

Neural Correlates of Levels of Emotional Awareness: Evidence of an Interaction between Emotion and Attention in the Anterior Cingulate Cortex

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Abstract

Recent functional imaging studies have begun to identify the neural correlates of emotion in healthy volunteers. However, studies to date have not differentially addressed the brain areas associated with the perception, experience, or expression of emotion during emotional arousal. To explore the neural correlates of emotional experience, we used positron emission tomography (PET) and ^{15}O -water to measure cerebral blood flow (CBF) in 12 healthy women during film- and recall-induced emotion and correlated CBF changes attributable to emotion with subjects' scores on the Levels of Emotional Awareness Scale (LEAS), a measure of individual differences in the capacity to experience emotion in a differentiated and complex way. A conjunction analysis revealed that the correla-

tions between LEAS and CBF during film- and recall-induced emotion overlapped significantly ($z = 3.74, p < 0.001$) in Brodmann's area 24 of the anterior cingulate cortex (ACC). This finding suggests that individual differences in the ability to accurately detect emotional signals interoceptively or exteroceptively may at least in part be a function of the degree to which the ACC participates in the experiential processing and response to emotion cues. To the extent that this finding is consistent with the functions of the ACC involving attention and response selection, it suggests that this neural correlate of conscious emotional experience is not exclusive to emotion. ■

INTRODUCTION

Compelling evidence now exists suggesting that emotional perception, judgments, and behavior can proceed outside of conscious awareness (LeDoux, 1996; Ohman & Soares, 1993). This raises the question of whether the conscious experience of emotion is an essential feature of emotion or an epiphenomenon. Animal models of emotional behavior (LeDoux, 1996) are consistent with

the latter position, leading to the prediction that the neural correlates of conscious emotional experience, if found, will not be specific to emotion. However, many who study human behavior consider conscious experience to be an essential component of human emotion (Clore, 1994). For example, the impairments in decision-making observed in patients with lesions that interfere with emotional experience suggest that emotional experience has important adaptational consequences

(Damasio, 1994). Therefore, the search for the correlates of conscious emotional experience is important for both theoretical and practical reasons.

The usual approach to the assessment of emotional experience is to ask people to rate the frequency or intensity of specific emotions during daily events or in response to a specific stimulus. Underlying the use of such approaches is the assumption that self-reported information is accurate. However, to the extent that conscious awareness represents only a fraction of the automatic, unconscious emotion-related computations that occur, individual differences in the capacity to be aware of emotion are likely. To the extent that such individual differences exist, they may be used as a vehicle to gain insight into the neural substrates of conscious emotional experience.

Lane and Schwartz (1987) propose that an individual's ability to recognize and describe emotion in oneself and others is a cognitive skill that undergoes a developmental process similar to that which Piaget described for cognition in general. Their cognitive-developmental model posits five "levels of emotional awareness" that share the structural characteristics of Piaget's stages of cognitive development. The five levels of emotional awareness in ascending order are physical sensations, action tendencies, single emotions, blends of emotion, and blends of blends of emotional experience. The five levels are characterized by progressively greater degrees of differentiation and integration of the schemata used to process emotional information, whether that information comes from the external world or the internal world of experience. Higher levels of emotional awareness are associated with a greater capacity to appreciate complexity in the experience of self and other. This model is consistent with that of successors to Piaget such as Karmiloff-Smith (1994), who holds that cognitive development in different domains of knowledge proceeds through a process called *representational re-description*, which involves transformation of knowledge from implicit (procedural, sensorimotor) to explicit (conscious thought) forms through the use of language (or other representation mode).

The Levels of Emotional Awareness Scale (LEAS) (Lane, Quinlan, Schwartz, Walker, & Zeitlin, 1990) was specifically designed to measure these individual differences and test the hypotheses that follow from this model. The LEAS is a written performance measure that asks the subject to describe his or her anticipated feelings and those of another person in each of 20 scenes described in two to four sentences. Highly reliable structural scoring criteria are used to evaluate the degree of differentiation and integration of the words denoting emotion attributed to self and other. Higher scores reflect greater differentiation in emotion and greater awareness of emotional complexity in self and other. Indeed, a recent study found that the ability to identify emotion cues either verbally or nonverbally is positively correlated with

scores on the LEAS (Lane et al., 1996). Interestingly, the LEAS does not correlate with the intensity of self-reported positive or negative affect (Lane, Kevley, DuBois, Shamasundara, & Schwartz, 1995; Lane et al., 1996), consistent with its focus on the structure or complexity, rather than the specific content or quantity, of experience.

As a first approach to the exploration of the neural correlates of emotional awareness, the association between LEAS scores and the degree of right-hemispheric dominance in the perception of facial emotion was evaluated (Lane et al., 1995). Consistent with prediction, higher LEAS scores were associated with greater right-hemispheric dominance in the performance on the Levy Chimeric Faces Test. These data suggest that greater emotional awareness is associated with preferential use of those structures, such as the right parietal cortex, which are specialized for the evaluation and integration of exteroceptive emotion information. However, the neural correlates of emotional experience are likely to be different from those involved in perception of exteroceptive emotion cues.

A review of the animal and human literature suggests that a number of structures participate in the neural representation of emotion and could play a role in emotional experience. These include the thalamus (Cannon, 1929), hypothalamus (Bard, 1928), ventral striatum (Everitt & Robbins, 1992), amygdala (Aggleton, 1992), ACC (Papez, 1937; Devinsky, Morrell, & Vogt, 1995), anterior insula (Augustine, 1996), orbito-frontal cortex (Damasio, 1994), and mesial prefrontal cortex (Lane, Reiman, Ahern, Schwartz, & Davidson, 1997; Reiman, et al., 1997; Lane et al., 1997). Given our current state of knowledge, it is difficult to predict the extent to which any or all of these structures could participate in emotional experience. Functional imaging studies of emotion have recently been performed that begin to identify the neural correlates of emotion in intact human volunteers (Breiter et al., 1996; George et al., 1995; Morris et al. 1996; Pardo, Pardo, & Raichle, 1993; Schneider et al., 1995). However, to date these studies have focused on group effects rather than individual differences, and they typically have not been designed to disentangle the perceptual, expressive, and experiential components of emotion.

In a recent PET study we explored the neural correlates of film- and recall-induced emotion (Lane et al., 1997; Reiman et al., 1997). Meaningful similarities and differences were observed between these induction methods. This study therefore afforded us the opportunity to explore the association between scores on the LEAS and CBF specifically attributable to emotion. As a first approximation, we hypothesized that greater emotional awareness would be associated with increased activity in those structures previously implicated in emotional experience: the thalamus, hypothalamus, ventral striatum, amygdala, ACC, anterior insula, orbito-frontal

cortex, and/or mesial prefrontal cortex. The design of this PET experiment also enabled us to explore the neural correlates of emotion induced either externally through film or internally through recall and the conjunction or overlap between the two. To the extent that common schemata are used in the processing of emotional information arising internally or externally, common neural correlates of emotional awareness across the film and recall conditions were predicted.

RESULTS

Subjects reported large, significant, and relatively pure increases in the relevant target emotion during the emotion-generating film ($F(1, 11) = 226, p < 0.001$) and recall ($F(1, 11) = 1041, p < 0.001$) tasks compared to the ratings of corresponding emotions during the control tasks (Figure 1).

All subjects scored above the median for women in their age group on the LEAS (range 68 to 88). There were no significant correlations between LEAS scores and self-reported experience of the target emotions during each scan, consistent with results from previous studies with the LEAS, the restricted range in self-reported target emotions, and the small sample size.

Covariate analyses involving the LEAS were performed separately for film- and recall-induced emotion as described below. Neither analysis generated results that survived correction for multiple comparisons for the entire volume of interest.

Findings from the covariate analysis involving LEAS

that equaled or exceeded a height threshold of $z = 3.09, p < 0.001$ uncorrected for multiple comparisons, and an extent threshold of 5 voxels, were then examined. There was one cluster for film-induced emotion with a maximum located in the right midcingulate cortex (BA 23; coordinates of maximum = $[16, -18, 32]; z = 3.40, p < 0.001$ uncorrected) that met these criteria. There were no findings for recall-induced emotion that equaled or exceeded these thresholds. However, the most statistically significant cluster was located in the right anterior cingulate cortex (BA 24; coordinates of maximum = $[16, 6, 30]; z = 2.82, p < 0.005$ uncorrected).

A conjunction analysis was performed next to identify areas of significant overlap between the two covariance analyses. With a height threshold of $z = 3.09, p < 0.001$, and an extent threshold of 5 voxels, a single cluster was observed in the right ACC (BA 24) maximal at $[14, 6, 30] z = 3.74, p < 0.001 (p = 9.2 \times 10^{-5})$ uncorrected. As can be observed in Figure 2, the point of maximum change is located in white matter adjacent to the ACC. Given that CBF changes in white matter are unlikely, the imprecision in anatomical localization associated with image normalization, the extension of the area of significant change into the ACC, and the absence of other gray matter structures in the immediate vicinity, the likeliest location of this cluster is the ACC.

It was noted above that there are several structures that have been previously implicated in emotional experience. Activation of any of these structures would not be considered a chance finding. However, to correct for the possibility that within this group of structures the

Figure 1. Mean ratings ($n = 12$) of happiness, sadness, and disgust for each type of film and recall stimulus. Ratings on a 0-to-8 analog scale were obtained on multiple emotions immediately after each scan. The values for film and recall controls each represent the mean values for three scans.

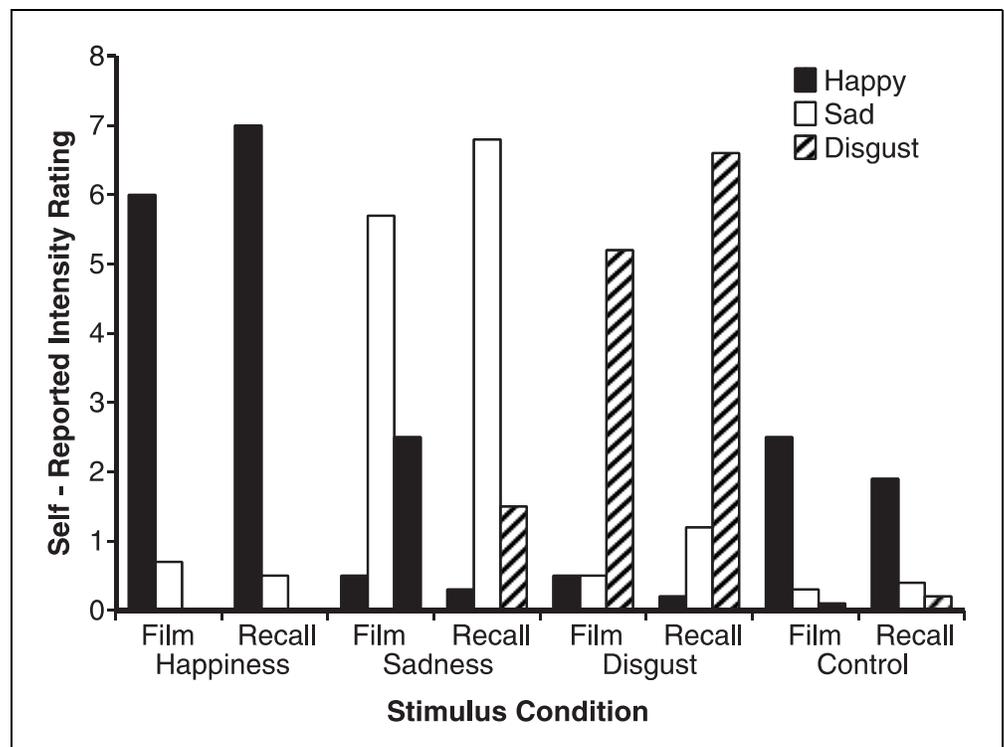
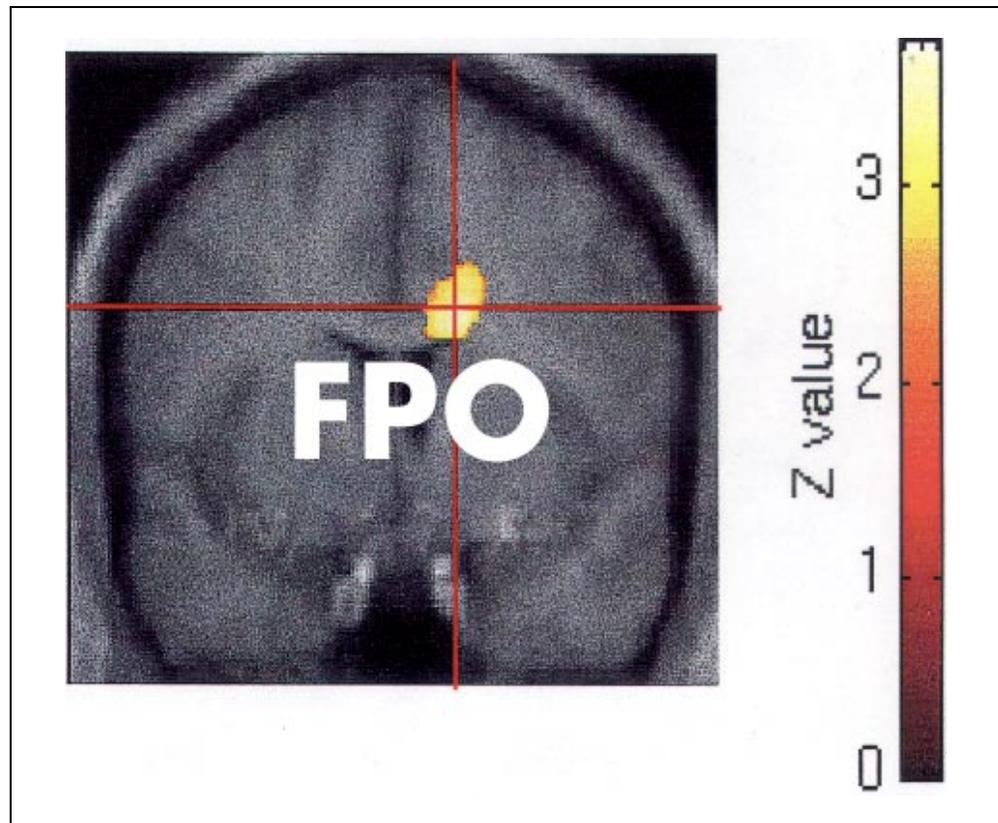


Figure 2. Results of the conjunction analysis demonstrating overlap of the separate associations during film- and recall-induced emotion between LEAS and CBF in the ACC. The cluster depicted contains 66 voxels with a maximum activation at coordinates [14, 6, 30], $z = 3.74$, $p < 0.001$. These results are displayed on an average of the subjects' brain MRIs.



correlation in the ACC occurred by chance, one can multiply the p value of the correlation in the ACC by the number of resolution elements collectively occupied by the structures specified a priori. The smoothness of the statistic image was equivalent to 279 resolution elements. It is conservatively estimated that the structures specified a priori collectively occupy at most 10% of these resolution elements. An approximate Bonferroni correction for the number of resolution elements based on this estimate ($9.2 \times 10^{-5} \times 27.9 = p = 0.003$) is highly significant, a result that would certainly remain significant ($p < 0.05$) using a more exact method (Worsley et al., 1995) that is complicated and not generally available.

Activity in the ACC was then examined in the film and in recall emotion-minus-neutral comparisons independent of their associations with LEAS. There were no significant CBF increases in ACC during film- or recall-induced emotion. However, there were significant decreases in CBF in the ACC during film-induced emotions in an extensive area (452 voxels) maximal in BA 32 (coordinates = [2, 22, 38]; $z = 4.52$, $p < 0.03$ corrected). There were no significant decreases in CBF in the ACC during recall-induced emotion.

DISCUSSION

The purpose of this study was to identify those brain areas activated during emotional arousal that are prefer-

entially associated with the conscious experience of emotion. To do so we identified changes during film- and recall-induced emotion that covaried with scores on the LEAS, a measure of individual differences in the differentiation and complexity of emotional experience. Although the women in this study all scored above the median on the LEAS for their age group (Lane, Sechrest, Axelrod, Weldon, & Schwartz, in preparation), thus restricting the range of LEAS scores, positive associations between LEAS and CBF calculated separately for film- and recall-induced emotion were found to overlap maximally in BA 24 of ACC. Given the strong evidence supporting the prediction that the ACC could be involved in the experiential aspects of emotion (see below), this result was statistically quite robust.

The ACC is a complex structure with numerous functions that "are difficult to quantify or even describe" (Vogt, Finch, & Olson, 1992). Traditionally the ACC was thought to have a primarily affective function (Papez, 1937; Vogt, Finch, & Olson, 1992). However, in addition to emotion, it is now recognized to play important roles in attention, pain, response selection, maternal behavior, vocalization, skeletomotor function, and autonomic control (Vogt & Gabriel, 1993). The multiple functions of the ACC no doubt contribute to the significant changes in activation that have been observed in a variety of studies. How can these different functions be reconciled with the present findings involving emotional awareness?

One answer might be that these various functions of

the ACC may reflect its superordinate role in executive control of attention and motor responses. According to this view, emotion, pain, or other salient exteroceptive or interoceptive stimuli provide moment-to-moment guidance regarding the most suitable allocation of attentional resources for the purpose of optimizing motor responses in interaction with the environment. The conscious experience of emotion could occur concomitantly and automatically as attention gets redirected by emotion. As such, a role of the ACC in the conscious experience of emotion fits well with its other functions but suggests that this role is not exclusive to emotion.

Activation of the ACC has been observed in a variety of PET studies of cognitive and motor tasks, including the Stroop interference effect (Bench et al., 1993; Pardo, Pardo, Janer, & Raichle, 1990), divided versus focused attention (Corbetta, Miezin, Dobmeyer, Shulman, & Petersen, 1990, 1991), semantic association (Frith et al., 1991a; Petersen, Fox, Posner, Mintun, & Raichle, 1988), and control of oculomotor, manual, and speech responses (Paus, Petrides, Evans, & Meyer, 1993). These studies reveal that the ACC is activated by the selection of targets from competing inputs, dividing attention simultaneously among several different attributes or by willed action. The ACC facilitates appropriate responses and suppresses inappropriate responses. The ACC is not active when the subject can rely on automatic or overlearned responses to specific stimuli. Thus, the ACC is thought to participate in the cognitive processing or attention to a stimulus that is used to guide selection of a response (Posner, 1994).

There is also abundant evidence that the ACC is activated during emotion and pain. Several recent PET studies have demonstrated ACC activation during a variety of emotion conditions, including recalled sadness (George et al., 1995; Mayburg, Liotti, Jerabek, Martin, & Fox, 1995), perception of emotion in faces (George et al., 1993), provocation of symptoms of posttraumatic stress disorder (Rauch et al., 1996), procaine-induced dysphoria (Ketter et al., 1996), CCK-induced anxiety (Benkelfat et al., 1995), REM sleep (Maquet et al., 1996), and anticipation of a cognitive challenge (Murtha, Chertkow, Beauregard, Dixon, & Evans, 1996). CBF decreases in the ACC have also been observed in PET (Bench et al., 1993) and SPECT (Mayburg, Lewis, Regenold, & Wagner, 1994) studies of depressed patients. Lesions of the ACC producing akinetic mutism are associated with blunting of subjective emotional experience (Damasio & Van Hoesen, 1983). The ACC has also been consistently observed to be activated by pain in PET studies involving painful heat (Talbot et al., 1991) or interlaced warm and cold bars producing a thermal illusion of pain (Craig, Reiman, Evans, & Bushnell, 1996). Anterior cingulotomy is an accepted treatment for intractable pain (Gybels & Sweet, 1989). Interestingly, postoperatively, patients report that they still feel the pain but that it doesn't bother them as much, suggesting that the emotional component of the

pain has been lessened. The conclusion that the ACC participates in the emotional component of pain was supported by a recent PET study (Rainville et al., 1997). This surgical procedure has been associated with postoperative emotional blunting in 57% of one series of patients (Wilson & Chang, 1974), again supporting the role of the ACC in emotion regulation and perhaps suggesting the presence of individual differences in the degree to which the ACC contributes to emotional experience.

People who have a high level of emotional awareness are especially good at accurately detecting and discriminating emotional signals in themselves and others. Thus, a greater number of emotion targets may be identified within, or more internal emotional information may be generated from, a given external emotional stimulus. Thus, CBF in the ACC during emotional arousal may be a function of both the complexity or amount of emotional information inherent in the subjective experience and the concomitant complexity in the associated motor response orchestrated by the ACC.

An alternative interpretation focuses on the possible role of voluntarily directed attention in this study. Appreciation of greater complexity may be mediated by covert switching of attention to different aspects of the stimulus (Posner & Dehaene, 1994). It is known that this switching does not require eye movement in the case of an external stimulus. In this study during both the film and recall tasks, subjects were instructed to focus on feeling the target emotion. The decrease in CBF in the ACC during the film emotion tasks may reflect greater maintenance of a single attentional focus during the emotion compared to the neutral tasks. For higher LEAS subjects this may have required a greater effort at suppressing attention to other nontarget emotions during the emotion stimuli, which may have been associated with greater relative activation of the ACC. Thus, the mechanisms that have been attributed to the ACC in attention generally may be involved in attention to interoceptive emotional signals. It should be noted, however, that preliminary analyses in another PET study (Lane et al., 1997) in which subjects were not asked to maintain a specific attentional focus during emotion induction reveal a similar correlation between LEAS and ACC activity.

It is important to note that the present findings address the nature or degree of conscious awareness of emotion, a continuum that in this study did not include unconscious emotion. The structures specified a priori could well participate in the latter function. The failure to observe a correlation between LEAS and activity in these structures could be due to the focus in this study on emotion generally rather than specific types of emotion, such as fear (amygdala) or pleasure (ventral striatum). Negative findings are less meaningful than positive findings in PET studies due to limitations in spatial resolution, statistical power, possible heterogene-

ity in the cognitive strategies used to perform a task, or a change in the pattern rather than the level of neuronal activity.

The findings in this study suggest that the degree to which the ACC is activated during emotion varies across individuals. Additional research is clearly needed to determine whether these findings apply to men as well as women, to individuals who span the entire range of emotional awareness scores, to some emotions and not others, or to other related individual difference variables, such as repression or alexithymia. It will be important to test whether the relationship between LEAS and ACC activity is observed when processing cognitive stimuli without emotional content. It is also possible that ACC activity and LEAS measurements are each related to some aspect of emotion or the emotion-generating tasks other than emotional awareness. A rigorous test of the current finding would involve determining whether a psychoeducational program designed to improve emotional awareness can modify the degree of ACC activity during emotional arousal. Experimental paradigms would also be useful in determining the role of the ACC in mediating how alterations in attentional focus or mood influence each other.

In conclusion, this study examined individual differences in the differentiation and complexity of emotional experience and found an association with greater activation in the ACC during emotional arousal. These results extend those from a previous behavioral study indicating that LEAS scores correlate positively with the accuracy of the perception of emotion cues. It is hypothesized that ACC activity increases as the amount of information inherent in an emotional experience and the associated complexity of the concomitant motor response increases, consistent with a superordinate role of the ACC in attention and response selection. To the extent that the anterior attentional system is more readily engaged by emotion as a function of level of emotional awareness, greater sensitivity and attention to emotion cues would be expected, which could provide ongoing opportunities for continued emotional growth.

METHOD

Subjects

A screening procedure was used to identify 12 right-handed, neurologically and psychiatrically well, unmedicated female volunteers who were likely to have intense emotional responses in the PET laboratory. The sample was restricted to females to maximize the homogeneity of emotion-dependent changes in CBF and the likelihood of intense self-reported emotional experiences (Shields, 1991). An advertisement was used to recruit female volunteers between the ages of 18 and 30 who were "able to accurately describe [their] emotional reactions to daily events." Psychiatric and medical histories, a neuro-

logical exam, the Structured Clinical Interview for DSM-III-R—Non-Patient Version (SCID-NP) (Spitzer, Williams, Gibbon, & First, 1994), the Edinburgh Handedness Inventory (Oldfield, 1971), and a complete neurological exam were used to identify prospective subjects for further evaluation. Prospective subjects were included in the PET study if they reported separate experiences during the previous six months of happiness, sadness, and disgust that were each rated at least 6 on a 0 to 8 visual analog scale (8 representing the most intense experience of that kind in their lives) and if they rated each of an alternate screening set of three films targeting happiness, sadness, and disgust, respectively, at least 5 on an 8-point scale. After a complete description of the study was given to the subjects, written informed consent was obtained. Subjects received compensation for their participation in the PET study. The 12 subjects who completed the PET protocol had a mean age of 23.3 years ($SD = 3.2$).

Psychological Measures

Psychological measures were administered to prospective subjects who met those screening criteria that could be assessed by telephone. Psychological measures were used to describe but not select subjects.

Levels of Emotional Awareness Scale

The LEAS is a written performance measure that asks the subject to describe her anticipated feelings and those of another person in each of 20 scenes (vignettes) described in two to four sentences. Highly reliable structural scoring criteria are used to evaluate the degree of differentiation and integration of the words denoting emotion attributed to self and other. Higher scores reflect greater differentiation in emotion and greater awareness of emotional complexity in self and other.

In previous research, the LEAS has been shown to correlate positively with two cognitive-developmental measures, the Sentence Completion Test of Ego Development ($r = 0.25$; $n = 94$; $p < 0.05$) (Loevinger & Wessler, 1970; Loevinger, Wessler, & Redmore, 1970) and the cognitive complexity of the description of parents ($r = 0.26$; $n = 92$; $p < 0.05$) (Blatt, Wein, Chevron, & Quinlan, 1979). The magnitude of the latter two correlations suggests that the LEAS is not just a measure of cognitive complexity. The LEAS correlates positively with the WAIS vocabulary subtest ($r = 0.36$, $n = 91$, $p < 0.001$) and the Shipley Institute of Living scale of verbal ability ($r = 0.19$, $n = 45$, *ns*). Women score higher than men on the LEAS (Levine, Marziali, & Hood, 1997) even when controlling for verbal ability (Barrett, Lane, Sechrest, & Schwartz, submitted), and the LEAS predicts emotion recognition accuracy on purely nonverbal tasks (Lane et al., 1996), evidence that the LEAS is not just a measure of verbal ability. As noted above, the LEAS also correlates positively

with the degree of right-hemispheric dominance in the judgment of facial emotion (13). Inter-rater reliability of LEAS total score has been consistently high with intraclass $r = 0.84$ (3) and Pearson product moment $r = 0.97$ (13). An adequate estimate of the test-retest reliability of the LEAS in the general population is not available.

One scene is presented per page, followed by two questions, "How would you feel?" and "How would the other person feel?" at the top of each page. Subjects write their responses on the remainder of each page. They are instructed to use as much or as little of the page as needed to answer the two questions.

Responses are scored separately for each scene. Each scene receives a score of 0 to 5 corresponding to the underlying cognitive-developmental theory of five levels of emotional awareness, resulting in a maximum total score of 100. Each reply receives separate scores for the emotion described for the "self" and for the "other." The lowest score (level 0) is for nonemotion responses in which the word *feel* is used to describe a thought rather than a feeling. Level 1 reflects an awareness of physiological cues (e.g., "I'd feel tired"). Level 2 consists of words that are typically used in other contexts but are frequently used to convey relatively undifferentiated emotion (e.g., "I'd feel bad") or use of the word *feel* to convey an action tendency, "I'd feel like punching the wall." Level 3 responses involve use of one word conveying typical, differentiated emotion (e.g., happy, sad, angry). A glossary of words at each level was created prior to this study to guide scoring. The highest score for the "self" and "other," Level 4, is given when two or more Level 3 words are used that conveyed greater emotional differentiation than either word alone. Each subject thus receives a separate score for the self response and for the other response from 0 to 4. In addition, a third "total" score is given, equal to the higher of these two (self and other) scores, except in the case in which both self and other received Level 4 scores. Under these circumstances, a total score of Level 5 is given for the scene if the emotions for self and other can be differentiated from one another. Only results using the total score are reported. Thus, the ratings are based entirely on structure, involve no inference regarding the meaning of words, and do not require any rating for appropriateness of the response.

Protocols were identified only by subject number; each scene was coded independently of the others across all subjects. All protocols were scored by one expert rater.

Other Measures

Right-handedness was determined by scores on the Edinburgh Handedness Inventory (Oldfield, 1971). Subjects in this study had above average scores on the Vividness of Visual Imagery Scale (Marks, 1989) measure of imagery ability and average scores compared to women of

the same age on the Affect Intensity Measure (Diener, Sandvik, & Larsen, 1985), a measure of the tendency to experience emotions intensely.

Experimental Design

During the PET session, three empirically validated silent, color, feature film clips (Tomarken, Davidson, Henriques, 1990) were used for the external generation of three subjectively, facially, and electrophysiologically well-characterized target emotions: happiness, sadness, and disgust. The film clips activate relatively pure emotion and are each approximately 2 min in duration. It is notable that all of these clips include actors displaying facial expressions. The 1-min segment from each emotion film that evoked the target emotion most intensely in the investigators was selected for viewing during the 1-min scan. Three additional, emotionally "neutral" silent film clips were used to control for potentially confounding features of the emotion-generating film task, such as emotionally irrelevant visual stimulation and eye movement. These clips were culled from nature films (scenes of a beach, woods, etc.) and did not include people.

During the PET session, autobiographical scripts of three recent experiences were used for the internal generation of the same three target emotions. Three additional, emotionally "neutral" autobiographical scripts of recent experiences were used to control for potentially confounding features of the emotion-generating recall task, such as emotionally irrelevant recall memory and visual imagery. Subjects were instructed to focus during recall on a previously identified moment during which the target emotion was experienced very intensely and other emotions were experienced much less intensely.

Immediately prior to each PET scan, the subject listened to either a brief synopsis of the film clip or the autobiographical script. For the emotion-generating film and recall tasks, subjects were asked to feel the relevant target emotion. For the control film and recall tasks, subjects were asked to feel emotionally "neutral." During the film task the subjects' eyes were open and fixed on the center of a ceiling-mounted 27-in television monitor. During the recall tasks, the subjects' eyes were closed and directed forward.

The 12 scans were performed in blocks of six for film and recall, respectively. The order of the blocks was counterbalanced. Emotion-generating and control tasks were performed in an alternating sequence within each block. Whether each block began with an elicitor or control was counterbalanced across subjects. Within these constraints, the order of the three elicitors and three controls in each block was randomized. Subjective ratings of seven emotions (interest, amusement, happy, sad, fear, disgust, anger) were recorded immediately after each scan on an eight-point visual analog scale.

Imaging Procedures

Magnetic resonance images (MRIs) of the head were acquired prior to the PET session to ensure structural normality of the brain, facilitate head positioning in the PET scanner, and permit coregistration between the PET and MRI images.

Subject preparation for PET included the insertion of a catheter in the left antecubital vein to permit tracer administration, head immobilization using tape rather than a fast-hardening foam mold to permit quantitative EEG measurement during the PET session, and the performance of a transmission scan using a $^{68}\text{germanium}/^{68}\text{gallium}$ ring source to correct subsequent emission images for radiation attenuation. During each scan, the subjects rested quietly in the supine position without movement.

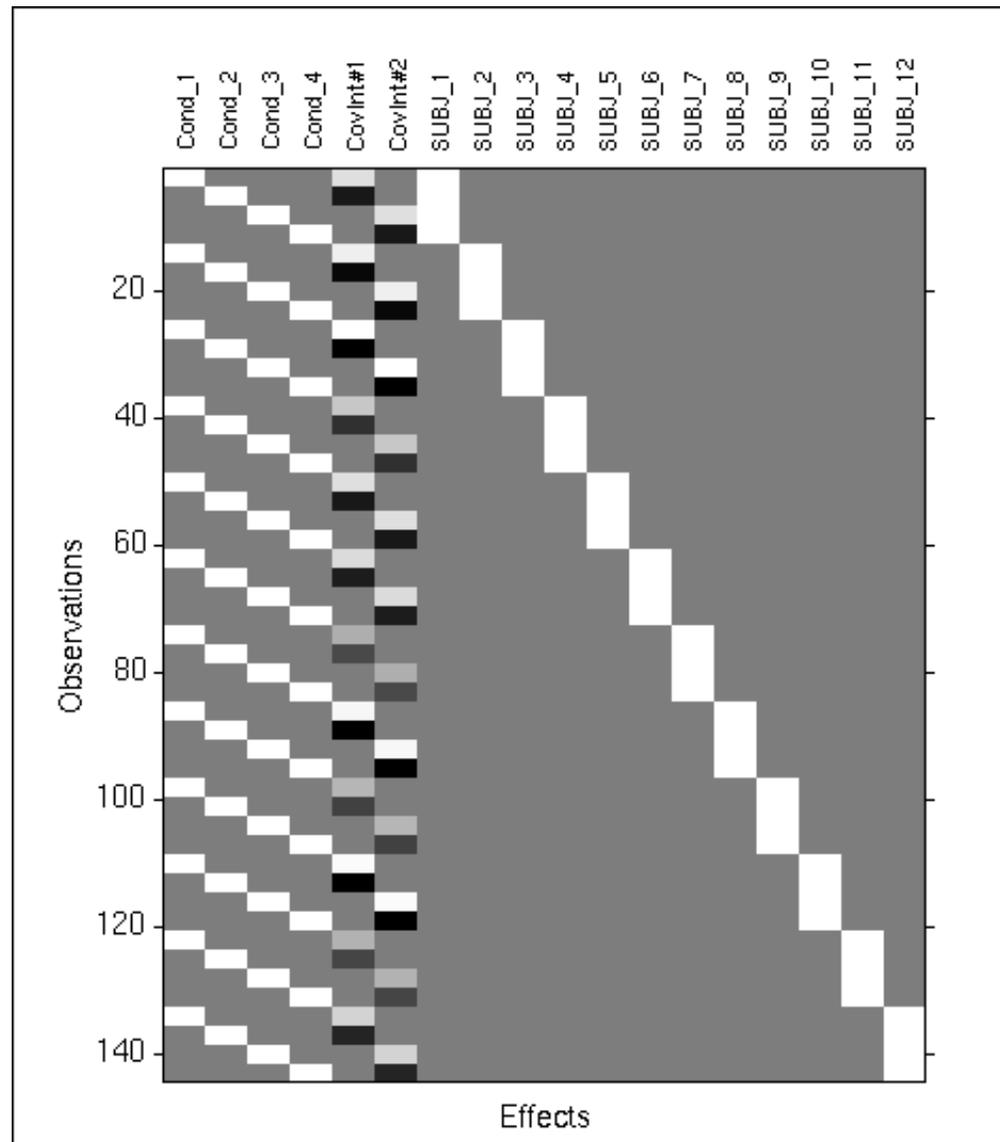
Twelve 31-slice PET images of regional CBF were obtained in each subject as she alternated between emo-

tion-eliciting and control tasks using the ECAT 951/31 scanner (Siemens, Knoxville, TN), 40 mCi intravenous bolus injections of ^{15}O -water, 60-sec scans, and an interval of 10 to 15 min between scans (Frith et al., 1991b; Reiman, Fusselman, Fox, & Raichle, 1989; Reiman, Mintun, et al., 1989). The radiotracer was administered at predetermined times shortly after the onset of the film and recall tasks. PET images were reconstructed with an in-plane resolution of 10 mm full width half maximum (FWHM) and a slice thickness of 5 mm FWHM.

Image Analysis

The data were analyzed with statistical parametric mapping (Friston et al., 1995; Friston et al., 1996) using SPM96 software from the Wellcome Department of Cognitive Neurology, London, implemented in Matlab (Mathworks, Sherborn, MA). After initial realignment, the scans

Figure 3. Design matrix for covariate analysis. A blocked (by subject) ANCOVA model with four conditions (1 = film emotion, 2 = film neutral, 3 = recall emotion, and 4 = recall neutral, each consisting of three scans) and two covariates. Covariate 1 consists of the subject's LEAS score weighted positively for condition 1 and negatively for condition 2. Covariate 2 consists of subject's LEAS score weighted positively for condition 3 and negatively for condition 4. The gray-scale shading of the covariates is proportional to the LEAS score.



were transformed into standard stereotactic space (Talairach & Tournoux, 1988). The scans were smoothed using a Gaussian filter set at 16 mm FWHM. The regional CBF equivalent measurements were adjusted to a global mean of 50 ml/dl/min by proportional scaling.

A blocked (by subject) analysis of covariance (ANCOVA) model with four conditions (film emotion, film neutral, recall emotion, and recall neutral, each consisting of three scans) was used. To assess the significance of the LEAS on the difference between the emotion and neutral conditions within each stimulus modality (film or recall), the LEAS covariate was added as an emotion-minus-neutral interaction within each stimulus modality (see Figure 3). This is equivalent to correlating the LEAS for each subject with the emotion-minus-neutral difference within each stimulus modality for each subject, without reducing each condition to a single data point per subject. The effects of the LEAS covariate at each voxel within stimulus modality were assessed using the *t* statistic for a positive LEAS by emotion/neutral interaction, giving two statistic images. A conjunction analysis (Price & Friston, 1997) was then performed to identify where there were significant areas of overlap between these two covariate analyses.

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