explicitly learned cues were likely to drive performance, greater MTL activity was associated with diminished basal ganglia activity. It should be noted that on these trials, the implicitly learned cues were still relevant to accurate performance, in fact, more relevant than the explicitly learned cues, but with basal ganglia activity diminished under these conditions behavioral performance suffered.

### **Future directions: Reflective and reflexive *modes* of social cognition**

It is a contrast between two modes of practice. One is the pushing, slam-bang, act-first and think-afterwards mode, to which events may yield as they give way to any strong force. The other mode is wary, observant...and inhibited...an ineffective Hamlet in performance.

Dewey, *Experience and Nature*, p. 256

The research reviewed in this chapter suggests that the X- and C-systems are differentially recruited during automatic and controlled processes of social cognition. The pattern of results seen

across these studies indicates that within the domain of social cognition, automatic processes are qualitatively distinct from controlled processes, as the activation patterns associated with automatic social cognition do not look like controlled processes with increased efficiency. If that were the case, one would expect to see efficiency associated primarily with decreased C-system activity. The fact that conditions promoting automaticity leads to increased activity in regions not associated with controlled processing indicates that distinct processes are being recruited. Additionally, evidence was presented suggesting that C-system activations can disrupt X-system activity. Thus the systems are independent in the sense that they rely on different neural structures, but they are not independent in the sense that only one of these systems is operating at a time. In most everyday experiences, it is likely that both systems are operating and contributing to ongoing thought and behavior, albeit in different ways.

Given that C-system activity can interfere with X-system activity under certain processing conditions, one might conclude that C-system activity leads to a self-sustaining *reflective mode* of social cognition and behavior in which the C-system has greater control over thought and behavior. One might also reasonably conclude that situations that do not recruit significant C-system activity, there may exist a *reflexive mode* of social cognition and behavior. What has not been examined in this chapter is the possibility that the reflexive mode is also self-sustaining, tending to inhibit C-system activity. There are indeed some tantalizing hints that this might be the case.

Noradrenaline (also norepinephrine) serves as one of the major agents of physiological and neural arousal, helping to increase attention, vigilance, and autonomic readiness in response to potential threats (Berridge & Foote, 1991; Bouret, Duvel, Onat, & Sara, 2003). Over the past decade, numerous studies by Arnsten (1998) have demonstrated the deleterious consequences of noradrenaline and other catecholamines on the processing efficiency of LPFC. LPFC seems to follow an inverted-U processing efficiency curve with respect to noradrenaline such that increases from low to moderate levels enhance LPFC processing efficiency. This is thought to occur because the  $\alpha_2$ -receptor responds to noradrenaline in low concentrations and tends to facilitate neural efficiency. Once past a moderate level of

noradrenaline, further increases tend to diminish the processing of LPFC efficiency. This is thought to occur because the  $\alpha$ 1-neuroadrenaline receptor is only receptive to high concentrations of noradrenaline and tends to inhibit or mute the function of LPFC.

Consistent with this account, Callicott et al. (1999) observed an inverted-U response in LPFC and PPC to increasing levels of stress during a working memory task. Activity in these regions increased parametrically with task difficulty up to a point, but then became less active with higher levels of stress. Alternatively, the dACC in the X-system was one of the few regions found to increase activity linearly across all levels of task difficulty. Beversdorf et al., (2002) also found evidence that general cognitive flexibility, a hallmark of LPFC function, diminished with the administration of an adrenergic agonist and enhanced with the administration of an adrenergic antagonist. Thus, the C-system region seems to get 'tired' or 'frazzled' consistent with Baumeister's claims about the draining effects of self-regulation on further self-regulation attempts (Baumeister et al., 1998).

There is no evidence that X-system structures get frazzled from high arousal in the same way that LPFC does. To the contrary, amygdala activity enhances the noradrenaline production in the medulla (Dayas & Day, 2001) and locus coeruleus (Bouret, Duvel, Onat, & Sara, 2003), two major centers of noradrenaline production in the brain. Additionally, high levels of noradrenaline and stress are associated with enhanced amygdala function (McIntyre, Hatfield, & McGaugh, 2002; Shors & Mathew, 1998). Though the adrenergic effect of the amygdala on prefrontal cortex is presumably mediated by the locus coeruleus, there is evidence that electric stimulation of the amygdala does result in noradrenaline increases in the neocortex (Kapp, Supple, & Whalen, 1994).

The tradeoff between the X- and C-system responses to arousal extends to the long-term consequences of chronic stress as well. There is ample evidence that chronic stress damages MTL neurons (McEwen, 1999), producing dendritic shortening (Conrad, Galea, Kuroda, & McEwen, 1996). However, recently it has also been discovered that chronic stress facilitates neuronal growth in the amygdala, producing dendritic lengthening (Vyas, Mitra, Shankaranarayana Rao, & Chattarji, 2002).

These findings linking stress, arousal, and noradrenaline suggest that C-system structures function best at low to moderate levels of arousal, whereas the X-system may function better at higher levels of arousal especially when it is considered that at higher levels of arousal, C-system structures may be less able to regulate X-system activity. These findings are quite reminiscent of Zajonc's finding that arousal facilitates dominant responses but impairs non-dominant responses (Bond & Titus, 1983; Yerkes-Dodson, 1908; Zajonc, 1965) and why dominant responses are facilitated by stress. If response dominance is considered equivalent to habit strength, then it would be reasonable to say that X-system responses are more dominant than C-system responses.

Why would humans and other mammals have evolved these two modes controlled by arousal or stress level? If arousal is assumed, among other things, to index the intensity and immediacy of potential threats, then having these two modes triggered by arousal would be highly adaptive. When threats are not imminent, people are best served by gathering new information and flexibly considering options. However, our ability to think and learn flexibly comes at a cost – time and effort. When threats are imminent, especially the kind of threats that were relevant in our evolutionary past, taking the time to think through options might put one's life at risk. Thus, when threats are imminent and arousal is high, our brain takes the decision out of the hands of the C-system and leaves it to the X-system. If the X-system has strong contextually appropriate habits and impulses than the individual will likely escape unharmed. If the situation is novel such that the individual lacks contextually appropriate habits and the threat is truly imminent, C-system processes may have proved too inefficient to be of service. Thus, future work may examine the interaction of situational demands and arousal on the generation and maintenance of these two modes of social cognitive processing.

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Figure 1. Neural correlates of the C-system and X-system displayed on a canonical brain rendering from (a) side and (b) bottom views. Note: the hippocampus, nucleus accumbens, and amygdala are subcortical structures that are displayed here on the cortical surface for ease of presentation..

