Separate neural circuits for primary emotions? Brain activity during self-induced sadness and happiness in professional actors

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The question of whether distinct or similar neural substrates underlie primary emotions has not been resolved yet. To address this issue, we used fMRI to scan professional actors during self-induced states of sadness and happiness. Results demonstrated that, relative to an emotionally Neutral state, both the Sad and the Happy states were associated with significant loci of activation, bilaterally, in the orbitofrontal cortex, and in the left medial prefrontal cortex, left ventrolateral prefrontal cortex, left anterior temporal pole, and right pons. These loci of activation were localized distinctly within these regions, that is, in different sub-regions. These results suggest that sadness and happiness may be associated with similar brain regions but distinct sub-regions and neural circuits. *NeuroReport* 14:1111–1116 © 2003 Lippincott Williams & Wilkins.

Key words: Functional magnetic resonance imaging (fMRI); Happiness; Primary emotions; Professional actors; Sadness

INTRODUCTION

A fundamental goal within the fields of affective and cognitive neurosciences is the identification of the neural circuitry underlying primary emotions. Several functional neuroimaging studies have been carried out during the last decade to address this issue. In particular, a number of functional neuroimaging studies have attempted to identify the neural circuitry of sadness and/or happiness in healthy subjects [1–7]. Collectively, the results of these studies are plagued by a serious lack of consistency. Despite this state of affairs, a commonly held view is that separate neural circuits exist for primary emotions (for discussion of this segregationist stance, see [8,9]).

The present fMRI study sought to test the validity of the view that separate neural circuits exist with respect to the experiential dimension (the feeling) of primary emotion. In order to do so, professional actors were scanned during self-induced states of sadness and happiness. These professionally trained individuals were selected on the basis of their capacity to self-induce and experience powerful emotional states.

MATERIALS AND METHODS

Subjects: Nine professional right-handed actors (five males and four females; mean age 33 years; age range 25–41 years) living in Montreal participated in the study. None had a history of neurological or psychiatric disorder. All subjects gave written informed consent and the study was approved by the ethics committee of Centre hospitalier de l'Université de Montréal (CHUM), Hôpital Notre-Dame.

Behavioral procedures: Blood oxygen level-dependent (BOLD) signal changes were measured during three conditions: Sad, Happy and emotionally Neutral state. The week preceding the experiment, subjects were asked to recall powerful and personal emotional episodes involving sadness or happiness (the saddest life episode and the happiest life episode), as well as an emotionally neutral life episode. During that week, subjects were also requested to re-experience, on a daily basis, the three episodes selected. Subjects were not constrained to recall life episodes related to a specific time span or implicating the same individuals

and locations, to allow them to access the autobiographical episodes they considered emotionally most intense. Not surprisingly, the recalled episodes turned out to be comparable across subjects. Thus, the death of a relative or close friend was used to induce sadness, whereas a declaration of love, the birth of one's child, or a family reunion were selected to induce happiness. The neutral state consisted of recalling unemotional episodes, such as getting up, taking a shower, walking or driving to work and so forth.

Two runs were carried out (one contrasting the Sad state and the Neutral state, the other contrasting the Happy state and the Neutral state). Each run comprised six blocks which lasted 45 s each. In the first, third, and fifth block of each run, subjects had to voluntarily self-induce the target emotional state (either the Sad or the Happy state) by recalling and re-experiencing the appropriate personal episodes. In the second, fourth, and sixth block of each run, subjects had to self-induce the emotionally Neutral state. Blocks were separated by resting periods of 15 s. The order of presentation of the runs was counterbalanced across subjects.

To assess phenomenological experience, immediately at the end of each run, subjects were asked to rate verbally, on a numerical (analogue) rating scale ranging from 0 (absence of any emotional reaction) to 8 (strongest emotion ever felt in one's lifetime), the intensity of primary emotions (e.g., sadness, happiness, disgust, fear, anger, surprise) [10] felt during the Sad, Happy, and Neutral states.

Image acquisition: Echoplanar images (EPI) were acquired on a 1.5 T system (Magnetom Vision, Siemens Electric, Erlangen, Germany). Twenty-eight slices (5 mm thick) were acquired every 3 s in an inclined axial plane, aligned with the AC-PC axis (the duration required to acquire 28 slices was 2.65 s). These T2* weighted functional images were acquired using an EPI pulse sequence (TR = 0.8 ms, TE = 54 ms, flip = 90°, FOV = 215 mm, matrix = 64 × 64). Following functional scanning, high-resolution data were acquired via a Tl-weighted 3D volume acquisition obtained using a gradient echo pulse sequence (TR = 9.7 ms, TE = 4 ms, flip = 12°, FOV = 250 mm, matrix = 256 × 256).

Image analysis: Data were analyzed using Statistical Parametric Mapping software (SPM99, Wellcome Department of Cognitive Neurology, London, UK). Images for all subjects were realigned to correct for artifacts due to small head movements and spatially normalized (voxel size: 3 × 3 × 3 mm) into an MRI stereotactic space [11]. Images were then convolved in space with a 3D isotropic gaussian kernel (12 mm FWHM) to improve the signal-to-noise ratio and to accommodate residual variations in functional neuroanat-

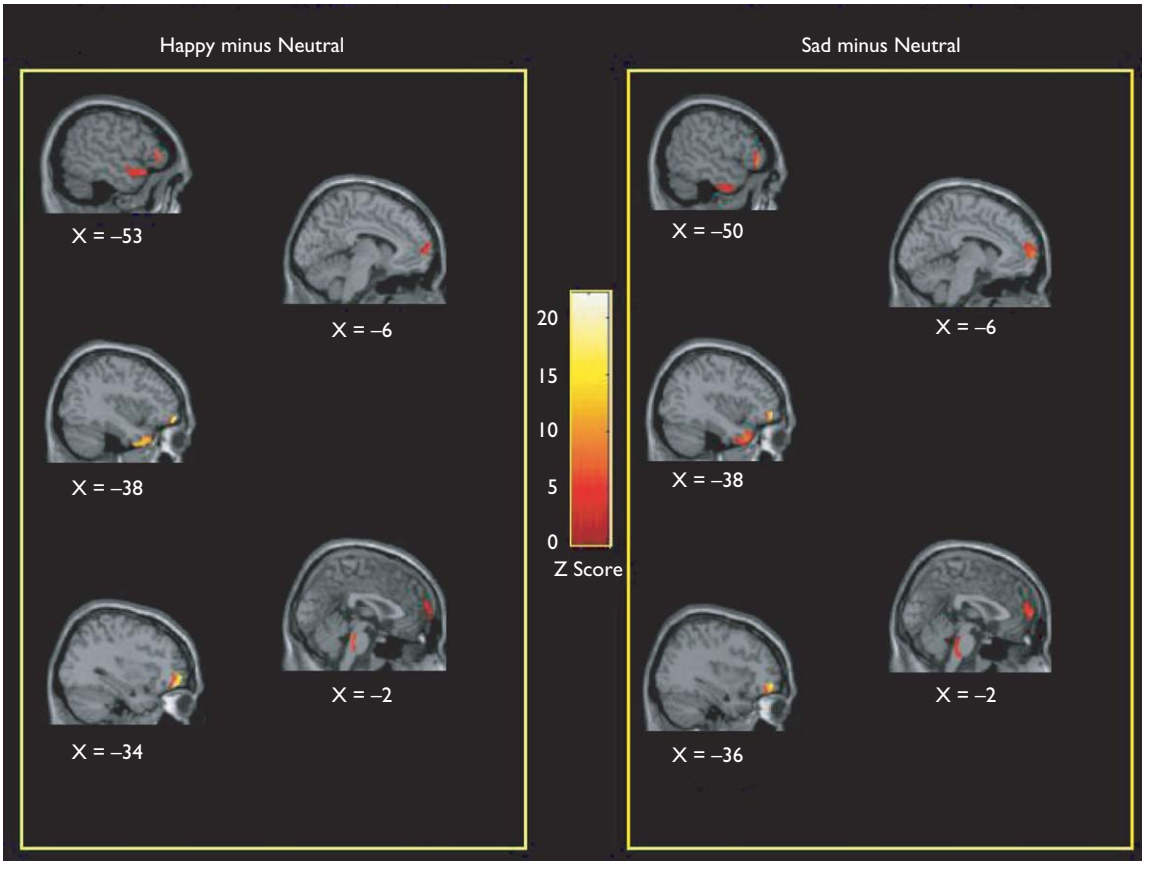

Fig. 1. Statistical activation maps showing activated voxels in the Happy minus Neutral contrast and the Sad minus Neutral contrast. Images are sagittal sections for the data averaged across subjects. The activation is displayed as a Z-statistical map coded according to the color bars.

Table 1. Bold signal increases in the Sad minus Neutral contrast and the Happy minus Neutral contrast.

		Talairach coordinates (mm)				
	Region	Brodmann area	x	y	z	Z-statistic
Sad minus Neutral	L orbitofrontal	11	−38	50	−9	17.96
	L ventrolateral prefrontal cortex	47	−50	34	−8	10.60
	R medial prefrontal cortex	9	6	60	3	9.04
	L medial prefrontal cortex	10	−6	60	2	9.01
	R orbitofrontal	11	36	52	−9	8.56
	R pons		2	−33	−33	6.19
	L pons		−4	−34	−29	6.05
	L anterior temporal pole	20	−48	8	−30	5.34
Happy minus Neutral	L orbitofrontal	11	−38	50	−10	11.50
	R orbitofrontal	11	34	50	−9	11.16
	R pons		2	−30	−29	7.63
	L medial prefrontal cortex	10	−6	61	1	5.62
	L medial prefrontal cortex	9	−6	59	21	5.47
	L anterior temporal pole	38	−53	13	−20	5.39
	R medial prefrontal cortex	10	6	60	6	5.17
	L ventrolateral prefrontal cortex	47	−53	30	2	4.90

Stereotaxic coordinates are derived from the human atlas of Talairach and Tournoux [11] and refer to medial–lateral position (x) relative to medline (positive = right), anterior–posterior position (y) relative to the anterior commissure (positive = anterior), and superior–inferior position (z) relative to the commissural line (positive = superior). Designation of Brodmann areas for cortical areas are also based on this atlas. L, left; R, right.

omy that usually persist between subjects after spatial normalization.

For statistical analysis, the time series of the images were correlated with the delayed box-car function which approximates the activation patterns. Effects at each and every voxel were estimated using the general linear model. Voxel values for the contrasts of interest yielded a statistical parametric map of the *t*-statistic (SPM *t*), subsequently transformed to the unit normal distribution, (SPM Z). For both the Sad and the Happy states, a conventional subtraction method was used with a fixed-effects model to contrast the brain activity associated with these states (Sad minus Happy, Happy minus Sad), and that associated with the emotionally Neutral state (Sad minus Neutral, Happy minus Neutral).

An *a priori* regional directed search strategy was employed. This *a priori* search was carried out within the orbitofrontal cortex and medial prefrontal cortex, anterior temporal pole, anterior cingulate cortex, insular cortex, amygdala, hypothalamus, pons and midbrain, given that these brain regions have been found activated on a more or less consistent basis in previous functional neuroimaging studies of either sadness or happiness [1–7]. A corrected probability threshold of $p < 0.05$ was used. Only clusters showing a spatial extent of ≥ 5 contiguous voxels were kept for image analysis.

RESULTS

Subjective data: Phenomenologically, the intensity ratings averaged 5 for sadness and 5 for happiness. These ratings were significantly different than the average Neutral state rating (Student's *t*-test, $p < 0.01$). In both the Sad and the Happy states, subjects reported having succeeded in self-inducing relatively pure states of sadness and happiness, i.e. the intensity ratings averaged < 1 for disgust, fear, anger, and surprise (mean levels: sad state: fear = 0.7; anger = 0.3; surprise = 0.4; happiness = 0.5; disgust = 0.3; happy state: fear = 0.2; anger = 0.1; surprise = 0.8; sadness = 0.2; disgust = 0.1). In the Neutral state, subjects did not report experiencing any primary emotion (i.e. intensity ratings averaged 0).

FMRI data: Subtraction analyses when the brain activity associated with the Neutral state was subtracted from that associated with the Sad state, significant BOLD signal increases were noted, bilaterally, in the pons, orbitofrontal cortex (Brodmann area (BA) 11), and medial prefrontal cortex (right BA 9 and left BA 10). Significant loci of activation were also seen in the left ventrolateral prefrontal cortex (BA 47) and left anterior temporal pole (BA 20; Fig. 1, Table 1).

When the brain activity associated with the Neutral state was subtracted from that associated with the Happy state, significant BOLD signal increases were found, bilaterally, in the orbitofrontal cortex (BA 11) and medial prefrontal cortex (left BA 9, right and left BA 10). Significant peaks of activation were also detected in the right pons, left ventrolateral prefrontal cortex (BA 47), and left anterior temporal pole (BA 38; Fig. 1, Table 1).

When the brain activity associated with the Happy state was subtracted from that associated with the Sad state, significant BOLD signal increases were found, bilaterally, in the pons. Significant loci of activation were also seen in the right orbitofrontal cortex (BA 11) and left ventrolateral prefrontal cortex (BA 47; Fig. 2, Table 2).

When the brain activity associated with the Sad state was subtracted from that associated with the Happy state, significant BOLD signal increases were noted, bilaterally, in the medial prefrontal cortex (BA 10). Significant peaks of activation were also detected in the left orbitofrontal cortex (BA 11; Fig. 2, Table 2).

Post-hoc analysis: To verify whether the Sad state and the Happy state were associated with significant loci of

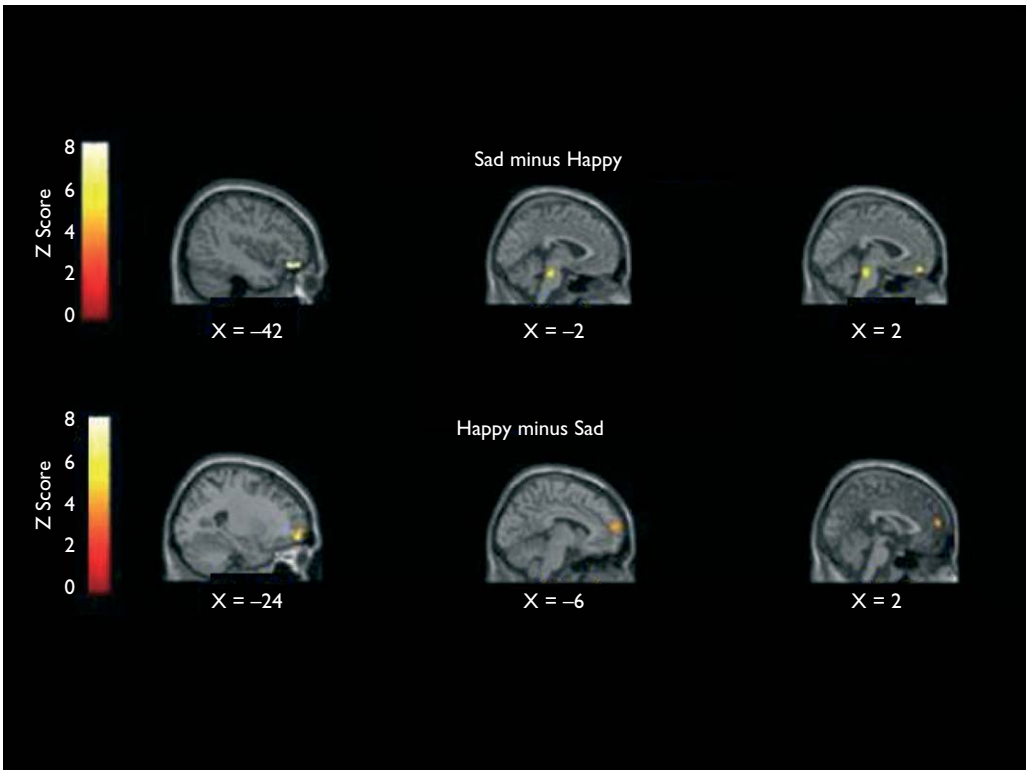

Fig. 2. Statistical activation maps showing activated voxels in the Sad minus Happy contrast and the Happy minus Sad contrast.

Table 2. Bold signal increases in the Sad minus Happy contrast and the Happy minus Sad contrast.

		Talairach coordinates (mm)				
	Region	Brodmann area	x	y	z	Z-statistic
Sad minus Happy	L ventrolateral prefrontal cortex	47	−42	35	10	7.20
	R pons		4	−26	−17	6.84
	L pons		−2	−26	−17	6.45
	R orbitofrontal	11	24	7	−17	5.29
Happy minus Sad	L orbitofrontal	11	−24	56	−13	9.04
	L medial prefrontal cortex	10	−6	61	10	6.38
	R medial prefrontal cortex	10	2	58	7	5.79

L, left; R, right.

activation in separate subdivisions of similar brain regions, we compared (using Student's *t*-test) individual subject's coordinates noted for each axis (X, Y, and Z) and every brain region activated in both the Sad minus Neutral and Happy minus Neutral contrasts (e.g. right and left orbitofrontal cortex BA 11, left medial prefrontal cortex BA 10, left ventrolateral prefrontal cortex BA 47, right pons). Results revealed that, in the right pons, the average activation centroid was significantly more posterior, in the Y axis, in the Sad state than in the Happy state (Happy −26 mm, Sad −31 mm; $p < 0.05$) whereas in the Z axis, the average activation centroid was significantly higher in the Happy state than in the Sad state (Happy −25 mm, Sad −34 mm; $p < 0.05$). In the orbitofrontal cortex (right and left) and Y axis, the average activation centroids were significantly more anterior in the Sad state than in the Happy state (right hemisphere: Happy 51 mm, Sad 59 mm, $p < 0.01$; left hemisphere: Happy 55 mm, Sad 59 mm, $p < 0.05$). Finally, in the left orbitofrontal cortex and Z axis, the average activation centroid was significantly higher in the Happy state than in the Sad state (Happy −11 mm, Sad −15 mm; $p < 0.05$).

DISCUSSION

Comparison with prior functional neuroimaging studies of sadness and happiness in healthy subjects: On one hand, the present findings are consistent with previous functional neuroimaging studies of sadness and happiness in healthy subjects in the sense that all the regions activated in the sad and happy states have been reported to be activated in either of these investigations [1–7]. On the other hand, the present findings are only partially consistent

with previous findings in the sense that they do not perfectly replicate the results of either of these studies. Nevertheless, inconsistency characterizes most of the previous functional brain investigations of sadness and happiness in normal subjects. How can we explain this state of affairs?

Regarding this issue, a recent meta-analysis of emotion activation studies using PET or fMRI [12] has convincingly demonstrated that this variability may reflect, at least partially, differences in induction paradigms and tasks. Thus, this meta-analysis has revealed that induction by emotional recall/imagery often recruits the anterior cingulate and amygdala, whereas emotional induction by visual stimuli tends to be associated with activity in the occipital cortex and the amygdala. In addition, this meta-analysis has shown that emotional tasks with cognitive demand recruits the anterior cingulate and insula more often than emotional tasks without cognitive demand.

In several of the functional neuroanatomic studies of sadness and happiness, comparable tasks, instructions, and functional neuroimaging techniques were used (compare, for instance, [1] and [7]). In such cases, other factors must account for this variability. One possible factor regards heterogeneity in task strategy, which refers to individual differences in the way subjects approach a particular task. In fact, there is some evidence that heterogeneity in task strategy leads to individual differences in the regions of the brain that are recruited throughout the course of task performance [13–17]. With respect to intersubject variability, mounting evidence indicates that there are individual differences in the way some cortical and subcortical regions of the brain (e.g., prefrontal cortex, amygdala) are activated during emotion processing. In keeping with this, our group recently conducted two separate fMRI studies to measure the impact of individual differences on the neural circuitry underlying primary emotions [18]. In these two methodologically identical studies, two different groups ($n = 10$ for each study) of healthy female subjects were scanned while they experienced a transient state of sadness induced by viewing sad film excerpts. Sadness was associated with significant loci of activation, bilaterally, in the ventrolateral prefrontal cortex and in the left medial prefrontal cortex and left insula in one of these studies; and, with significant activation, bilaterally, of the anterior temporal pole and of the right insula in the other study. Individual statistical parametric maps revealed an important degree of inter-individual variability in both investigations. These results emphasize the possibility that the subjective experience of a given primary emotion (e.g., sadness, happiness) may be associated with distinct neural correlates in different individuals. These results also support the view that individual differences may be responsible for the inconsistencies found in the literature regarding the neural substrates of sadness and of other primary emotions. Such differences appear to be related to personality [19–23].

Separate neural circuits for primary emotions? At first glance, the results of the Sad minus Neutral contrast and the Happy minus Neutral contrast suggest that sadness and happiness may be associated with patterns of neural activity within the same brain regions. However, direct subtraction of the brain activity associated with the sad and happy states (Sad minus Happy, Happy minus Sad), and the results of the *post-hoc* analysis indicate that, to a large extent, sad and happy feelings were associated with distinct subdivisions within the same brain regions (Table 3). Such a specificity may imply that these sub-regions, and the neural circuits associated with them, are implicated in the processing of aspects uniquely related to either sadness or happiness. For instance, the differential pattern of pontine activity evidenced here, in the Sad *vs* Happy states, may be related to the fact that different bodily states are associated with those feelings.

Table 3. Comparison of the brain regions significantly activated in the Sad minus Neutral contrast and the Happy minus Neutral contrast.

Region	Brodmann area	Sad minus Neutral	Happy minus Neutral
R orbitofrontal	11	X	X
L orbitofrontal	11	X	X
R medial prefrontal cortex	9	X	
R medial prefrontal cortex	10		X
L medial prefrontal cortex	9		X
L medial prefrontal cortex	10	X	X
L ventrolateral prefrontal cortex	47	X	X
L anterior temporal pole	20	X	
L anterior temporal pole	38		X
R pons		X	X
L pons		X	

In other words, primary emotions may be associated with similar brain regions but distinct sub-regions and neural circuits. Such a conclusion is in line with the view that the neurophysiological, neurochemical, and neuroendocrine correlates of primary emotions should exhibit some degree of specificity [24,25]. This conclusion is also consistent with the notion proposed by Damasio [26] that differences in the neural patterns underlying the multidimensional perceptual maps on which feelings are grounded are different for each primary emotion. Such differences would furnish distinctive perceptual landscapes of the organism's internal state and constitute the main reason why each primary emotion feels different.

Limitations of the present study: Before concluding, we would like to acknowledge some of the limitations inherent to this study. First, the fact that we studied professionally trained (i.e. expert) individuals may present certain problems, given that distinctions between experts and typical, untrained individuals, can be quite marked. However, professional actors were selected on the basis of their capacity to self-induce and experience powerful emotional states, and the brain regions seen activated in the Sad and Happy states have all been reported to be activated in previous functional neuroimaging studies of sadness and happiness. Second, because we did not constrain the subjects to recall life episodes related to a specific time span or implicating the same individuals and locations, it is possible that confounding variables may have given rise to some of the patterns of brain activation noted here. For

instance, the type and degree of social content of individual memories/experiences may have varied across subjects, as well as the degree of activation of theory of mind processes. Likewise, when recalling life episodes, some subjects may have behaved as an active agent whereas other subjects may have played the role of a passive bystander.

CONCLUSIONS

The present findings showed that sadness and happiness were associated with bilateral activation of the orbitofrontal and medial prefrontal cortices, and activation of the right pons and left anterior temporal pole. However, direct subtraction of the brain activity associated with the Sad and Happy states, and *post-hoc* analysis of the subject's activation centroids, revealed that there was an important degree of regional specificity in terms of the voxels activated in these brain regions. That is, the significantly activated voxels, during the transient states of sadness and happiness, were selectively localized in distinct subdivisions within the same brain regions. Such a specificity suggests that these sub-regions may be involved in the processing of aspects uniquely related to either sadness or happiness. Sadness and happiness may be associated with similar brain regions but distinct sub-regions and neural circuits.

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