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Hemispheric Lateralization of Functions Related to Emotion

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We have reviewed the evidence that processes and functions related to perception and expression of emotions are represented asymmetrically in the cerebral hemispheres. The literature describes three possible aspects of emotional lateralization: that emotions are better recognized by the right hemisphere; that control of emotional expression and related behaviors takes place principally in the right hemisphere; and that the right hemisphere is specialized for dealing with negative emotions, while the left is specialized for dealing with positive emotions. Evidence for the three hypotheses derives from methodologically diverse studies in unimpaired, brain-lesioned, and mood-disordered populations. Relatively little of the work has been precisely replicated, and conclusions rest on parallel lines of evidence from diverse sources. The present level of knowledge suggests a model of emotional control based on interactive inhibition between a right negatively biased and left positively biased hemisphere. However, the details of such a model, including the precise conditions under which emotion-related functions are lateralized, and the mechanisms of such lateralization have yet to be elucidated.

INTRODUCTION

It is well known that the two cerebral hemispheres of humans are not identical in function. The sides of the brain have been shown to differ in their capacity to handle different stimuli and in the manner in which they process information. There are also indications that the hemispheres differ in their involvement with regulation of emotions and related behavior. The existence and nature of such affective lateralization is the subject of the present review.

Emotional behavior is generally divided into parameters relating to subjective mood or feeling, concomitant autonomic and physiologic reactivity, and resultant motivated action. Studies in humans relevant to lateralization of affect involve subjective feeling states and related observable behaviors, autonomic components of emotion, and cognitive

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processing of emotional aspects of stimuli. Methodologically, these studies are extremely diverse, using measures ranging from physiologic parameters to subjective assessments of mood and affect. There are, at present, only small numbers of studies of each type, leaving the evidence scattered among many methodologically disparate investigations. The reviewer must, therefore, draw conclusions based on parallel lines of evidence from many independent sources.

The literature of affective lateralization comprises three types of studies, each characterized by a different kind of subject population. One group deals with normal functioning. In these studies, lateralized physiologic measures are monitored while subjects process material with emotional content. Conversely, performance on cognitive processing tasks may be measured when material to be processed is presented to the right vs. left hemispheres by tachistoscopic or dichotic listening techniques. Such studies provide data about lateralized processing of affectively laden stimuli, but not about lateralized control of mood and mood-related behavior. The second group of studies looks at subjects with brain lesions localized to one hemisphere. They investigate whether subjects have changes in mood and affect, or deficits in emotional processing related to the side of the lesion. Finally, studies of affectively ill patients investigate whether disordered mood states are associated with measurable dysfunction in one or the other hemisphere.

Three general hypotheses arise from this diverse literature. The first is that the nondominant hemisphere is superior for recognizing emotional aspects of information. The second is that the right hemisphere predominates in regulation of mood and affect. The third is that recognition and regulation of emotion are bilateral, but the right hemisphere is specialized for handling negative emotions, while the left is specialized for positive emotions. We will review the state of the evidence for each of these hypotheses, focusing on the paradoxes and discrepancies attendant on each hypothesis. We will then suggest possible areas of resolution of these discrepancies and directions for future research.

THE RIGHT HEMISPHERE IS SUPERIOR FOR RECOGNIZING EMOTIONAL ASPECTS OF INFORMATION

A variety of studies in both unimpaired and brain-lesioned subjects have suggested that the right hemisphere is specialized for processing emotional aspects of information. The major theoretical problem with such studies lies in disentangling the effects of emotion per se from other putative nondominant functions such as pattern recognition, recognition of faces, and appreciation of musical (i.e., tonal or inflectional) aspects of speech. We will review studies which present information in a lateralized manner to normal subjects, and then describe the evidence from subjects with unilateral brain lesions.

Dichotic listening techniques have been used in unimpaired subjects to demonstrate left ear advantage (implying right hemisphere advantage (Kimura, 1964; Hall & Goldstein, 1968)) in recognition of nonverbal, emotional aspects of human speech, such as laughter or crying. Three studies have reported this finding, although one of them is weakened by a failure to find the expected right ear advantage for recognition of verbal content (King & Kimura 1972; Haggard & Parkinson, 1971; Carmon & Nachshon, 1973). Lateralized processing differences may also be elicited with monaural presentation of material (Bakker, 1970; Bever, Hurtig, & Handel, 1976). Using this technique, Safer and Leventhal (1977) found that the emotional tone of sentences is judged by verbal content when heard by the right ear, but by tone of voice when heard by the left ear. However, the right ear was found to be superior when subjects were asked to simultaneously judge emotional content and tone of voice, suggesting that heavy verbal processing requirements may produce right lateralization even in tasks requiring processing of emotional material. This result was partially confirmed by Zenhausern, Notaro, Grosso, & Schiano (1981), who also found that habitual cognitive style of subjects—tendency to think in words vs. images—was a more powerful determinant of the way in which subjects judged emotionality than was ear of input.

In another variant of the monaural paradigm, subjects viewed cartoons and heard spoken captions and laughter in either the left or right ear. They found the cartoons funnier when the laughter was heard by the left ear (DeWitt, 1978). This would imply that the specifically *emotional* aspect of the material was better appreciated when heard in the left ear (right hemisphere advantage), since subjects were presumably able to recognize the sound pattern as laughter when heard in the right ear, but did not have as intense an emotional response. The other studies cited above used no controls which would have helped distinguish nonverbal processing generally from emotional processing specifically.

Tachistoscopic studies have dealt with this distinction by comparing processing of emotional pictures with processing of nonemotional visuospatial material. Landis, Assal, & Perret (1979) showed that subjects responded faster when discriminating pictures of objects seen in the right than left visual field, but showed left visual field superiority in discriminating emotional faces. Other workers have found that left visual field superiority for recognition of faces is enhanced when the faces have emotional rather than neutral expressions (Suberi & McKeever, 1977; Ley & Bryden, 1979), and that degree of left visual field advantage in such task depends upon how highly subjects rate emotionality of the faces (McKeever & Dixon, 1981). These studies suggest that emotionality of stimuli confers right hemisphere advantage over and above the requirement for processing of patterns or faces.

The above studies do not show whether right hemisphere advantages

arise from exclusive right-sided decoding of emotional stimuli, or whether such processing is potentially bilateral, but is usually done by a strategy more congenial to the right hemisphere. Using an analysis of response hand by visual field interactions, Suberi and McKeever (1977) concluded in favor of exclusive right hemisphere processing of emotional stimuli, but a similar analysis by McKeever and Dixon (1981) suggested merely preferential processing. The latter authors propose that the degree of emotionality of stimuli may determine whether hemispheric differences are relative or absolute. Another study suggests that both hemispheres can decode emotional stimuli, but have different strategies for doing so (Safer, 1981). Subjects were asked to memorize faces by empathizing with their emotional expressions or by labeling the expressions. Those who used empathy recognized more faces in the left visual field (right hemisphere superiority), but those who labeled showed no laterality effect.

None of the above studies find differences due to type or valence of emotion. Evidence about possible differences due to sex of subjects is mixed. Laterality effects were found in males, but not in females by some investigators (DeWitt, 1978; Graves, Landis, & Goodglass, 1981; Safer, 1981) while others do find such effects in females (Suberi & McKeever, 1977; McKeever & Dixon, 1981; Ley & Bryden, 1979) or even in females exclusively (Lavadas, Umilta, & Ricci-Bitti, 1980). Replication of such results will be needed before possible sex–task interactions can be elucidated.

Studies in brain-lesioned subjects have the advantage of being less inferential than those in unimpaired subjects, since there is definite functional disruption of one hemisphere. However, questions of size, location, and chronicity of the lesions, as well as degree of tissue irritability versus inactivation, may all bear importantly on interpretation of studies in such populations, and need to be controlled. The lack of such controls in many of the present studies makes it difficult to draw conclusions about brain mechanisms, or to reconcile discrepancies.

Several studies in lesioned subjects confirm the finding in normals that the right hemisphere is superior for recognizing emotional aspects of stimuli. Right hemisphere-lesioned subjects have been found to be more deficient than left-lesioned subjects in identifying and discriminating emotional tones in spoken speech (Heilman, Scholes & Watson, 1975; Tucker, Watson, & Heilman, 1977), and emotional facial expressions (DeKosky, Heilman, Bowers, & Valenstein, 1980). However, these studies do not distinguish between emotional recognition and general pattern recognition, and in the DeKosky study, deficits in emotional recognition were found to be at least partially dependent on the presence of prosopagnosia. Furthermore, not all right hemisphere lesions produce such deficits. Patients with deficits in the above studies all had parietal lesions and/or neglect of the left half of their bodies. Patients with right-sided nonparietal lesions,

and without neglect, were identical to left-lesioned subjects in their ability to recognize emotional tone or content of sentences. Another study by Kolb and Taylor (1981) found, in contrast, that patients with either destructive frontal, temporal, or parieto-occipital lesions of the right hemisphere were unable to match pictures of faces for emotional expression. Another notable result from this study was that left hemisphere lesions disrupted subjects' ability to identify emotions from verbal descriptions.

The association between unilateral neglect and "emotional agnosia" suggests that the latter might arise from cerebral underarousal in response to emotional stimuli. Right hemisphere lesions more than left have been found to produce neglect (Albert, 1973) along with hyporesponsiveness to sensory stimuli (Howes & Boller, 1975; Green & Hamilton, 1976; Heilman, Schwartz, & Watson, 1978; Heilman & Watson, 1977) and to emotional stimuli in particular (Morrow, Vrtunski, Kim, & Boller, 1981). It is possible, therefore, that right hemisphere decoding of emotional stimuli may be mediated by actual *emotional reactions* in response to them (cf. Safer, 1981).

Other studies suggest that subjects may use other types of mediation for emotional recognition, however. In a study of humor recognition in right- and left-lesioned subjects, Gardner, Ling, Flamm, and Silverman (1975) found that the groups were impaired to an equal degree in picking out the most humorous cartoons from an array, but laughter responses were absent or inappropriate in the right hemisphere group only (cf. DeWitt, 1978, above). Subjects with left (but not right) unilateral epileptic foci have also been found deficient in assigning appropriate emotional labels to printed descriptions of scenes (McIntyre, Pritchard, & Lambroso, 1976). Such studies suggest that both hemispheres may have strategies for decoding emotional stimuli (cf. Safer, 1981, above) but that an intact right hemisphere is needed to mediate felt emotional responses. While ability to recognize emotions is potentially impaired by disruption of either hemisphere, use of complex tasks may elicit qualitatively different types of impairment depending on the side of the lesion. Thus, when asked to remember emotionally charged and neutral anecdotes, both right- and left-lesioned patients remembered *fewer elements* of the emotional stories, but only right-lesioned subjects distorted the *meaning* of them (Wechsler, 1973).

Other evidence of lateralized emotional recognition comes from studies of "split brain" subjects, who have had total or partial section of their corpus callosa and commisures for treatment of intractable epilepsy. A group of such patients has been described as being unable to give accurate verbal descriptions of their own emotional states (Hoppe & Bogen, 1977). This has been interpreted to mean that emotional recognition is exclusively right-sided, and has no way of reaching the verbal hemisphere in split brain subjects. However, Gazzaniga, Risse, Springer, Clark, & Wilson

(1975) found little impairment in split brain subjects' ability to describe pictures of emotional facial expressions. Differences in degree of separation of the hemispheres and functional reprogramming of the hemispheres prior to separation (such as occurs with lesions incurred very early) may account for these discrepancies.

None of the studies in lesioned subjects report processing differences due to type of emotion, nor do any describe differences between men and women.

Summary. Studies in both normal and lesioned subjects suggest that the right hemisphere is superior for recognizing emotional aspects of stimuli. A few provide evidence that emotionality itself, rather than general pattern processing, is a factor in such dominance, but the two aspects of stimuli are confounded in most of the studies. There is evidence that both hemispheres may be able to decode emotional information using different strategies, although the right hemisphere strategy may be more commonly employed in the usual experimental tasks. The right hemisphere strategy may involve production of felt emotional reactions as mediators of the recognition process. The evidence for differences in lateralized emotional processing due to sex is contradictory and inconclusive.

THE RIGHT HEMISPHERE IS DOMINANT IN REGULATION OF MOOD AND AFFECT

In the present section, we review the evidence that the right hemisphere predominates in regulating mood, affect, and related observable behavior. Two general types of studies have appeared in support of such a conclusion. The first provides evidence that the right hemisphere is preferentially activated during periods of felt emotion in normal subjects, while the second correlates disorders of mood and affect with changes in right hemisphere function. While such studies are conceptually straightforward, they demand interpretation of a wide variety of physiologic measures, precise specification of type of lesion, and careful characterization of complex changes in mood and affect of the subjects. Much of the uncertainty in the studies described in this section stems from difficulties in these areas.

A series of studies has used lateralized electrophysiologic parameters measured during emotionally charged and neutral mental states. Subjects have shown relative right hemisphere activation (as measured by decreased alpha power) during recollection of past events associated with anger or relaxation (Davidson & Schwartz, 1976) and during self-reported emotional reactions to visual material (Davidson, Schwartz, Saron, Bennett, & Goleman, 1979). Other investigators have reported alterations in *left* hemisphere activity which corresponded to variations in the emotional content of mental imagery (Harman & Ray, 1977). The apparent discrepancy may be due to methodological differences, since the latter study employed verbal mediation throughout the mental imagery task, as well as monitoring

a broader band of EEG frequencies, less specifically indicative of activation. Such divergent findings highlight the need to distinguish between effects due to language-related mental activity, and those due to experiences of felt emotion. Independent measures of intensity of felt emotion were not employed in these studies. Other studies have found relative right hemisphere activation in subjects when generating emotional imagery (Karlin, Weinapple, Rochford, & Goldstein, 1979), during painful stimulation (Karlin et al., 1979), and during hypnotically induced depression (Tucker, Stenslie, Roth, & Shearer, 1981). Relative right hemisphere deactivation has been found in periods following intense expressions of emotion (such as crying or screaming) (Hoffman & Goldstein, 1981). Only in the latter study were systematic observations of emotional intensity made.

Location at which measurements are made within the hemisphere may be an important parameter in studies of this kind. Tucker et al. (1981) found frontal but not posterior activation during depressed states, while Davidson et al. (1979) found that lateralized activation patterns depended on mood valence in frontal areas, but favored the right hemisphere regardless of valence in posterior regions (see following section).

A variety of other measures have also been used as indicators of hemispheric function during periods of felt emotion. In a series of studies, Tucker and coworkers have found increased right visual field errors on verbal and spatial tasks during periods of increased anxiety (Tucker, Antes, Stenslie, & Barnhardt, 1978), and right ear bias in the perception of tones in subjects with high trait anxiety (Tucker et al., 1978) and during periods of depressed (but not euphoric) mood (Tucker et al., 1981). While the authors argue that these results indicate *left* hemisphere activation during depression and anxiety, the data are open to other interpretations. For example, poorer right visual field (left hemisphere) performance may stem from right hemisphere activation during anxious periods, rather than engagement of the left hemisphere in production of anxiety (thereby detracting from its cognitive performance) as the authors suggest. The authors' own findings of increased right EEG activation and increased left lateral eye movements (see below) during anxiety would tend to contradict their interpretation.

Lateral eye movements (LEMs) following initiation of a mood-related mental task have also been used to infer levels of hemispheric activation. Such studies are analagous to investigations which have demonstrated a tendency toward right LEMs following initiation of verbal processing, and left LEMs at the start of visuospatial processing (Kinsbourne, 1972; Gur & Gur, 1977). Left initial LEMs, suggesting right hemisphere activation, have been found to be more frequent in subjects performing emotion-laden than neutral mental tasks (Schwartz, Davidson, & Maer, 1975) and in anxious than nonanxious subjects (Tucker et al., 1977). Standardized measures of mood were used in the latter but not the former study.

Habitual left eye movers have also been found to be higher in intensity and frequency of emotional reactions and communications than right eye movers (Woods, 1977). These data must be cautiously interpreted, however, since associations between LEMs and cognitive, physiologic, or personality measures have not been consistently demonstrated, and the relationship between LEMs and lateral hemispheric activation remains hypothetical (see review by Ehrlichman & Weinberger, 1978).

Asymmetries of facial expression have also been used to support the idea of right hemisphere dominance in production of emotional states. Several investigators have demonstrated that registration of emotional expression is stronger in the left than the right half of the face (Campbell, 1978; Sackeim & Gur, 1978; Borod & Caron, 1980; Rubin & Rubin, 1980). Since control of the lower facial musculature is contralateral, such a finding might imply greater right hemisphere involvement in producing emotional expressions. The most problematic feature of these studies is that they have used posed rather than spontaneous facial expression, and therefore may not reflect actual feeling states of the subjects (Ekman, 1980). Some investigators have failed to find comparable asymmetries in spontaneous facial expressions (Ekman, Hager, & Friesen, 1981), while others have found spontaneous as well as posed expressions to be stronger on the left side (Moscovitch & Olds, 1982; Borod, Kuff, & White, 1983).

With the exception of the study by Davidson et al. (1979) none of the studies reviewed above have demonstrated differences in lateral activation due to type of emotion. However, there was a tendency across many of the studies for right hemisphere activation to be more closely associated with negative emotional states (Davidson & Schwartz, 1976; Sackeim & Gur, 1978; Karlin et al., 1979; Tucker et al., 1981; Borod et al., 1983). Two studies reported greater lateralization in females than males (Davidson & Schwartz, 1976; Moscovitch & Olds, 1982), while two report the reverse (Woods, 1977; Borod et al., 1983). In the remainder of the studies, differences due to sex were not mentioned or not found.

The second major group of studies has examined lateralized hemispheric functioning in relation to disorders of mood and affect. If the right hemisphere were dominant for emotional regulation, one would expect an association between right hemisphere pathology and mood disorders. In one type of study, alterations in mood and affect are observed in patients with known hemispheric pathology; in the second, signs of hemispheric dysfunction are sought in patients with primary mood disorders.

Studies of traumatic head injury have generally associated left hemisphere disruption with more severe psychopathology. However, only one has looked specifically at affective disturbances as a function of side of injury. Lishman (1968) surveyed 144 cases of penetrating brain injury with "severe psychiatric disability" and found that affective disturbances were more common following right hemisphere injury (particularly of the frontal

lobe) while intellectual disturbances were more frequent following left-sided injuries. Furthermore, while smaller lesions tended to result in depression, anxiety, irritability, and aggression, more extensive lesions were associated with euphoria and apathy. These relationships suggest that varying degrees of activation vs. inactivation of the right hemisphere may produce corresponding degrees of dysphoria vs. euphoria. The degree of tissue irritability therefore may be important in determining the resultant affective changes, but was not specified in Lishman's study.

A literature describing mania secondary to focal cerebral lesions also suggests an association between right hemisphere dysfunction and affective dysregulation. As summarized recently by Cummings and Mendez (1984) almost all the reported cases of mania secondary to lateralized, focal lesions have had right-sided lesions. Such an association is not absolute, however, since mania secondary to left-sided lesions has also been reported in right-handed patients (Jampala & Abrams, 1983).

Changes in mood and affect have also been observed in patients with unilateral epileptic foci. Flor-Henry (1969) reviewed the records of 50 patients with psychosis and temporal lobe epilepsy. He found that of patients with manic-depressive psychoses 44% had right-sided foci, and only 22% had left-sided foci; for schizophreniform psychoses the corresponding proportions were 9.5% right-sided and 43% left-sided. The author's criteria for schizophrenia include disturbances in affect, however, implying that left- as well as right-sided lesions may disturb affective regulation, though possibly in qualitatively different ways.

Bear and Fedio (1977) examined patients with right- and left-sided temporal epileptic foci for evidence of interictal personality changes. As rated by observers on a specially constructed scale "the right group was distinguished by items stressing externally demonstrated affect . . . unusual sexual attractions, remonstrations of helplessness, periods of sadness, emotional arousability, or moralistic fervor . . . left-temporal patients were identified with a sense of personal destiny and a concern for meanings and significance behind events." Thus, right-sided foci were associated with affective and left-sided with cognitive changes in personality style. Small numbers of subjects and unequal sex ratios between right and left groups are major drawbacks of the study. While some subsequent investigators have confirmed the association between right epileptic foci and affective dysregulation (Seidman, Mirsky, & Harrison, in press), others have not (Mungas, 1982).

Other methodologies have produced diverse findings in epileptic patients. Serafetinedes (1965) found that patients with left-sided temporal foci were more likely than those with right-sided foci to exhibit overt physical aggressiveness, but he did not report on other aspects of personality or behavior. Taylor (1972) reported predominance of right-sided foci in a group of epileptics with concomittant "neurotic" diagnoses, including

depression, anxiety, and phobias. McIntyre et al. (1976) found that right-sided epileptics had an "impulsive style" on a visual discrimination task while those with left-sided foci had a more "reflective" response pattern. Such results are difficult to integrate because widely different parameters were observed, and factors related to the lesion (e.g., seizure type and frequency, duration of illness, etiology) were not specified.

Another aspect of emotional behavior, the ability to impart affective qualities to speech, has been investigated by Ross and Mesulam (1979). They described two patients whose speech lost its emotional intonation following right hemisphere strokes. These deficits occurred in the absence of either aphasia or mood disturbance. The original observation of this phenomenon dates to Jackson (1879), who suggested that affective speech is mediated by the right hemisphere.

Little is known about the effects on emotional behavior of lateralized subcortical as opposed to cortical lesions. Riklan and Levita (1965) described a group of subjects with unilateral thalamic or basal ganglia lesions. They inferred from a battery of neuropsychological tests that factors related to "impulse control" and "emotional reactivity" were associated with left hemisphere lesions. However, the authors also stressed the overall similarity of the left- and right-sided groups, and stated that "no significant behavioral differences were obtained as a function of lateralized involvement." More recently, however, clinically apparent mania has been reported following right thalamectomy (Whitlock, 1982) and right thalamic infarction (Cummings & Mendez, 1984), suggesting that subcortical as well as cortical disruptions of the right hemisphere may produce changes in mood and affect.

The literature dealing with lateralized dysfunction in primary mood disorders relies on inference drawn from physiologic or cognitive measurement, and is therefore inherently less direct than that dealing with brain-lesioned populations. Two lines of evidence emerge from this literature: The first suggests that primary mood disorders are associated with disrupted functioning of one hemisphere (generally interpreted to be the right), while the other finds delateralization or reversed lateralization of cognitive functions in such disorders. An important methodological omission in almost all of the studies described below is that specific aspects of affective illness are not correlated with laterality measures. It is therefore impossible to tell whether affective, ideational, or vegetative changes are associated with hemispheric dysfunction.

The largest body of data on lateralized dysfunction in affective illness comes from electroencephalographic studies. A number of such studies use the mean integrated amplitude (MIA) of the waveform and the within-patient variance (WPV) of this amplitude as their major physiologic measures. In a series of studies with depressed patients, low left to right ratios of MIA and WPV were found in depressed but not in recovered

patients; lower ratios correlated with more severe depression and more impaired verbal learning ability. Changes following recovery appeared to result from altered left rather than right hemisphere measures (d'Elia & Perris, 1973, 1974; Perris, 1975). The finding of low left to right amplitude and variance ratios was essentially replicated by Rochford, Swartzburg, Chaudhery, and Goldstein (1976), who found these patterns to be characteristic of depressed but not schizophrenic patients or controls. The interpretation of alterations in MIA and WPV is less consistent than the finding; d'Elia and Perris refer to possible "functional depression" of the left hemisphere, while Rochford's interpretation stresses abnormal right hemisphere physiology.

In another series of studies, Perris (1974, 1975) reported low left to right amplitude ratios in visually evoked potentials of depressed but not schizophrenic patients; low ratios correlated with depth of depression and tended to reverse upon recovery. These findings were interpreted as reduced reactivity of the left compared to the right hemisphere in depression. More recent reports by Perris, Monakhov, VonKnorring, Botskarev, and Nikiforov (1978) and Perris and Monakhov (1979) have found that right frontal activation (as measured by increased beta activity) correlated with depressed mood, but left frontal activation correlated with depressive ideation. This finding points up the importance of specifying precisely which aspects of complex mood disorders are being measured. Roemer, Shagass, Straumanis, and Amadeo (1978) used stability of visually evoked waveforms as a dependent measure, and found greater right hemisphere stability in depressed than normal subjects (but greater left stability in schizophrenics). They also confirmed the Perris finding of decreased evoked potential amplitudes on the left. The data are interpreted as demonstrating right hemisphere pathology. Buchsbaum et al. (1971) compared the evoked responses to light flashes under conditions of attention and inattention in depressed, schizophrenic, temporal lobectomized, and control subjects. Examining the N120 component, thought to reflect selective attention, they found that depressed subjects and right temporal lobectomy patients had high amplitude responses from the left hemisphere under conditions of attention. This was interpreted as reflecting failure of normal right hemisphere inhibitory influences in the affective group.

The electrophysiologic studies summarized above may all be viewed as demonstrating a shift in the balance of hemispheric activity in favor of the right hemisphere during depressive illness. Divergence of opinion centers on whether these findings reflect pathological left-sided underresponsiveness or right-sided overresponsiveness (or perhaps both). Somewhat more weight may perhaps be given to the right hemisphere interpretation, since it has been made on the basis of studies comparing depressed to normal rather than depressed-recovered subjects. A study of clinical EEG records in depressed and schizophrenic subjects (Abrams

& Taylor, 1979) suggests a similar conclusion. The authors found an excess of right-sided parieto-occipital abnormalities (consisting primarily of slowing) in depressed as compared to schizophrenic subjects.

A body of data based on galvanic skin response (GSR) measurements in depressed subjects also provides evidence of lateralized dysfunction. Lower right-handed GSRs (Gruzelier & Venables, 1973, 1974; Schneider, 1983) and higher left-handed GSRs (Myslobodsky & Horesh, 1978) have been found in depressed patients. Which side of the brain may be responsible for these changes is not clear, however. It is still a matter of debate whether control over electrodermal responses is ipsilateral or contralateral, and whether it is primarily inhibitory or excitatory (Holloway & Parsons, 1969; Lacroix and Comper, 1979; Myslobodsky & Rattok, 1977). The finding of lateralized GSR differences may also depend on the conditions under which it is measured, since one report of depressed patients measured at rest (as opposed to performing cognitive tasks, as in the above studies) failed to find such differences (Storrie, Doerr, & Johnson, 1981). Another recent study failed to find any differences, lateralized or nonlateralized, between GSRs of depressed and control subjects (Toone, Cooke, & Lader, 1981). The reason for this discrepency is not apparent. A more recent report found no asymmetries in recovered depressed patients, suggesting that to the extent that such asymmetries exist, they are related to the acute illness rather than being stable traits of depression-prone individuals (Iacono & Tuason, 1983).

Right hemisphere dysfunction in depression has been inferred from performance on neuropsychological test batteries, based on the finding that depressed patients show more deficits on standardized visuo-spatial than verbal tasks (Flor-Henry, 1976, 1983; Goldstein, Filskow, Weaver, & Ives, 1977; Kronfol, Hamsher, Digre, & Wazir, 1978). Some of the published conclusions are difficult to evaluate independently, since they are presented without supporting data (Goldstein et al., 1977; Flor-Henry, 1983). Other reports present data which demonstrate more differences in severity than laterality of deficits between depressives and schizophrenics (Flor-Henry, 1976). Using a detailed test of logical reasoning, Silberman, Weingartner, and Post (1983) found a pattern of errors in depressed subjects resembling that of right temporal lobectomized patients. The degree of cognitive impairment correlated with the overall severity of depression.

Not all investigators have found non-dominant cognitive defects in affectively ill subjects. Taylor, Greenspan, and Abrams (1979), using a form of the Wepman Aphasia Screening Test, found that schizophrenics show an excess over depressives in left hemisphere-type deficits, but depressives show no excess over schizophrenics in right hemisphere-type deficits. Other negative reports have found no abnormalities or lateralizing signs on the Halstead–Reitan neuropsychological battery in

remitted depressed patients (Small, Small, Milstein, & Moore, 1972), and no differences between affectively ill subjects and controls on a task comparing sequential (left hemisphere) vs. simultaneous (right hemisphere) visual tasks (Gur, 1979). Cognitive strategies such as those above suggest, at most, *relatively* greater right hemisphere dysfunction in affective illness; most of these neuropsychological studies demonstrate some impairment on traditionally left as well as right hemispheric tasks, as does the large literature describing impaired verbal learning and memory performance in depression (Weingartner & Silberman, 1982).

The efficacy of right unilateral electroconvulsive therapy (ECT) in the treatment of depression has been cited by some authors as evidence for selective right hemisphere dysfunction (Galin, 1974). They argue that since right ECT is as effective as bilateral treatment, the right hemisphere must be preferentially involved in depressive illness. There is evidence of greater electrophysiologic disruption on the side of treatment (d'Elia & Perris, 1970; Small & Small, 1971; Sand-Stromgren & Juul-Jensen, 1975), and that clinical improvement is correlated with the degree of impairment of hemispheric functioning (Fink & Kahn, 1957; Nilsson & Smith, 1965). Such findings might suggest that selective inactivation of the right hemisphere is associated with amelioration of depression. However, the above findings have not always been replicated (McAndrew, Berkey, & Matthews, 1967; d'Elia & Perris, 1970). Furthermore, the literature is about equally divided as to whether left unilateral ECT is as effective as right (Small, Small, Milstein, & Sharpley, 1973; Kronfol et al., 1978; Heshe, Roder, & Theilgaard, 1978). In addition, several studies find that there is a greater involvement of the *left* hemisphere in bilateral ECT (Abrams, Fink, Dornbush, Feldstein, & Roubicek, 1972; Marjerrison, James, & Reichert, 1975; Sand-Stromgren & Juul-Jensen, 1975). Thus, the ECT literature offers, at best, weak support for the hypothesis of selective right hemisphere pathology in depression.

While attempts to demonstrate predominantly right hemispheric pathology in affective illness have not been uniformly convincing, a much more consistent line of evidence has been developing which suggests functional delateralization or reversed lateralization in such conditions. Bruder (1983) has recently reviewed the literature on dichotic listening studies in psychiatric conditions, and found that they consistently demonstrate decreased lateralization of both verbal and nonverbal tasks in affective disorders. With bipolar patients, reversal of lateralization (that is, right ear–left hemisphere superiority) for nonverbal tasks has been found. There is some evidence that delateralization reverts to normal with remission of the illness, and that it may be a function of psychotic illness in general, rather than affective disease particularly (Lishman, Toone, Colburn, McMeekan, & Mance, 1978; Wexler & Heninger, 1979). In other studies, however, altered lateralization has been found in affectively

ill but not schizophrenic patients (Colbourn & Lishman, 1974; Yozawitz et al., 1979; Johnson & Crockett, 1982). Bruder concludes, based on differing methodologies of the studies, that differences between schizophrenics and affectively ill patients have been demonstrated only for nonverbal tasks.

Other evidence that bihemispheric reversals in lateralization occur in affective illness comes from a variety of sources. Superiority on a verbal task has been found to switch from the right to the left visual field in depressed (primarily bipolar) patients (Silberman, Weingartner, Stillman, Chen, & Post, 1983). Using alpha EEG power as a measure of cortical activation, Flor-Henry reported a number of complex shifts in the balance of hemispheric activity in bipolar manic and depressed patients. In the depressed phase he found abnormally high right parietal activity at rest, left temporal activation during spatial tasks, and right pariental activation during verbal tasks (Flor-Henry, 1979; Flor-Henry & Koles, 1980). During mania, the authors found relative right temporal activation during verbal tasks (Flor-Henry & Koles 1980).

Very direct evidence for functional delateralization in affective illness comes from administration of the Wada test to depressed patients (Hommes & Panhuysen, 1971). In this procedure, the hemispheres are selectively deactivated by injection of sodium amytal into the right or left carotid artery, usually for the purpose of demonstrating the side of speech dominance prior to neurosurgery. In a small sample of depressed subjects (bipolar vs. unipolar not specified) almost all had a degree of aphasia following right-sided as well as left-sided injections. Furthermore, the degree of right-sided aphasia was directly correlated with the severity of depression. While this study is highly provocative, ethical considerations are likely to prevent its replication, since there were apparently no medical indications for performing the test.

Summary. A variety of studies suggest that the right hemisphere may be dominant for control of mood and affect. The right hemisphere has been found to be preferentially activated during periods of felt emotion, and possibly other nonverbal emotion-related activities such as generation of facial expressions. However, the left hemisphere appears to be involved when there is verbal mediation in the production of affective states. Right hemisphere activation has been more strongly associated with negative than positive emotions, and may involve frontal more than posterior regions of the hemispheres. Destructive and irritative lesions of the right hemisphere (both cortical and subcortical) have been found more likely than left hemisphere lesions to produce disorders of mood and affect. Greater right hemisphere activation may be associated with dysphoric and deactivation with euphoric mood.

It is difficult to draw conclusions about lateralization of emotional control from primary disorders of mood and affect. Such disorders produce

complex, multifaceted states, along with relatively subtle disturbances of physiology. Conclusions about right hemisphere pathology based on electrophysiologic or psychophysiologic data rest on disputed interpretations of test results. Cognitive and neuropsychological testing tend to show disruption of both dominant and nondominant capacities, although the latter are somewhat more prominent. These studies generally have not addressed the question of which specific aspects of depressive or manic syndromes (e.g., affective, ideational, or neurovegetative) might be associated with right-sided dysfunction. A stronger line of evidence suggests that primary affective illnesses are associated with loss or reversal of both right and left hemisphere dominance effects.

THE RIGHT HEMISPHERE IS SPECIALIZED FOR NEGATIVE AFFECTS, WHILE THE LEFT IS SPECIALIZED FOR POSITIVE AFFECTS

The studies reviewed above have been used to support the hypothesis that one hemisphere (generally the right) is dominant for perception and production of affects in humans. There is a major strain of evidence, however, which suggests that both hemispheres process emotionally related behaviors, but do so for different types of emotions. Most commonly, the right hemisphere has been implicated in regulation of negative affects, while the left is associated with positive emotions.

The most dramatic demonstration of different emotional responses from the hemispheres comes from observation of patients undergoing the Wada test. Early users of the test were surprised to find that amytal injections in the left side usually produced a "catastrophic reaction" of the type described by Goldstein, (1939), while right-sided infusions produced euphoric behavior (Terzian, 1964; Alema, Rosadini, & Rossi, 1961; Perria, Rosadini, & Rossi, 1961; Rossi & Rosadini, 1967). As commonly described, the depressive reaction consists of crying, pessimistic statements, guilt, feelings of nothingness, indignity, despair, complaints, and worries about the future. The euphoric reaction comprises lack of apprehension, smiling, joking, laughing, mimicry, relaxation, optimism, and a sense of well-being. The lone dissenter from these descriptions is Milner (1967) who reported less than 5% of her patients becoming depressed, with the rest showing euphoric behavior regardless of the side of the injection. A very likely reason for this discrepancy is that Milner used a higher dose of amytal than the other investigators. There is a linear relationship between the dose of amytal used and the tendency to observe exclusively euphoric reactions as described above in the Wada test literature. Since higher doses of drug are more likely to produce bilateral cortical effects (Werman, Anderson, & Cristoff, 1959; Terzian & Cecotto, 1959; Magni, Moruzzi, Rossi, & Zanchetti, 1959), there may be an association between bilateral deactivation and euphoric response. Possibly relevant to this effect are

the observations that ambidextrous subjects (Rossi & Rosadini, 1967), those with bilateral lesions (Alema et al., 1961), and those with bilateral speech representation (Hommes & Panhuysen, 1971, see above) tend to show euphoric rather than depressive responses. This pattern may suggest that control of emotional behavior principally occurs through regulation of level of negative emotions, since it is these emotions which are attenuated in Wada test subjects with bilateral functional representation.

The usual interpretation of the Wada test studies is that mood changes result from release of one hemisphere from contralateral inhibitory influences. Thus, the right hemisphere, when not counterbalanced, would produce dysphoria, while the unbalanced left hemisphere would produce euphoria. Because mood changes occur at a time when gross motor impairment has worn off, it is less likely that they are simply a reaction to sudden impairment. Furthermore, there is no apparent reason why patients with acute left hemiplegia should react euphorically. It is more plausible, therefore, that mood changes actually result from disruption of the neural mechanisms involving emotion.

The Wada test findings have been supported by observations of patients with other (than chemically induced) types of brain lesions. Gainotti (1972) found that three times as many left- as right-lesioned patients had "catastrophic"-type behaviors, while the proportions were reversed for "indifference reactions." Direct affective expressions, such as tears, anxiety, and swearing, were associated with left-sided lesions, while depressive ideation was not lateralized. Patients with right-sided lesions tended to show indifference, denial of illness, and inappropriate joking. Indifference was present only in those patients with left-sided neglect, suggesting that the two syndromes are related (cf. Heilman et al., 1975, discussed above).

Other investigators have confirmed the finding that patients with left brain injuries are more likely than right-lesioned patients to become clinically depressed (Robinson & Price, 1982) and that patients with right- but not left-sided stroke may become inappropriately cheerful (Robinson, 1983). However, location of the lesion within the hemisphere may be as important as side of lesion in determining emotional state. Anterior left-sided lesions were more likely to produce depression, whereas *posterior* right-sided lesions were more likely to do so (Robinson & Szetela, 1981, Robinson et al., 1984). It is important to note that mood was independent of overall level of cognitive impairment in these studies, so that mood changes were not simply responses by patients to their own disabilities. These findings contradict an earlier report (Folstein, Malberger, & McHugh, 1977) in which depressive symptoms were found to be equally common in patients with right- and left-sided strokes. Location of lesions within the hemisphere was not controlled in the earlier study, however, and may account for the divergent finding. It is noteworthy that an "irritability"

syndrome associated with right hemisphere strokes in this report includes items related to neglect and inattention, and thus may overlap with the right-sided euphoric syndrome described by others.

Similar results have also been found in two studies using the Minnesota Multiphasia Personality Inventory (MMPI) in patients with unilateral destructive brain lesions (Black, 1975; Gasparrini, Satz, Heilman, & Coolidge, 1978). In these studies, patients with left- but not right-sided lesions tended to show elevated depression (D) scales. The majority of studies using the MMPI have failed to differentiate right- from left-sided lesions, however, possibly because the test has been standardized on psychiatric rather than neurologic patients (Reitan, 1976).

Further light has recently been thrown on the differing emotional valances of the hemispheres in an important study by Sackeim and his colleagues (Sackeim et al., 1982). They reviewed the literature on pathological laughing and crying in patients with both irritative and destructive cortical lesions, and noted that no work had been done to correlate side of the lesion with type of emotional expression. The authors undertook three studies to clarify the cortical mechanisms of emotional control. In the first, a series of cases of pathological laughing and crying was reviewed to determine predominant type of emotional expression, and predominant side of the lesion. Destructive lesions of the right hemisphere were associated with pathological laughter and positive mood change, while lesions of the left hemisphere were associated with crying and negative mood change. Strongly *bilateral* lesions were much more likely to produce laughter than crying (similarly to Wada test findings). The association between laterality and type of emotion continued to hold when type of gross neurological impairment was held constant. In the second study, cases of right hemispherectomy were reviewed and found to be associated with chronically elevated mood; cases of left hemispherectomy were too few for conclusions to be drawn. In the third study, reports of laughter and crying as ictal manisfestations were reviewed. In contrast to destructive lesions, left-sided irritative foci were more likely to be associated with laughter, and right-sided foci with crying. The authors also note that in all three studies, pathological crying and dysphoric mood were more often found in females, while laughter and mood elevation were commoner in males.

The authors support the interactive inhibition model described above in connection with the Wada test. They reason that cortical inhibition of emotion must be contralateral rather than ipsilateral because pathological mood elevation results from both partial and complete destruction of the right hemisphere. Although this finding does not rule out the possibility that such euphoria results from release of ipsilateral *subcortical* centers, Sackeim's review of epileptic manifestations indicates that such mood changes may be produced by irritable foci in the cortex.

Other more fragmentary data from the study of brain-lesioned patients also provide evidence of hemispheric specialization for regulating different types of emotion. The study of temporal lobe epileptics by Bear and Fedio (1977) cited above suggests affective vs. cognitively centered personality changes in patients with right- vs. left-sided foci. However, the authors also report that patients with right temporal lesions tend to minimize their own pathology compared to how it is viewed by others, while those with left-sided foci tend to exaggerate their deficits. Since the study deals with interictal rather than ictal behavior, it is not clear to what extent personality changes might result from deactivation (e.g., Kuhl, Engel, Phelps, & Selin, 1980) rather than hyperactivity of cortical centers. The former interpretation would be in accord with findings from the Wada test, while the latter would tend to contradict them.

One report of a commisurectomized ("split brain") patient also suggests different emotional proclivities of the hemispheres. One such patient, who had an unusual degree of verbal capability in his right hemisphere, was found to express consistently more negative attitudes with that hemisphere than with his left (LeDoux, Wilson, & Gazzaniga, 1977). The patient's behavior was dysphoric and aggressive on days when the two hemispheres were in strong disagreement.

Another line of evidence for different emotional valences of the hemispheres comes from studies in unimpaired subjects. In these studies, physiologic measures of hemispheric activation are monitored during positive and negative mood states. In one report by Davidson et al. (1979), subjects indicated their emotional responses while watching a television program with varying emotional content. During periods of positive emotional response, frontal EEG leads displayed relative left hemisphere activation (as measured by decreased alpha power); the relative activation in frontal leads reversed during periods of negative emotion. Parietal leads, on the other hand, showed right hemisphere activation during all periods of felt emotion. In a more recent study, Davidson and Fox (1982) monitored EEG activity in 10-month-old infants who watched an actress spontaneously generating happy and sad facial expressions. There was greater activation of the left than right frontal regions in response to the happy faces, and a higher left to right activity ratio in response to happy than sad faces. Parietal leads did not discriminate between emotional conditions. The intensity of the infants' mood changes during this procedure was not independently measured. In contrast to these findings, Tucker and Dawson (1984) reported relative left hemisphere activation in actors self-generating feelings of depression, and relative right hemisphere activation during periods of sexual arousal. The laterality effect was more prominent in posterior then anterior leads, which is opposite to the findings of Davidson and his colleagues. This finding may

reflect anterior–posterior differences similar to those reported by Robinson and his colleagues in stroke victims (discussed above).

Other measures of hemispheric activation have also been employed in normals. In their study of asymmetries of facial expression, Sackeim and Gur (1978) noted that the tendency for expressions to be stronger on the left side of the face was more pronounced for negative than positive emotions. Schwartz, Ahern, and Brown (1979) used electromyography to measure facial asymmetries of subjects during spontaneous mood fluctuations. They found that right-sided contractions were stronger during periods of happiness or excitement, and left-sided contractions were stronger during sadness and fear; however, voluntary posed expressions showed stronger left-sided contractions regardless of type of affect.

Using lateral eye movements as a measure of hemispheric activation, Ahern and Schwartz (1979) found more right LEMs in subjects responding to questions which provoked happiness or excitement, but more left LEMs during responses containing sad or fearful affects. While studies of facial asymmetry and LEMs support the right–negative left–positive emotional dichotomy, the uncertainties about these methodologies (see discussion above) must be considered in weighing the results.

There is also some recent evidence that positive and negative emotions may be recognized differently by the two hemispheres. Reuter-Lorenz, Givis, and Moscovitch (1983) showed a happy or sad expression in one hemifield, and a neutral expression by the same poser in the opposite hemifield, and asked subjects to identify the side containing the emotional face. Reaction times were shorter for happy faces shown to the RVF and sad faces shown to the LVF. The authors suggest that previous findings of overall LVF (right hemisphere) advantage for perception of emotions may have resulted from tasks biased toward other right hemisphere perceptual capabilities (i.e., discrimination or matching of facial expressions rather than simple detection of emotion). Similar results were reported by Natale, Gur, and Gur (1983). They presented happy, sad, and mixed (chimeric) faces tachistoscopically to subjects and found that emotional ratings differentiated the three types better when they were presented to the left visual field (LVF). However, they also found that chimeric faces were more likely to be judged as predominantly positive when shown to the right visual field. The experimenters concluded that the right hemisphere is superior for discrimination of emotional valence, and that the left hemisphere has a perceptual bias toward positive aspects of emotional stimuli. Data were insufficient to evaluate possible right hemisphere biases. In these studies, females gave more negative ratings overall than males, while males showed evidence of biases toward positive emotional aspects of the stimuli.

A few studies of depressed patients may be interpreted as lending some support for hemispheric specialization for different emotions. To

be included in this group, a study would have to show evidence specifically of hemispheric overactivation or underactivation during depressive illness, rather than simply hemispheric *dysfunction*. Since there are considerable difficulties in interpreting physiologic indicators of cerebral functioning (see discussion above), it is not surprising that the relevant body of literature is small.

Lateral eye movements as a measure of hemispheric activation have been compared in depressed and normal subjects (Myslobodsky & Horesh, 1978). Depressed patients, in contrast to controls, did not change direction of LEMs with different mental tasks, but showed predominantly left LEMs (implying right hemisphere activation) in response to verbal, spatial, emotional, and neutral conditions. A subsequent report (Schweitzer, 1979) described increased numbers of left LEMs across a variety of tasks in depressed patients, but not in schizophrenics or controls.

A unique study employed alternating right- and left-sided electroconvulsive therapy in a heterogeneous group of depressed and schizophrenic patients (Deglin & Nikolaenko, 1975). Following ECT (which presumably produced hemispheric depression), the mood was reported elevated if the treatment had been on the right side, but depressed if the treatment had been on the left. Such a result would seem consistent with the reports of mood changes following intracarotid sodium amytal administration in neurologic patients. However, as discussed above, the vast majority of the ECT literature describes mood elevation resulting from both left- and right-sided treatments in depressed patients.

Finally, the studies of Perris and his colleagues of EEG and cortical-evoked potential in depressed subjects may support the association of the left hemisphere with positive and the right with negative emotions (Perris, 1974, 1975; d'Elia & Perris, 1973, 1974; Perris et al., 1978; Perris & Monakhov, 1979). Such a conclusion would depend upon the authors' interpretation of their results as reflecting left hemisphere depression, rather than right hemisphere dysfunction, as others have contended.

Summary. In contrast to studies which support overall right hemisphere dominance for perception and modulation of emotions, there is a separate line of evidence suggesting that the right hemisphere is specialized for dealing with negative emotions, while the left is specialized for positive emotions. Converging lines of evidence from subjects with unilateral brain lesions, those with depression, and normal subjects support such a view. Differential hemispheric functioning has been associated with subjective mood states, nonverbal expressions of affect, such as laughing, crying, and facial expressions, and recognition of emotional aspects of stimuli. The pattern of left–positive right–negative specialization has been demonstrated most strongly for anterior portions of the hemispheres; more posterior regions show no emotional asymmetry, or even reversed asymmetry. There is evidence that males have a predilection for positive

emotional behaviors and perceptions, while females have a tendency toward negative emotional behaviors and perceptions.

DISCUSSION

Evidence for hemispheric lateralization of processes related to emotion comes from highly diverse methodologies applied to a wide variety of clinical and normal populations. The convergence of many lines from such diverse sources is, therefore, strong evidence that there are emotion-related processes which take place asymmetrically in the brain. However, because relatively few of these studies have been directly replicated, the details of such emotional lateralization are not well understood, and the emerging picture must still be painted in rather broad strokes: The right hemisphere is superior for processing of emotional aspects of information, and shows overall dominance for regulating states of subjective emotional feeling and associated behaviors. The right hemisphere also is particularly involved in handling of negative emotions, while the left hemisphere is more closely associated with processing of positive emotions.

Although not all the evidence supports these conclusions, many of the relatively small number of contradictory results can be accounted for by methodological considerations. In studies of normal subjects, such considerations most often involve experimental task factors; in brain-lesioned populations, the nature of the lesion and its location within the hemisphere are crucial parameters; in studies of affectively disordered patients, conclusions often rest on interpretation of physiologic measures. In all three groups, results may depend upon which aspects of complex mood states or cognitive processes are being monitored.

The aspect of emotion most clearly associated with the right hemisphere appears to be subjective feeling of emotion, particularly of negative emotion. Such a feeling state may be a mediating step in the evaluation of emotional information, or part of a mood state and its associated behaviors. The data suggest, however, that the left hemisphere plays an important role in verbally mediated aspects of emotional information processing and mood states. The conditions under which emotion-related processes become bilateral remain to be determined. The situation may be analogous to that described by de Renzi and co-workers for the processing of spatial information (de Renzi, 1978); only the simplest tasks show strong right hemisphere superiority, while with increasing complexity there is increasing bilateral participation, even in the absence of specifically verbal requirements.

It would appear difficult to reconcile overall right hemisphere superiority for emotion-related processes with a positive–negative split between the left and right hemispheres. The paradox may be more apparent than real, however. Most of the studies linking right hemisphere pathology with mood changes have described *dysphoric* states, especially when the right

hemisphere is relatively activated (as with epileptic foci). Similarly, studies in normal subjects have tended to find greater right hemisphere activation during periods of negative emotion. While earlier studies have not found valence-dependent differences in perception of emotions, newer methodologies have successfully demonstrated such differences. It has been suggested that the earlier methods were biased in favor of other (non-emotional) right hemisphere processing capabilities. Furthermore, the range of human emotions seems to include more negatives than positives (Ekman, Friesen, & Ellsworth, 1972), so that right hemisphere specialization for negative emotions may imply inherent dominance. The most difficult portion of the literature to integrate are the studies in normal subjects which look for, but do not find, laterality differences dependent on emotional valence. It remains to be seen whether their methodologies have obscured such differences, or whether hemispheric specialication for type of emotion is more subtle in normal than in brain-lesioned subjects.

The model most consistent with our present knowledge is that of interactive inhibition between the hemispheres, with the right hemisphere responsible for mediating negative and the left for mediating positive emotions. In such a model, the right hemisphere would retain dominance for controlling the balance between positive and negative affects, thereby controlling overall emotional tone. Such emotional dominance may be related to right hemisphere dominance for regulating bilateral cortical arousal levels (Howes & Boller, 1975; Green & Hamilton, 1976; Heilman et al., 1978; Heilman & Van Den Abeli, 1979), a function inherent in modulating responses to emotionally meaningful stimuli.

Other models of hemispheric emotional regulation have also been proposed. Levy, Meller, Banich, and Burton (1983) stress the role of the right hemisphere in control of emotion, proposing that when its arousal level is high, negative affect prevails, and when it is low, positive affect predominates. While this view is consistent with the literature, it fails to take into account the striking effects on mood of alterations in *left* hemisphere function. Tucker (1981) proposes that the right hemisphere generates positive emotional states, while the left generates negative states, but at a subcortical rather than a cortical level. Right hemisphere deactivation (for example) would therefore release ipsilateral subcortical centers from frontal cortical inhibition, resulting in elevated mood, while right hyperactivity would produce dysphoric mood. However, it is doubtful whether cortical activation demonstrated in the present studies is purely inhibitory; lateral eye movements, for example, represent motor *activation* from contralateral centers. Furthermore, it has been shown that left-sided foci at the cortical level tend to produce bursts of positive affect during ictal periods, in contradiction to Tucker's model (Sackeim et al., 1982). Data on the emotional effects of subcortical lesions would be crucial in testing the ipsilateral vs. contralateral inhibition models. Un-

fortunately, such data are presently very sparse, but the two recent reports describing mania following right thalamic destruction (Whitlock, 1982; Cummings & Mendez, 1984) would tend to support the contralateral hypothesis.

The emerging picture of emotional lateralization may be viewed in the context of other known aspects of hemispheric specialization. It has been suggested that differentiation of the hemispheres adds markedly to the processing capacity of the brain as a whole, and perhaps contributes to uniquely human intellectual capabilities (Levy, 1977). The same may be true for emotional behavior in humans as well. Several properties of the right hemisphere may make it more suitable for the processing of emotionally significant material. Semmes (1968) found that elementary functions are more diffusely represented in the right than the left hemisphere, and Gur et al. (1980) have demonstrated a higher ratio of white to gray matter in the right hemisphere; both findings imply that the right hemisphere is better equipped than the left to integrate information across modalities. It has been suggested that such an organization is especially suited to emotional processing, which may involve integration of simultaneous inputs from external and visceral sources (Safer & Leventhal, 1977; Tucker, 1981).

As noted above, the right hemisphere also appears dominant for modulation of cortical arousal levels. Some authors have postulated that there are two types of orienting responses (Maltzman, Langdon, Pendery, & Wolff, 1977; Myslobodsky & Rattok, 1977). The first, mediated by the right hemisphere, is concerned with the immediate, involuntary global assessment of the external world, while the second occurs at a later stage of processing, involves conscious problem solving or detailed scrutiny, and is mediated by the left hemisphere. Quick evaluation of emotionally salient aspects of stimuli (especially potentially negative or aversive aspects) would be linked to right hemisphere-mediated cortical arousal in the initial orienting response. In a similar vein, it has been postulated that the right hemisphere is specialized for avoidance behaviors and their associated emotions (Ahern & Schwartz, 1979), while the left hemisphere is specialized for approach behaviors (Kinsbourne, 1978). In this formulation, language and skilled motor coordination are seen as approach behaviors because they facilitate contact, exploration, and communication. Right hemisphere dominance for emotional regulation might therefore reflect an organization which gives priority to avoidance or defensive mechanisms, which have high survival value.

We will close with some general comments on methodological issues in future research. Until recently there has been relatively little attempt to replicate earlier findings, so that the literature has been extremely scattered. Furthermore, many studies have paid insufficient attention to subject, task, or behavioral variables. For example, sex differences are

known to be important in lateralization of many functions (McGlone, 1977; Rizzolati & Buchtel, 1977), but are uncontrolled in many of the present studies. In brain-lesioned patients, size of the lesion, location within the hemisphere, and presence of tissue irritability need to be clearly specified. In cognitive studies, more care must be taken to separate the contribution of emotion from other lateralizing aspects of tasks, such as verbal or visuo-spatial recognition. As noted above, degree of complexity of cognitive tasks may also be of crucial importance, but has not been systematically studied as it applies to processing of emotional information. Similarly, when complex mood states are the dependent variable, specific aspects of subjective feeling, as well as specific components of observable behavior, must be correlated with laterality measures since different aspects of such states may be modulated by different brain centers. There may also be important differences between emotions *within* the positive and negative groups. Tucker (1981) comments, for example, that emotions such as fear and anger, while both "negative," may have very different behavioral consequences, and thus may be differently lateralized. Another neglected area is measurement of both cognitive and mood data in the same patients, which could be used to explore the interdependence of thought and emotion, both functionally, and on an anatomical level.

A particularly difficult area conceptually has been the interpretation of lateralized differences in performance. One hemisphere may show a disadvantage because it is incapable of performing a task, because it performs the task less efficiently, or because it is relatively inactive. As several authors have pointed out (Gur, 1979; Tucker et al., 1981), "more active" does not necessarily imply "better," since a hyperaroused hemisphere may seize tasks for which it is ill suited. Techniques exist for differentiating relative versus absolute dominance by manipulating task difficulty (Colbourn, 1979; Besner, Grimsell, & Davis, 1979) or visual field–response hand interactions (Suberi & McKeever, 1977), and would be well employed in studying emotional processing. Another strategy would use simultaneous measures of hemispheric activation and performance level, as represented, for example, by reaction time and error rate (Posner & Boies, 1971). In depressed populations electrophysiologic measures would be more informative if they were coupled with assessments of cognitive functioning.

Other emerging lines of investigation may also shed light on emotional lateralization. Robinson, for example, has found lateralized neurochemical differences following stroke which may parallel lateralized mood changes (Robinson, 1979). Mandell and Knapp (1979) have described modification of hemispheric serotonin imbalance by the mood stabilizing drug lithium carbonate, and there are scattered reports in the literature associating antidepressants with lateralized EEG changes (Paul, 1973; Harding, Lolas-Stepke, & Jenner, 1976).

Although the evidence is preliminary, lateralized hemispheric function offers promise as a model of affective regulation and its disorders. Coordinated physiologic, behavioral, and biochemical studies may further elucidate the mechanism of these functions.

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