

Neural correlates of “hot” and “cold” emotional processing: a multilevel approach to the functional anatomy of emotion

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Abstract: The neural correlates of two hypothesized emotional processing modes, i.e., schematic and propositional modes, were investigated with positron emission tomography. Nineteen subjects performed an emotional mental imagery task while mentally repeating sentences linked to the meaning of the imagery script. In the schematic conditions, participants repeated metaphoric sentences, whereas in the propositional conditions, the sentences were explicit questions about specific emotional appraisals of the imagery scenario. Five types of emotional scripts were proposed to the subjects (happiness, anger, affection, sadness, and a neutral scenario). The results supported the hypothesized distinction between schematic and propositional emotional processing modes. Specifically, schematic mode was associated with increased activity in the ventromedial prefrontal cortex whereas propositional mode was associated with activation of the anterolateral prefrontal cortex. In addition, interaction analyses showed that schematic versus propositional processing of happiness (compared with the neutral scenario) was associated with increased activity in the ventral striatum whereas “schematic anger” was tentatively associated with activation of the ventral pallidum.

Keywords: Emotion; Positron emission tomography; Ventromedial prefrontal cortex; Anterolateral prefrontal cortex; Ventral pallidum; Ventral striatum

INTRODUCTION

In recent years, a wealth of studies have investigated the neural correlates of emotion (e.g., Aalto et al., 2002; Blair et al., 1999; Canli et al., 1998; Damasio et al., 2000; Dougherty et al., 1999; George et al., 1995, 1996; Kimbrell et al., 1999; Kesler et al., 2001; Lane et al., 1997a, b; Northoff et al., 2000; Paradiso et al., 1999; Schneider et al., 1995, 1996, 2000; Shin et al., 2000). In most of these studies, participants were exposed to emotional and nonemotional stimuli (e.g., an emotional film vs a neutral film) or to emotional stimuli of different nature (e.g., a sad film vs a happy film). With some exceptions (e.g., Critchley et al., 2000; Hariri et al., 2000; Teasdale et al., 1999), these experimental manipulations consisted of varying emotional *contents*, without considering the different *processes* that could be applied to these contents, as if there was only one unique processing “route” for emotional information. However, emotional stimuli can elicit multiple cognitive processes ranging from a fast and automatic processing mode (Öhman et al., 2000) to a diversity of complex processes (e.g., rationalization, reasoning, voluntary modulation, labeling) that all impact on emotional experience (Teasdale, 1999). Therefore, it appears that a thorough understanding of the neural mechanisms of human emotion requires that neuroimaging studies of emotion rely on a theoretical model that takes into account that emotion encompasses a variety of different cognitive processes.

The dual-memory model of emotion (Philippot and Schaefer, 2001) is an integration of Multilevel models of emotion (Johnson and Multhaup, 1992; Leventhal and Scherer, 1987; Ochsner and Feldman-Barret, 2001; Power and Dalgleish, 1997; Smith and Kirby, 2000; Teasdale and Barnard, 1993), i.e. a class of theoretical models postulating the existence of different cognitive processes involved in emotion. It distinguishes between two emotional processing systems: The *schematic* system and the *propositional* system. The *schematic* system is based on schemata: A schema is an abstract and implicit representation integrating sensory, perceptual, and semantic information typical of a given category of emotional experiences. In addition, each schema has connections with bodily response systems. The schematic system is responsible for “hot” emotional processing: Apart from innate basic affective reactions, any “actual” emotional response (i.e., with autonomic, subjective, and expressive changes) is generated by the activation of a schema. There is one schema for each kind of emotion, and the content of each schema can be viewed as a holistic prototypical theme, e.g., the theme of “threat” for the emotion of fear (Lazarus, 1991). The subjective experience associated with schematic processing is characterized by a holistic, spontaneous way of appraising a situation. The *propositional* system is responsible

for the “cold” processing of emotions, i.e., the volitional and controlled processing of declarative knowledge about emotion. It is thought to rely heavily on high-level executive processes similar to Baddeley’s (1996) executive functions, and the declarative information on which it operates consists of discrete concepts about the different elements of the emotional situation. The propositional system is neither sufficient nor necessary to activate emotional reactions. It is involved primarily in the voluntary self-regulation of emotions. Indeed, emotional self-regulation encompasses several controlled cognitive strategies of emotional processing (Bonanno, 2001; Gross, 1998). Overall, propositional processing is associated with an analytical, “rational” mode of emotional processing.

The main purpose of the present study is to explore the neural correlates of the two modes of emotional processing postulated in the dual-memory model of emotion. The underlying idea is that isolating schematic from propositional processing is necessary to identify the neural correlates of the processes that specifically lead to actual emotional responses. Indeed, subtracting “cold” aspects of an emotional task should allow to capture what is specifically emotional in this task (Stemmler, 1992; Stemmler et al., 2001). To this end, participants were asked to perform a task designed to differentiate between schematic and propositional processing modes (Schaefer and Philippot, 2000). The ventromedial prefrontal cortex (VMPFC) is hypothesized to be the brain locus of schematic processing. Indeed, brain lesion studies suggest that the ventromedial prefrontal cortex plays a major role in the generation of human adult emotional reactions (Bechara et al., 1994, 1995, 1996, 1997, 1998, 1999a, b, 2000, Damasio, 1994, 2000; Tranel and Damasio, 1993). The propositional system is more likely to be associated with an activation of the lateral prefrontal cortex (LPFC). Actually, the propositional mode involves explicit and voluntary processing of emotional information, requiring high-level executive processes often associated with an activity of the LPFC. Indeed, the LPFC has been consistently activated by several executive tasks (for reviews, see Collette and Van der Linden, 2002; Duncan and Owen, 2000). Accordingly, Beauregard et al. (2001) and Ochsner et al. (in press) found that voluntary attempts at regulating emotional reactions were associated with LPFC activation. The second purpose of the present study is to contribute to the study of the neural correlates of specific emotions, more particularly, anger, sadness, happiness, and affection. The distinction between schematic and propositional processing offers a new insight into this question. Indeed, isolating the schematic activation of a discrete emotion from its propositional aspects should reveal the neural circuits specifically involved in the actual elicitation of that emotion, by controlling for “cold” aspects of the process. In other words, this procedure might bring out a purer delimitation of the neural structures associated with specific emotions than the classic comparisons between an emotional stimulus and a neutral stimulus. The great heterogeneity in presently available results only allows for predictions regarding broad categories of emotions. Indeed, the amygdala is likely to be associated with negative emotions (Ochsner and Feldman-Barret, 2001), whereas positive emotions might be associated with basal ganglia, more specifically the ventral striatum (Cacioppo et al., 1999).

METHODS

Subjects

Twenty healthy right-handed males took part in the experiment (mean age: 23.4, *SD*: 1.9). The subjects were selected according to several criteria: (1) no current medication; (2) no past history of neurological or psychiatric illnesses; (3) normal scores on three questionnaires assessing emotional dimensions: Beck Depression Inventory (Beck and Steer, 1988), Spielberger’s Trait Anxiety Inventory (Spielberger et al., 1970), and the Toronto Alexythymia Scale (Bagby et al., 1994). Subjects were paid 125 Euros for their participation. One participant was excluded from the data after the experiment: His difference score between emotional intensity for schematic and propositional modes was two standard deviations under the sample mean, indicating that he had not successfully performed the experimental tasks (see below). Written informed consent was obtained from all subjects according to the Helsinki Declaration. The Ethics Committee of the Faculty of Medicine of the University of Liège approved the study.

Experimental tasks

Subjects were exposed to emotional information (mental images) and constrained to process that information according to a schematic or a propositional mode. Specifically, they performed a “mental role-playing task.” i.e., a combination of a standard emotional imagery task (Vrana et al., 1986) and a sentence repetition task. Practically, the task consisted of: (1) mentally experiencing an emotional scenario (e.g., “*Imagine that someone tells you that one of your friends died in a car accident*”) following the procedure recommended by Vrana et al. (1986) and simultaneously (2) mentally repeating sentences reflecting a particular way of appraising the imagined scenario. In addition, subjects were instructed to imagine that these sentences were their own thoughts occurring during the situation being imagined. The schematic or propositional mode of processing was manipulated using either of two sets of sentences. For the schematic mode, metaphoric sentences reflecting a

holistic, spontaneous way of appraising the situation were used (e.g., “*Everything collapses around me*”). For the propositional mode, explicit, analytical questions about specific elements of the scenario were used (“*Is this situation important for me?*”). A previous behavioral study successfully used this procedure to differentiate between schematic and propositional processing modes, yielding higher scores of emotional intensity in the schematic mode (Schaefer and Philippot, 2000).

Imagery scripts were selected according to a pilot study in which 20 participants were asked to select from a subsample of scenarios issued from the ISEAR international data bank (Scherer et al., 1994) those that were the most typical of anger, sadness, happiness, and affection. In the end, two scenarios were chosen for each emotion. Both schematic and propositional sentences were derived from Lazarus and Smith's (1991) model that postulates that an emotional situation can activate a holistic emotional theme (e.g., the theme of threat for fear and the theme of loss/helplessness for sadness) and/or a pattern of specific appraisal dimensions [e.g., a situation eliciting anger is generally appraised by the subject as (1) important, (2) negative, and (3) intentionally caused by another person]. Several schematic sentences were constructed as meta-phoric sentences implicitly communicating each of five emotional themes (“Loss/Helplessness” for sadness, “Success” for happiness, “Other-Blame” for anger, “Attachment” for affection, and “Indifference” for neutral, according to Smith et al., 1993), and the propositional sentences were constructed as several explicit questions about 15 possible specific appraisal dimensions. The most relevant sentences were chosen for each of the study's imagery scenarios on the basis of a pilot study in which 20 participants rated the degree of relevance of each sentence to each scenario.

Each subject imagined 10 scenarios according to the “mental role-playing” procedure, following a 2 × 5 Processing Mode (schematic vs propositional) × Emotion (anger vs sadness vs happiness vs affection vs neutral) fully counterbalanced design. In the course of each imagery trial, participants first performed a 1-min relaxation task. Next, they heard through headphones a description of the imagery script and were asked to “mentally live” this situation. While they were imagining the situation, subjects heard and mentally repeated four schematic or propositional sentences at regular intervals. The first sentence was delivered 10 s after the onset of the imagery task. The acquisition scan started just after the participant heard the first sentence to be repeated and lasted for the remaining 60 s of the imagery task. During the 30 s following the imagery task, subjects were asked to relax. At the end, participants made several ratings about what they felt during the imagery task. Self-rating scales were displayed on a 17-in. screen. Heart rate was recorded during the relaxation and the imagery tasks. In order to obtain optimal performance from the participants, each of them completed a training session one week before the experiment. During this session, they were introduced to the “mental role-playing” paradigm and performed six trials with scenarios different from those used during the experiment.

Behavioral measures

After each imagery trial, participants rated the global intensity of their feelings on a 7-point scale (1 = “no emotions at all” to 7 = “very intense emotions”). They also completed a 14-item questionnaire about the specific type of feelings they had during the mental role-playing task. Each item consisted of groups of emotional adjectives: (1) *interested, concentrated, alert*; (2) *amused, joyful, merry*; (3) *warmhearted, gleeful, elated*; (4) *sad, downhearted, blue*; (5) *angry, irritated, mad*; (6) *fearful, scared, afraid*; (7) *anxious, tense, nervous*; (8) *disgusted, turned off, repulsed*; (9) *disdainful, scornful, contemptuous*; (10) *surprised, amazed, astonished*; (11) *loving, affectionate, friendly*; (12) *guilty, remorseful*; (13) *moved*; (14) *calm, serene, relaxed*. Participants rated on a 7-point scale (1 = “not at all” to 7 = “very intense”) the extent to which they felt each emotional state during the imagery task. One additional scale was presented to the participants with respect to the difficulty they had in performing the mental role-playing task (1 = “no difficulty at all” to 7 = “extremely difficult”).

Heart rate (HR) was measured in beats per minute (b/m) with the Vitaport I system (University of Köln, Köln, Germany) and derived from the R-R intervals of an ECG signal measured with Ag/AgCl electrodes placed on the chest. HR sample rate was set at 5 Hz. All statistical analyses concerning HR were performed on delta scores (i.e., the difference between the mean of the values registered during the imagery task and the mean of the values registered during the relaxation task just preceding it). For technical reasons, HR data could not be obtained for two subjects. Hence, statistical analyses on HR data were performed on 17 subjects.

Positron emission tomography scanning

PET data were acquired on a Siemens CT1 951 R 16/31 scanner (Siemens, Erlangen) in 3D mode. The subject's head was stabilized by a thermoplastic face mask secured to the head holder (Truscan Imaging, MA, USA) and a venous catheter was inserted in a left antebraial vein. First, a 20-min transmission scan was acquired for attenuation correction using three rotating sources of ⁶⁸Ge. Then, regional cerebral blood flow (rCBF), taken as a marker of local neuronal activity (Jueptner and Weiller, 1995), was estimated during 12 emission scans. Each scan consisted of two frames: a 30-s background frame and a 90-s acquisition frame. The slow intravenous water (H₂¹⁵O) infusion began 10 s before the second frame. Six millicuries (222 MBq) was injected for each scan, in 5 cc saline, over a period of 20 s. The infusion was totally automated so as not to disturb the subject during the

scanning period. Data were reconstructed using a Hanning filter (cutoff frequency: 0.5 cycle/pixel) and corrected for attenuation and background activity. The emotional tasks were pseudo-randomly distributed between subjects, with the constraint that all schematic processing tasks were administered successively and all propositional processing tasks were administered successively. Two relaxation tasks were also administered as first or last scan or between the blocks of schematic and propositional tasks.

Data analysis

PET data were analyzed using statistical parametric mapping (SPM99; Wellcome Department of Cognitive Neurology, Institute of Neurology, London, UK) implemented in MATLAB (Mathworks Inc., Sherborn, MA, USA). For each subject, all scans were realigned together, then normalized to a standard PET template using the same transformations (Frackowiak et al., 1997). Finally, PET images were smoothed using a Gaussian kernel of 16-mm full width at half-maximum (FWHM) to accommodate inter subject differences in gyral and functional anatomy and to suppress high-frequency noise in the images. Such transformations of the data allow for voxel-by-voxel averaging of data across subjects and for direct cross-reference to the anatomical features in a standard stereotactic space (conforming to the atlas of Talairach and Tournoux, 1988).

The covariance analysis subject-specific design matrix used in this study included one scan per subject for each experimental condition and considered block effect and individual global flow as confounds. The resulting set of voxel values for each contrast constituted a map of the t statistic [SPM(t)], transformed to the unit normal distribution [SPM(Z)]. In our factorial design, the main effect of the emotional processing mode was determined by contrasting the four emotional imagery scripts (anger, sadness, happiness, affection) in the propositional and schematic modes (fixed-effect subtraction analysis). The imagery scenarios in the schematic mode were compared with the imagery scenarios in the propositional mode to determine the cerebral areas associated with the schematic processing of emotion. The reverse contrast was performed (propositional-schematic) to determine the neural basis of propositional emotional processes. In a second step, the interaction effect between the variables "processing mode" (schematic vs propositional) and emotion (anger, sadness, happiness, affection vs neutral) was computed.

A SPM thresholded at $P < 0.001$ (voxel level) was used, with further correction for multiple comparisons ($P < 0.05$). Based on previous human lesion and neuroimaging studies, we predicted activation in ventromedial prefrontal cortex for the schematic processing (Bechara et al., 1994, 1995, 1996, 1997, 1998, 1999a,b, 2000, Damasio, 1994, 2000; Tranel and Damasio, 1993), in LPFC for the propositional processing (Collette and Vanderlinden, 2002; Duncan and Owen, 2000; Ochsner et al., 2002), in ventral striatum for schematic positive emotions (Cacioppo et al., 1999), and in amygdala for schematic negative emotions (Ochsner and Feldman-Barret, 2001). Small volume correction (20-mm-radius sphere) was applied when looking for activation in those predicted regions. Self-report and HR data were analyzed with ANOVA models, with a significance threshold fixed at $P < 0.05$.

RESULTS

Self-report data

An ANOVA was computed on global emotion intensity ratings to test the effect of processing mode across all the emotional conditions (happiness, anger, sadness, and affection). The main effect was significant, $F(1, 18) = 211.1$, $P < 0.0001$, $\eta^2 = 0.92$, showing that participants reported more intense feelings in schematic than in propositional processing mode. This difference was significant for each of the four emotional conditions ($P < 0.0001$). Contrast analyses performed on global intensity ratings tested the differences between each emotional condition and the neutral script, separately for schematic and propositional modes. Within schematic mode, each difference was significant at $P < 0.0001$. Within the propositional mode, the contrasts were significant for anger ($P < 0.001$) and affection ($P < 0.02$) conditions, and not for happiness and sadness. Means and standard deviations are presented in Table 1. Further, a multivariate ANOVA computed on the 14-item questionnaire on specific feelings showed a significant difference between schematic and propositional modes for relevant items (i.e., items assessing emotional feelings congruent with the emotion condition). For instance, the mean score of the item assessing anger feelings in the anger condition was significantly higher for schematic than for propositional processing mode. All these effects were significant at $P < 0.001$. In addition, the main effect of processing mode on subjective task difficulty ratings was not significant, $F(1, 18) = 1.3$, $P = .27$, $\eta^2 = 0.07$, suggesting that the observed differences in self-reported emotion cannot be explained by a difference in difficulty between schematic and propositional tasks.

Table 1: Mean scores of self-reported global emotional intensity

	Schematic		Propositional	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Anger	5.63	0.76	2.2	1.03
Happiness	5.26	0.87	1.84	0.83
Sadness	5.42	1.02	1.84	1.01
Affection	4.79	0.97	1.83	0.99
Neutral	1.58	0.69	1.42	0.77

Heart rate data

The main effect of processing mode was significant for HR, showing that schematic trials generated higher HR values than propositional trials, $F(1, 16) = 5.78, P < 0.03, \eta^2 = 0.26$. An interaction between processing mode and emotion was also observed, $F(3, 48) = 3.37, P < .03, \eta^2 = 0.17$. Simple effects showed that the difference between schematic and propositional modes was significant for anger and happiness conditions, respectively, $F(1, 16) = 6.33, P < 0.02, \eta^2 = 0.28$, and $F(1, 16) = 5.7, P < .03, \eta^2 = 0.26$, but did not reach the significance threshold for sadness and affection. Contrasts between each schematic emotional condition and the neutral one were significant for anger ($P < 0.006$) and happiness ($P < 0.01$). A marginal trend was observed for sadness ($P = 0.066$), and it was nonsignificant for affection. Within propositional mode, no significant differences were observed. HR means and standard deviations are presented in Table 2.

Table 2: Heart rate delta mean scores (b/min)

	Schematic		Propositional	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Anger	6.07	7.15	2.23	3.28
Happiness	6.02	7.12	2.22	2.52
Sadness	2.73	5.61	1.27	4.87
Affection	.61	3.01	.95	3.52
Neutral	.45	3.83	1.81	2.54

Imaging data

Subtraction analysis (main effects)

Consistent with our predictions, the brain area that was more active in the schematic compared to the propositional processing mode (averaging all emotional conditions) corresponded to the ventromedial prefrontal cortex [Brodmann's area (BA) 10/32]. See Table 3 and Fig. 1A.

Conversely, areas where activity was increased in the four propositional imagery scripts compared with the four schematic imagery scenarios were observed bilaterally in the LPFC (BA 10),¹ more specifically, in the anterolateral prefrontal cortex. See Table 4 and Fig. 1B.

Interaction analyses

First, we explored cerebral areas more activated in the schematic than in the propositional mode when subjects had to process a particular emotional content (i.e., anger, sadness, happiness, or affection) in comparison to a neutral condition. Interaction analysis between mode of processing (schematic vs propositional) and emotional content of happiness (vs neutral condition) yielded activation of the left ventral striatum (see Table 5, Fig. 2A).

¹ The two main effect analyses were also performed using a random effect model (Holmes and Friston, 1998), to specify cerebral areas involved in schematic and propositional processes that were activated in each of our 19 subjects, so that activation can be generalized to the student population from which we sampled our volunteers. Results are similar to those using the fixed effect model. A random effect model was not used in interaction analysis because only one scan per condition was available for each subject.

Schematic anger was tentatively associated with activation of the left ventral pallidum, close to the previous ventral striatal activation (see Table 6, Fig. 2B). Schematic sadness and affection did not yield any significant activation. Next, cerebral areas specifically associated with propositional emotional processing were sought, but there was no significant activation for any of the emotional scripts.

Table 3: Main effect: schematic–propositional emotional processing

Brain area	Stereotaxic coordinate			Z score
	x	y	z	
Ventromedial prefrontal	-4	59	6	3.94 ^a
(BA 10/32)	-4	46	-6	3.85 ^a

Note. Coordinates and Z scores for voxels in which there was significant activation when schematic emotional processing was compared with prop-ositional emotional processing. x, y, z (in mm) refer to coordinates in the Talairach space (Talairach and Tournoux, 1988).

^a Small volume correction (SVC, 20-mm-radius sphere) at voxel *P* value < 0.05.

Table 4: Main effect: propositional–schematic emotional processing

Brain area	Stereotaxic coordinate			Z score
	x	y	z	
L inferior frontal sulcus (BA 10)	−40	48	−6	4.31 ^a
R middle frontal gyrus (BA 10)	50	53	3	4.98 ^b

Note. Coordinates and Z scores for voxels in which there was significant activation when propositional emotional processing was compared with schematic emotional processing. L, left hemisphere; R, right hemisphere, x, y, z (in mm) refer to coordinates in the Talairach space (Talairach and Tournoux, 1988).

^a SVC at voxel *P* value < 0.05.

^b Significant at voxel *P* value < 0.001, corrected for multiple comparisons.

Table 5: Interaction analysis: cerebral areas specifically linked to the schematic processing of happiness

Brain area	Stereotaxic coordinate			Z score
	x	y	z	
L ventral striatum	−18	7	−7	4.90 ^a

Note. Coordinates and Z scores for voxels in which there was significant activation associated with the schematic emotional processing of happiness. L, left hemisphere, x, y, z (in mm) refer to coordinates in the Talairach space (Talairach and Tournoux, 1988).

^a Significant at voxel *P* value < 0.001, corrected for multiple comparisons.

Table 6: Interaction analysis: cerebral areas specifically linked to the schematic processing of anger

Brain area	Stereotaxic coordinate			Z score
	x	y	z	
L ventral pallidum	−18	−6	−6	4.12 ^a

Note. Coordinates and Z scores for voxels in which there was significant activation associated with the schematic motional processing of anger. L, left hemisphere. x, y, z (in mm) refer to coordinates in the Talairach pace (Talairach and Tournoux, 1988).

^a Not predicted, but reported for completeness at voxel *P* value < 0.001 uncorrected.

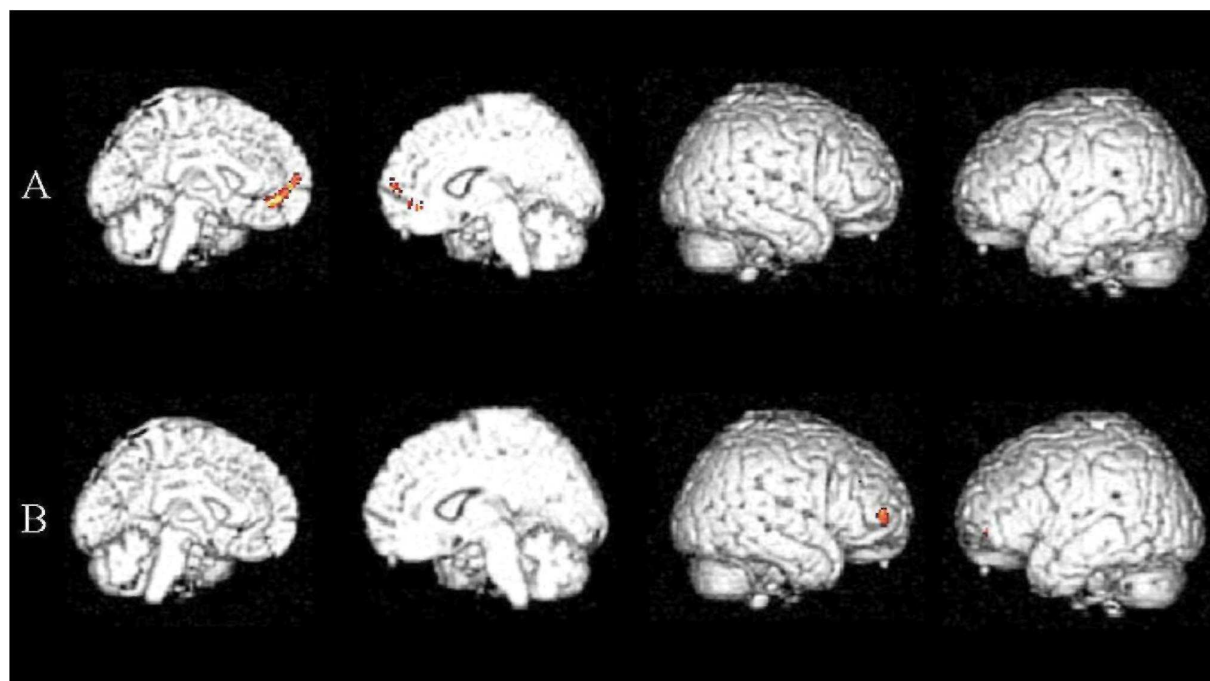


Fig. 1. Brain areas activated during (A) schematic compared with the propositional mode of emotional processing; (B) propositional versus schematic mode of emotional processing. Coordinates of significant regions are given in Tables 3 and 4. Brain areas are rendered on a standard brain MR image conforming to a stereotactic space (Talairach and Tournoux, 1988).

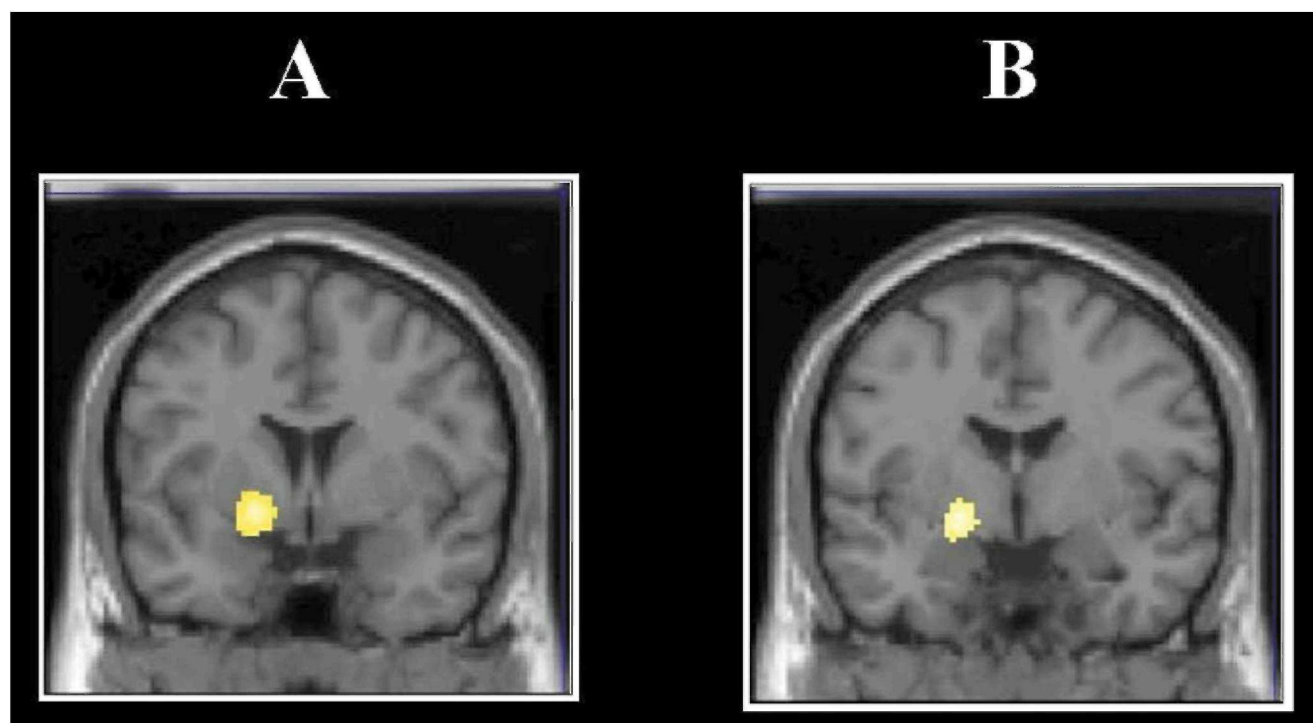


Fig. 2. Brain activation observed (A) for the schematic processing of happiness ($y = 7$ mm) and (B) for the schematic processing of anger ($y = -6$ mm). Coordinates of significant regions are given in Tables 5 and 6. Areas of activation are shown on coronal sections of a standard brain MR image conforming to a stereotactic space (Talairach and Tournoux, 1988). Y is the distance (in mm) from the anterior commissure.

DISCUSSION

The contrasts between schematic and propositional processing modes yielded two differentiated activation patterns congruent with the predictions derived from the literature. Schematic mode was associated with an activation of the ventromedial prefrontal cortex (BA 10/32), whereas the propositional processing mode activated the lateral prefrontal cortex (BA 10)². The activation of the VMPFC during the schematic condition is consistent with the predictions derived from brain lesion data (for a review, see Bechara, in press). Further, it is also consistent with several neuroimaging studies that have found medial frontal activations during emotional stimulation, suggesting that these areas have a general emotional processing role (for a review, see Luan Phan et al., 2002). However, several reported medial frontal activations do not correspond to the ventral portions of the medial frontal cortex activated in the present study. For instance, Lane and colleagues observed a dorsomedial prefrontal activation (BA 9) in all emotional versus neutral comparisons independently of the type of emotion (Lane et al., 1997b, c; Reiman et al., 1997), whereas our area of activation corresponds to the ventromedial prefrontal cortex. It is likely that this difference is due to the present study's experimental design. Unlike most previous studies, the present study's design does not rely on a comparison of emotional and neutral stimuli, but on a comparison between similar emotional stimuli (imagery scripts) appraised differently by the subjects. This design was used because when a subject is confronted with an emotional content, several activated cognitive processing components differ from those activated during a neutral situation (Stemmler, 1992). Thus, the several medial frontal activations reported in previous studies based on emotional versus neutral content comparisons might reflect various cognitive components associated with an emotional task, but not involved in emotional processing per se. More specifically, it could be argued that dorsomedial prefrontal areas found in the aforementioned studies are involved in the attention on subjective feelings³ as proposed by Lane et al., (1997a), whereas ventral areas would be involved in the processing leading to the generation of emotional responses. Several arguments are consistent with this view. First, Lane et al., (1997a) found that attending to one's subjective feelings activated a network including dor-somedial (BA 9) frontal areas and the anterior cingulate cortex. Second, Damasio et al. (2000) found that similar dorsomedial areas were activated in an experiment focusing on conscious emotional feelings. Third, the results of Bechara et al. (1997) suggest an association of the VMPFC with unconscious emotional responses, which in turn suggests that ventral areas of the prefrontal cortex are more likely to be involved in processing mechanisms leading to the generation of emotional responses, rather than being specifically involved in conscious feelings. This is consistent with the hypothesis that the VMPFC is involved primarily in a schematic processing underlying emotional generation. More particularly, the VMPFC might be a convergence/divergence zone (Bechara, in press; Damasio, 1989, 1994), coupling multimodal perceptual and semantic information characterizing a given abstract category of emotional situations to older response systems located in subcortical structures. Several arguments are consistent with this hypothesis: (1) The VMPFC is likely to be the brain region responsible for the classification of emotionally significant situations into abstract categories (Damasio, 1994; Bechara et al., 2000), which is an essential feature of the process of schemata formation according to multilevel models. (2) The VMPFC is connected with sensory cortices, subcortical structures, and anterior cingulate cortex as well as with frontal regions involved in the processing of declarative information (Ghashghaei and Barbas, 2001; Greenstein and Greenstein, 2000; Mercier et al., 1999). Therefore, the VMPFC has the anatomical features necessary to integrate the multimodal information needed for the construction of schemata and their links with bodily response systems. (3) Extensive neuropsychological data from brain lesion studies show that prefrontal cortex—and, more particularly, VMPFC—lesions impair the expression of emotions, as well as the learning of the affective value of a given situation (Bechara et al. 1995, 1996, 1997, 1998, 1999a, b, 2000; Damasio, 1994; Heilman et al., 2000; Meulemans and Vincent, 1999).

The reverse contrast (propositional–schematic) yielded a bilateral anterolateral prefrontal activation (BA 10) consistent with the predictions of LPFC activation. Previous studies found that this region is associated with

² There may be a systematic confound in the experimental task. Indeed, the schematic sentences were statements whereas the propositional ones were questions. This procedure was chosen because statements reflect a more spontaneous mode, whereas questions can reflect a more analytical mode typical of propositional processing. It could be argued that the observed results might partially reflect a difference in the processing of the format of the mentally repeated sentences independently of the schematic–propositional issue. We acknowledge that the present study's design cannot rule out this possibility. However, it should be stressed that the results of a behavioral study using the mental role-playing procedure found that the format of the sentences by itself had no effects on emotional measures, whereas the schematic–propositional manipulation yielded very significant differences (Schaefer and Philippot, 2000).

³ It is important to highlight that the attentional processes to which we refer are probably involved in conscious emotional feelings but are not by themselves conscious emotional feelings. Indeed, it is possible to direct one's attention to one's subjective experience without experiencing emotional feelings. In other terms, focusing one's attention on subjective feelings may be a necessary but not sufficient condition to experience conscious emotional feelings.

executive tasks. For instance, this area was associated with semantic inhibition processes using the Hayling task (Collette et al., 2001), inhibition of prevalent responses (George et al., 1994; Taylor et al., 1997), and updating tasks, i.e., manipulating the content of working memory according to internal (long-term memory retrieval) and external (sensory input) incoming information (Salmon et al., 1996; Van der Linden et al., 1999). These processes are likely to have been involved in the volitional and controlled appraisal of emotional information that was performed by the subjects in the propositional condition. Indeed, the controlled processing of information about emotion may require the inhibition of dominant responses elicited by an automatic schematic processing of the emotional images. In addition, the intentional selection and monitoring of incoming information from long-term memory is required to feed the controlled appraisal process.

Such processes are very likely to be strongly involved in emotional self-regulation. Indeed, controlling our emotions may certainly require the inhibition of prepotent automatic responses, whether they are motor (e.g., aggression or escape) or cognitive (e.g., automatic thoughts). In addition, the selection and monitoring of internal and external incoming information are probably necessary to reappraise a stimulus, i.e., voluntarily changing its emotional meaning by several cognitive strategies (Ochsner et al., 2002). It is therefore not surprising that the LPFC findings are consistent with some studies that have found LPFC activations associated with attempts at regulating emotional responses (Beauregard et al., 2001; Ochsner et al., 2002). Future research should investigate the neural processes by which the LPFC can influence medial frontal and subcortical areas, allowing volitional modulation of emotional responses. This issue is crucial for understanding the neural basis of affective disorders. Indeed, the disruption of self-regulatory processes could be the origin of several psychological disorders (Beauregard et al., 2001), and emotional self-regulation is crucial for several psychotherapeutic methods.

The similarity of our propositional activations with findings about the neural correlates of executive functions raises the question of the specificity of propositional processing: Is propositional emotional processing different from propositional processing in general? In other words, it could be argued that the propositional processing corresponds to an application of general executive processes on emotional contents. Although Multilevel models of emotion suggest that there would be a specific emotional propositional processing level, there is no substantial evidence that might disentangle these two hypotheses. That question has to be empirically addressed. More specifically, the specificity hypothesis predicts that executive tasks should yield different neural correlates according to the emotionality of the contents processed in the task. Some models of executive functions are consistent with the specificity hypothesis. Indeed, Goldman-Rakic (1995) and Kimberg and Farah (1993) posit the existence of a general executive system fractionated in several components according to the nature of the contents processed by the system. It could be postulated that one of these content-specific executive components would be specific to emotional content, and that this component would be essential for emotional self-regulation.

The second purpose of the present study was to identify the neural correlates of four specific emotions (happiness, anger, affection, and sadness), using the contrast between schematic and propositional processing modes to obtain a purer delimitation of the areas associated with these emotions. In interaction analyses, each emotional condition was contrasted with the neutral condition, separately within schematic and propositional modes. The underlying idea was that comparisons within schematic mode should evidence the loci associated with the production of actual emotional responses specific to a given emotional category, free from cold processing elements. It appeared that schematic processing of happiness activated the ventral striatum (VS), while "schematic anger" was tentatively related to ventral pallidum activation.

The activation of the ventral striatum for happiness fits well with our predictions. Indeed, several models postulate that VS is involved in positive emotions (e.g., Cacioppo et al., 1999). It is likely that VS is a structure specialized in (1) assessing the beneficial value of a given object for the organism; and (2) producing bodily responses that generate desirable states, creating an association between the object and the desirable response in order to foster the subject to seek further encounters with the beneficial object. Consistent with this view, research with animals documented the involvement of VS with reward-related behaviors (e.g., Apicella et al., 1991; Bowman et al., 1996; Carelli and James, 2001). Studies with humans also support this thesis. For instance, Elliott et al. (2000) found that financial reward was associated with VS activity, and Lane et al. (1997b) observed that VS activation was associated with exposure to positively valenced film clips. Further, it seems that VS plays an important role in dopaminergic circuits of the brain, and dopamine is likely to be involved in positive affect (Ashby et al., 1999). Indeed, Drevets et al. (2001) found that levels of dopamine release in the VS positively correlated with self-ratings of euphoria.

Activation of the ventral pallidum (VP) during schematic processing of anger was also observed. However, this un-predicted activation is less reliable and very close to the previous one. Indeed, a post hoc subtraction between schematic anger and schematic happiness did not reveal a reliable activation of the VP. We report this finding in the goal of being exhaustive, and any conclusion of association between the VP and anger has to be drawn with caution. In animal literature, the VP has been reported as being involved in goal-directed behaviors (Johnson and

Stellar, 1994; Panagis and Spyraiki, 1996; Panagis et al., 1995a, b, 1997) and with motor activity (Austin and Kalivas, 1991; Fletcher et al., 1998). More particularly, it has been hypothesized that the VP is responsible for the translation of motivational, goal-oriented information into motor actions (Li et al., 1999; Mogenson et al., 1980). Hence, the observed activation of the VP might reflect the activation of the motor action preparation component involved in anger as well as fear, or approach-like emotions like happiness (Davidson, 1992; Frijda, 1986).

The interaction analyses did not yield any significant activation for schematic sadness and schematic affection. A possible explanation is that these two emotions have a low level of arousal, whereas anger and happiness have a high level of arousal (Russel, 1980; Russel and Feldman-Barret 1999). Indeed, by trying to identify the purely schematic component of each discrete emotion, our interaction design isolated the areas leading to "actual" emotional responses. Therefore, specific emotions associated with a high level of bodily arousal were more likely to yield significant activations. It is noteworthy that schematic sadness and affection did not yield significant HR changes compared with their propositional counterparts. Further, interaction analyses did not yield any significant activation when emotional scripts (compared with neutral ones) were processed in the propositional versus the schematic mode. This result is not surprising since the propositional processes are supposed to operate on declarative knowledge about emotion, which is much more diversified and distributed than schematic knowledge (Philippot and Schaefer, 2001). Hence, the activity corresponding to the propositional processing of a given emotional script was probably too variably distributed to be captured by our interaction analyses.

Finally, it has to be pointed out that the expected activation of the amygdala for negative emotions did not emerge from our interactions, despite existing evidence of its involvement in negative emotions (e.g., Morris et al., 1998, 2001; Reiman et al., 1997; Whalen et al., 1998). In this respect, one should stress that (1) amygdala activation seems to be related only to stimuli that are physically present in the subject's environment (Damasio et al., 2000; Whalen, 1998), which may undermine the possibility of observing activation of the amygdala with a task based on mental imagery; and (2) some studies showed very rapid habituation of amygdala responses which can make it difficult to observe significant changes in amygdala with PET methods (Büchel et al., 1998; Wright et al., 2001). Hence, it may be that significant activation of amygdala was not observed in the present study because of an early habituation of its activity during our 60-s task.

In summary, the present study attempted to identify the neural correlates of distinct schematic and propositional levels of emotional processing. Consistent with our predictions, findings suggest that the schematic processing mode is associated with ventromedial areas of the prefrontal cortex, whereas the propositional mode activates anterolateral prefrontal areas. Nevertheless, future research should investigate the involvement of these areas in emotion using experimental procedures that dissociate subjective experience from operating mechanisms. In addition, the distinction between schematic and propositional processes allowed us to take a new approach to the issue of the neural correlates of discrete emotions: Interaction analyses suggested that the ventral striatum was involved with "schematic happiness," and the ventral pallidum was tentatively associated with "schematic anger." The present study's results support the view of emotion as a complex phenomenon involving several processing levels. From this perspective, searching for the neural correlates of these processing levels might bring new insights into the understanding of emotion and affective disorders.

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