An fMRI Study of Emotional Engagement In Decision-Making

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Abstract—***It has been suggested that decision making depends on sensitive feelings associated with cognitive processing rather than cognitive processing alone. From human lesions, we know the medial anterior inferior-ventral prefrontal cortex processes the sensitivity associated with cognitive processing, it being essentially responsible for decision making.***

In this fMRI (functional Magnetic Resonance Image) study 15 subjects were analyzed using moral dilemmas as probes to investigate the neural basis for painful-emotional sensitivity associated with decision making. We found that a network comprising the posterior and anterior cingulate and the medial anterior prefrontal cortex was significantly and specifically activated by painful moral dilemmas, but not by non-painful dilemmas.

These findings provide new evidence that the cingulate and medial anterior prefrontal are involved in processing painful emotional sensibility, in particular, when decision making takes place. We speculate that decision making has a cognitive component processed by cognitive brain areas and a sensitivity component processed by emotional brain areas. The structures activated suggest that decision making depends on painful emotional feeling processing rather than cognitive processing when painful feeling processing happens.

Index Terms: ***Cingulate cortex, Decision-making, Cognitive-emotional processing, Educational psychology, fMRI, Medial anterior inferior-ventral prefrontal cortex.***

1. INTRODUCTION

A clear distinction between emotion and cognition has not been established. The so called "appraisal" of the processed painful sensitivity has been suggested to be the primary reason for any emotional behavior, which points to sensitivity rather than cognition as a causal explanation. Additionally, this last notion is claimed to be applicable to emotional "order" and emotional "disorder" [1].

On the other hand, the cognitive phenomenon is far from being understood. A modern neurologically based concept, the PASS (Planning, Attention, Simultaneous, Successive) theory of learning, deserves very close attention [2]. Its essential principle is central processing is independent of both sensorial input and verbal or non-verbal output. This idea is crucial to understanding that decision making has to do with personal beliefs, which work more unconsciously than consciously at a neurological level.

It is well known that physical pain processing and emotional processing share, at least in part, anatomical areas and physiological functions. This allows us to suppose that both physical and emotional painful sensitivity are codified by the neurons as the same entity, in particular, as a danger signal for evolutionary reasons. Evidence from animal experiments indicates that painful-fearful sensitivity is unconsciously processed and controlled by the temporal amygdala, which sends unconscious, uncontrolled, automatic protective-defensive responses, involving even the prefrontal cortex [3]. A common unspecific processing of danger occurs in different situations like stress, fear, etc. Thirdly, from the investigations on human lesions it has been shown that two prefrontal cortices, the emotional and the cognitive, exist. The decision making seems to depend on the emotional prefrontal cortex rather than on the cognitive prefrontal cortex . How is it that patients with medial prefrontal lesions are intelligent and aware of the consequences of the acts, but they exhibit unsocial behavior without remorse or decide to play a high-risk game with unnoticed consequences [4, 5, 6, 7, 8, 9, 10]?. Fourth, evidence exists that decision making and feeling are interactive processes [2, 11].

The aim of this study was to dissociate the painful feeling processing network from the cognitive processing network and to associate the mental decision making act with the painful feeling processing network (emotional engagement). According to neural correlates of emotion [12], we predicted that the crucial difference between painful and non-painful decision making lies in the emotional engagement processing. We have attempted to develop an informed symbiosis of psychological theory and neuroscience method. The present

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study extends previous fMRI findings in decision making [13, 14]. These previous works compare a more painful with a less painful decision making. Indeed, painful dilemmas must be considered "personal moral dilemmas", "impersonal moral dilemmas", "difficult personal moral dilemmas", "easy personal moral dilemmas", "utilitarian difficult personal moral dilemmas" and non-utilitarian difficult personal moral dilemmas". Our study compares a painful with a non-painful decision making.

2. METHODS

We have designed an noninvasive fMRI study aimed to dissociate the painful-emotional prefrontal network from the cognitive network and to support that decision making depends on the emotional rather than on the cognitive prefrontal cortex. fMRI has no injected contrast or tracer and does not appear to have any risk with repeat exposure. Six males and nine females between 12 and 15 years of age, who (with their parents) were provided with written informed consent forms, were recruited from the local scholar community. The study was approved by the ethic committee. A medical screening was carried out to rule out any psychiatric or neurological illness or any medical condition or medication. All subjects were healthy and right-handed with average or above-average intelligence (WISC-III-R). The stimuli selected were dilemmas. These were divided into “emotional” and “non-emotional” categories according to both their nature and the responses of 30 pilot participants , according to the evaluation of two independent coders (validation). No emotional dilemma was felt emotional for one person and non-emotional for another. The emotional dilemmas involve a painful experience (blame sentiment) whatever the decision. Two options (A and B) are possible. Option A and B are painful, although one of them is the most painful. The selected non-emotional dilemmas are painless. We assume that “emotional dilemma” is emotionally engaging, which means an intensively badly felt (blame) sentiment depending on the decision making response. Blame sentiment is an experience involving painful-feeling sensitivity, although other different processes may be also operating. Testing materials were similar to those available online at www.sciencemag.org/cgi/content/full/293/5537/2105/DC1.14, September,2001. Distinguishing between cognitive and emotional tasks can be argued as somewhat arbitrary for some cognitive component is always present. For this reason we are talking in terms of more or less a predominant cognitive component. To minimize the cognitive requirement we used a quasi-passive viewing procedure, which reduces the linguistic cognitive component of the task to a minimum. This makes comparison between cognitive and emotional condition much easier. This task consists of viewing a picture (cartoon) that represents a selected emotional or non-emotional dilemma. Every dilemma had to have a “yes” / ”no” response option with the minimal motion of the 1^{st} or 2^{nd} finger of the hand. As a previous instruction, the subjects were presented pictures similar to those used during the session. Once the task was understood, the subjects were presented a visual display with each dilemma in the form of a picture or cartoon. Alternating blocks of emotional and non-emotional dilemmas were presented in random order in a series of three blocks of ten trials each. Every participant responded to each dilemma while undergoing brain scanning by fMRI. Stimuli were projected onto a white screen located in front of the child and automatically displayed for 5 s by means of a computerized system. A previous unpublished pilot study showed that this presentation rate allowed subjects to comfortably look at the picture and respond to it. Longer time on task tends to increase the involvement of cognitive network. The intertrial interval (ITI) lasted long enough to allow the hemodynamic response to return to baseline after each trial. During the ITI, participants viewed a fixation cross.

Anatomic and functional data were obtained with a 1.5 Tesla GE Signa scanner. For anatomical localization, scan parameters were: repetition time (TR), 3100 ms; echo time (TE), 30 ms, matrix, 256 x 256; FOV (Field Of View), 22 cm; slice thickness, 6 mm; 22 axial slices. For the functional scan, parameters were: TR, 2000 ms; TE, 40 ms; flip angle (FA), 90º; matrix, 256 x 160; FOV, 24 cm; 18 axial slices, 6 mm thick, 0 mm skip. Head motion was constrained by foam padding. At the end of each scanning session a T1-weighted structural image was acquired in each subject.

Data analysis were performed with SPM 99 (Statistical Parametric Mapping. Wellcome Department of Cognitive Neurology, University College of London) and included motion correction and smoothing [Gaussian filter = 8 mm FWHM (Full Width at Half Maximum)]. Individual analysis was performed by using the general linear model [15] on normalized data (fixed effects model, high-pass filter = 108 sec, low-pass-filter = hrf, global scaling). SPGR (SPoiled GRadient echo pulse sequence) was normalized to T1 template [MNI (Montreal Neurologic Institute) stereotaxic space] in SPM 99 and then used as a template to normalize the in-plane anatomy (sinc interpolation, 2-mm voxels). Contrast images for each subject were normalized (tri-linear interpolation, 1x1x1-mm voxels) by using the parameters from the in-plane normalization. The contrast images were entered into a one-sample t-test across the 15 subjects. Activation was averaged over the 15 subjects. Group analysis was performed with a random effects analysis [16]. According to the SPM approach, statistical contrasts are performed by essentially calculating an ANOVA across all of the images under consideration. Statistical maps were thresholded for significance (P < 0.01) and cluster size (20 voxels). A whole brain analysis was made to identify voxels significantly more activated during emotional dilemmas than non-emotional dilemmas.

3. RESULTS

Whole brain analysis, performed to identify brain regions that showed greater activity for emotional dilemmas, showed that emotional dilemma condition had increased activity in a number of brain regions (Table 1). The most statistically significant activation was in the posterior cingulate (BA 23/30/31). Other significantly activated regions included the anterior cingulate (BA 24/25/32) and medial anterior inferior-ventral prefrontal (BA 10/11) (Fig. 1). The locations and Z-scores of peak activation in activated regions are shown in Table 1.The number of activated voxels is defined as the area under the difference distribution having Z scores. These areas were not significantly activated in non-emotional condition. In contrast, the dorsolateral prefrontal, angular gyrus, several regions of frontal, parietal and temporal cortex were significantly more activated during non-emotional condition. This response has been shown in a number of studies across different methodologies.

Table 1. Significant activation during emotional dilemmas compared to non-emotional dilemmas

Brain region Brodmann's Area	Talairach Coordinates X	Y	Z	Z score
Frontal lobe				
Medial prefrontal				
10	-31	55	3	3.98
10,11	0	52	-12	3.86
11	7	62	-12	4.43
10,11	-10	46	-14	3.85
Limbic structures				
Anterior cingulate gyrus				
32,25	-10	26	-10	4.69
32,24	7	28	28	4.05
24,25	0	27	36	3.58
24,25	0	12	33	5.25
24,25	-3	24	33	4.07
24	6	3	45	4.33
Posterior cingulate gyrus				
31	0	-38	41	3.81
30	14	-38	7	4.92
23	-7	31	24	2.64
23	-12	-55	27	3.97

Voxelwise significance threshold $P < .01$; min cluster size 20 voxels.
Activated voxels were required to have a Z value for a claimed P.

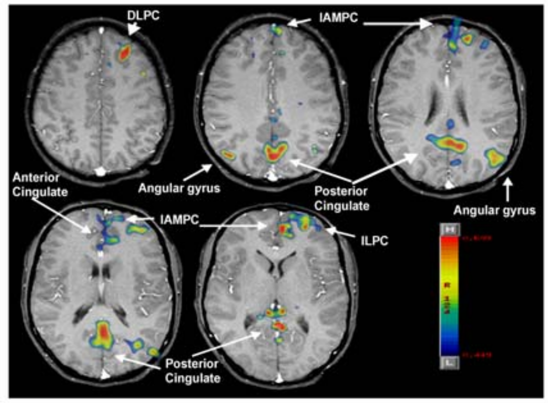

Fig. 1 DLPC: Dorso Lateral Prefrontal Cortex; IAMPC: Inferior Anterior Medial Prefrontal Cortex; ILPC: Inferior Lateral Prefrontal Cortex

4. DISCUSSION

The structures in this study are in agreement with the amygdala, anterior cingulate cortex, posterior cingulate cortex, insula, and medial anterior inferior emotional prefrontal cortex being associated with emotional condition as opposed to non-emotional condition that are supported by classically cognitive external cortical areas [12]. We count on evidences suggesting that the neural mechanism subserving both cognitive and emotional processing may be at least partially dissociated.

The thalamus, amygdala, cingulate gyrus, orbitofrontal gyrus, insula, secondary somatosensory cortex, and angular gyrus are structures that form part of the physical (somatic and visceral) and emotional-painful feeling network, [3, 12, 13, 14, 17, 18]. Although our conceptual framework suggests that physical pain and emotional pain processing share an unspecific network, it does not exclude the existence of other specific networks [18].

A substantial amount of fMRI evidence suggests a relationship between particular structures and the conscious versus unconscious nature of processing. Unconscious amygdala activation has been demonstrated. In contrast, the anterior cingulate cortex appears more frequently associated with processing the feeling related to the conscious cognitive component. The medial anterior ventral prefrontal cortex activates regardless of the conscious-unconscious cognitive component of the task. A rule can been proposed. The more conscious component is working, the more external-dorsal structure is also working, whatever cognitive-emotional task is being processed. Conversely, the more unconscious the operation is on, the more the inferior-interior structure works. For instance, the most cognitive conscious structure is the dorsolateral prefrontal cortex responsible for working memory. However, the anterior cingulate cortex, an older internal structure, satisfies the earlier mentioned rule. The more conscious level processing is on, the more the dorsal region activates [18]. In fact, the anterior cingulate cortex seems more related to conscious processing, as concluded from recalling experiences [12]. We must remark that conscious processing is linked to both cognitive and emotional processing. Therefore, both cognitive and emotional tasks can activate it. That anterior cingulate is associated with conflict or attention-to-action processing [14] could be explained because both tasks involve stressful processing, which would be a way of painful processing, something like a arousal state related to negative affective state [19]. In general, the more conscious the activity is required, the more the functionally associated structures appear on fMRI, and vice versa. In conclusion our fMRI pattern is more compatible with unconscious processing than conscious processing.

According to the PASS conception [2, 20], the information processing stream should be analyzed in terms of sensorial-unimodal input network (primary areas), intermediate multimodal input-dependent networks (association areas) , central input-independent networks (highly distributed functional networks) , intermediate multimodal output-dependent networks, and unimodal output-dependent network (verbal and non-verbal). According to the previous reported fMRI results, the medial anterior inferior ventral prefrontal acts as an input/output independent area [12]. In regard to input-dependency, the anterior cingulate cortex, as well as the insula, has been mostly linked to recall input than to visual and auditory input [12]. Thus, it appears to be linked to language-mediated processes [12, 21], which is not consistent with our study where language component of the task is reduced to a minimum. The input-dependency condition associates the activation with the input modality (visual or auditory), which must be taken into account to interpret possible associations.

The amygdala may be considered a sensitive organ, something close to the "sensory-perceptual level" [22, 23]. The anterior cingulate cortex appears to work at a higher level of processing with input-dependency. In contrast, the non-input dependent medial anterior prefrontal cortex may be considered to process the feeling of the cognitive content, working at an even higher functioning level. In other words, the neurons of the medial anterior prefrontal cortex presumably process and integrate both sensitivity and data cognitive information. In any case, the medial prefrontal cortex works as a higher order processor with higher discriminating capacity [3]. Conversely, the neurons of the dorsolateral prefrontal cortex presumably process exclusively conscious cognitive information.

Particular attention should be given to the posterior cingulate cortex. Several fMRI results unequivocally link this structure to the non-valence dependent emotional feeling and to the painful feeling network [21, 24] in both emotional order and emotional disorder. Non-input-dependency has been observed because it was consistently activated by verbal, pictorial, and recalling stimuli [25, 26]. A relationship between this cerebral area and the ocular saccade movements, especially when an emotional-feeling task involving visual processing is occurring, has been reported [27]. Probably, the significant activation seen here is because an important quantity of information of the task is processed by the posterior brain. We suggest that the posterior cingulate is a relevant part of the painful feeling network linked to the cognitive posterior brain processor.

The reported relationship between fRMI and similar techniques with the decision making process deserves attention [9, 24, 28, 29, 30, 31]. What we are calling the emotional prefrontal, namely the medial anterior inferior ventral prefrontal, is involved in the painful decision making process. Our study on the process of decision making involving painful-feeling processing indicates that the emotional prefrontal processes painful-feeling associated with the corresponding cognitive processing and determines the emotional response associated with the thought. We are unable to state whether the medial prefrontal neurons process only painful feeling sensitivity or process both sensitivity and informative cognitive data (cognitive concept used here) in an integrated way. Our contention is that the medial prefrontal cortex processes feeling sensitivity, but the cognitive dorsolateral prefrontal does not. Something like the somatotopic differentiation between motor cortex and sensitive cortex. This conclusion is in agreement with the lesion studies that indicate the lesion in these areas brings about a failure in logical decision making [2, 4, 10]. This involves a failure in foreseeing the consequences of the acts. In fact, it must be considered a failure in feeling rather than knowing the consequences [10]. Probably, that is why these patients exhibit unsocial behavior without remorse and an indifference to playing a high-risk game with unnoticed consequences [10].

We can reasonably deduce by comparing these fMRI results with other scientific evidences that the essential concept universally agreed upon is that independent of the behavior that is put in action, both cognitive (ideas) and feeling (sensitivity) processing happen at neurological level. That is, whether consciously or unconsciously, all action is really driven by both cognitive and affective-feeling processing. We believe our study demonstrates that painful decision making, but not non-painful decision making, activates the medial prefrontal. This can also be taken from the lesion studies. For instance, a patient with an emotional prefrontal lesion unsociably behaves because their emotional prefrontal is not processing or codifying the painful feeling associated with the corresponding cognitive processing. This is not because their cognitive dorsolateral prefrontal along with their temporal, parietal, and occipital cortices are unable to understand which consequence follows which behavior [4, 10].

The next thing to keep in mind is that painful feeling sensitivity is neurologically experienced in countless circumstances, we call countless linguistic terms, such as anxiety, depression, stress, fear, anger, and worry, as well as in unthinkable circumstances like aggression and violence. Likewise, "the empathy for pain" [18] or the experience of regret [4] and of punishment [31, 32] are painful experiences, which activate the brain areas linked to emotional painful processing. Recent neuroimaging studies continue to explore the neural correlates of decision making [17]. Our study compares painful with non-painful dilemmas, which is different from previous studies where more painful dilemmas are compared with less painful ones [13, 14]. For evolutionary reasons, it must be emphasized that neurons similarly codify as a danger what we call the countless linguistic terms, in particular blame sentiment, involved in our emotional dilemmas. More and more neurological evidence indicates that the painful sensitivity processing network counts on neurons processing and codifying sensitivity, but not cognitive informative data, even for the cognitive prefrontal, the cognitive cerebral lobe par excellence. In fact, this described functional mechanism agrees with what we now know about painful-fearful feeling processing in animals [3]).

According to our theory, many different tasks can activate the areas of our study, but also other different areas depending of the nature of the task. We postulate that the task used here allowed us to dissociate a sensitivity network from a cognitive network. We suggest that a longer time for response than that employed here involves the engagement of brain areas commonly associated with deliberative thought processes, which means a confound factor to dissociate the cognitive from the emotional (sensitivity) network. Moreover, we postulate that the deliberative thought associated with longer times for response reflects the engagement of conscious abstract reasoning processes, which happens later than the unconscious reasoning-feeling associated with the unconscious personal beliefs processing responsible for the response (decision making) when painful feeling processing takes place. It would be a reasoning process occurring after the point of decision [14]. The response would be in accordance with "unconscious" judgement of the personal beliefs. In support of this, we can mention the cognitive-psychological evidence that demonstrates the dissociation between verbal report and action. That is, a child is solving a task and we can verify that the verbally reported ("a posteriori" abstract reasoning) strategy is not that really being used, which we can deduce by observing the eye movements. That is, the unconscious strategy may be opaque to introspection. For example, the child is solving a task of searching for a number embedded in a field of other numbers. When asked how the target was located , we can see that screening eye movements tell us a different action than that verbally reported. [2]. Likewise, in an experiment [33], adult subjects were asked to do decision making tasks and a dissociation between verbal report and action was noticed frequently.

Guilty feeling processing is involved in the resolution (decision making) of the emotional dilemmas. Decision making involves the processing of personal beliefs. Personal beliefs influence decision making. Personal beliefs work basically at a central subconscious level beyond what we externally can see or hear between the input of information (dilemma presented) and the output of information (behavioral response). In pure PASS cognitive terms, for example, a child is presented with single separated letters, such as u, b, and s. He/she is asked to pronounce the successive combination [b u s], and he/she answers correctly. Later, he/she is asked to pronounce the sequence [q u s], and the answer is the same as before; this is obviously the incorrect answer. However, if the knowledge mentally processed is the symbol “b” is pronounced “/b/” independently of placing it right side up or not, then good logical reasoning has happened, because “a chair remains a chair whether its feet are on the floor or pointing toward the ceiling”. The response may be considered the consequence of a mental decision making act. What matters in decision making is the central mental processing in terms of beliefs [2]. This act involves both cognitive and feeling processing. In the case of painful feeling processing, according to animal experimentation, the neurons at the amygdala are inferred to be codifying danger, which determines that the medial prefrontal becomes active [3].We suggest that this central cognitive-sensitive processing is supported by the medial prefrontal according to our results.

5. Conclusion

The results of this study suggest that we can identify an emotional-painful processing network different from a cognitive processing network. The structures we observed are those being activated when painful feelings (in the form of blame sentiment in our study) are being processed. The structures activated, on the other hand, suggest that the decision making process depends on painful emotional feeling processing rather than cognitive processing when painful feeling processing happens. Future studies to further elucidate the functional significance of this fMRI activation, which allows us to establish not only diagnostic patterns but also the patterns in response to various treatments, will be needed.

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