Lateralization in Emotion and Emotional Disorders

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Research in the second half of the 20th century has led to enormous insights into the way the brain is organized to regulate emotion. Much of this information has been provided by investigations of hemispheric lateralization. Not only has laterality research advanced understanding of the neural mechanisms involved in emotion, but the findings have clarified important issues and raised key questions about the physiology and psychology of emotion and psychopathology. An ongoing dialogue between psychological theory and empirical work with behavioral and biological measures of laterality continues to illuminate fruitful avenues of study that contribute to understanding of normal emotion and of a variety of clinical disorders.

Nineteenth-century investigators turn out to have been quite accurate in attributing a special role to the right hemisphere in regulating emotional functions (for a review, see Harrington, 1995). However, the influential work of Papez (1937) and MacLean (1949) in the

first half of the 20th century disregarded the cerebral hemispheres (cortex), instead locating emotion in an interconnected subset of deeper structures (primarily subcortex) referred to as the limbic system. The emphasis on the limbic system dominated the field until the work of Roger Sperry and his colleagues with patients whose hemispheres were separated surgically stimulated a spate of research in hemispheric lateralization (see Reuter-Lorenz, this issue). Since the 1960s, a great deal has been learned about the role of the cortex in emotion. It has been well established that particular regions of the right hemisphere are specialized to interpret and express emotional information. Furthermore, research has shown that it is necessary to distinguish between "understanding" emotion, "expressing" emotion, and "feeling" emotion. The experience of emotion is not lateralized to one or the other hemisphere: Rather, it involves dynamic processes that include interactions between anterior and posterior re-
gions of both hemispheres, as well as between cortical and subcortical structures of the brain. As researchers uncover the mechanics of these interactions between various regions of the brain, they gain insights into the intricacy of brain function as well as into the complexity of human behavior. In this article, we review some of the knowledge that research in the laterality of emotion has afforded the fields of neuropsychology and psychopathology.

THE RIGHT HEMISPHERE AND EMOTION

Right-Hemisphere Specialization for Processing Emotional Information

The importance of lateralization in emotional information processing has been established by research indicating that the two sides of the brain are differentially involved in the interpretation of emotional information, as expressed by facial signals, vocal intonation, and gesture (for a review, see Heller, 1997). Patients with right-hemisphere lesions in posterior regions are impaired relative to patients with left-hemisphere lesions in comprehending emotional tone of voice (e.g., Tucker, Watson, & Heilman, 1977). Patients with right-brain damage also have difficulty recognizing facial expressions and naming emotional scenes (e.g., DeKosky, Heilman, Bowers, & Valenstein, 1980). They find it hard to match emotional expressions, and to group emotional scenes (either written or depicted in pictures) with the appropriate faces (e.g., Etcoff, 1984). In addition, patients with right-brain damage show deficits in the comprehension and appreciation of humorous or affective aspects of cartoons, films, and stories (e.g., Wapner, Hamby, & Gardner, 1981).

The conclusion that the right hemisphere plays a special role in understanding emotional information has been supported by many studies with non-brain-damaged participants as well. Because sensory and motor pathways are crossed, information that is presented in the right ear or right visual field is initially processed by posterior regions of the left hemisphere; information that is presented in the left ear or left visual field is initially processed by posterior regions of the right hemisphere. People make more accurate judgments about the emotional tone of voice presented to the left ear than to the right (e.g., Ley & Bryden, 1982), indicating that the right hemisphere is better at the task. They also discriminate emotional nonspeech sounds such as shrieking, laughing, and crying better with the left ear than with the right (e.g., King & Kimura, 1972). Studies in which visual information is presented to either the right or left visual field typically find a left-visual-field (right-hemisphere) advantage on tasks that require participants to discriminate facial expressions of emotion (e.g., Ladavas, Umiltà, & Ricci-Bitti, 1980), remember emotionally expressive faces (Suberi & McKeever, 1977), or match an emotional face to a spoken word (Hansch & Pirozzollo, 1980) or to a cartoon drawing of a face (Landis, Assal, & Perret, 1979).

Thus, a great deal of evidence across many paradigms suggests a special role for posterior regions of the right hemisphere in emotional information processing. These results have important implications for understanding normal emotion and conceptualizing emotional disorders.

Right-Hemisphere Specialization for Expressing Emotion

The right hemisphere has also been found to be more involved than the left hemisphere in the expression of emotion, although the results in this domain have been more variable. Generally, the left side of the face (largely regulated by the right hemisphere) is found to be more expressive than the right side (largely regulated by the left hemisphere) for both posed and spontaneous expressions, particularly for negative emotions (Borod, 1993; Heller & Levy, 1981). In contrast, the two sides of the face are often judged to be symmetric for expressions of positive emotion, such as smiles, and there have even been reports of greater right-sided expressivity for positive emotions. A possible explanation of these results is that positive emotional expressions are more related to the conventions of social communication than are negative emotional expressions (e.g., it is polite to look pleasant and smile in a public setting) and hence are less likely to reflect sincere emotional experience (for a review, see Heller, 1997).

Right-hemisphere specialization for emotional expression has emerged most consistently in studies examining healthy adults. In a recent review of this literature, Borod (1993) argued that studies of patients are inconsistent because factors other than which hemisphere is damaged are affecting facial expression. Lesion site, severity of damage, gender, and age all seem to influence facial expression of emotions after brain damage.

The right hemisphere has also been shown to be important for the ability to express emotion via tone of voice (referred to as prosody). A common approach has been to present brain-damaged patients with neutral sentences and ask them to repeat each sentence in a
different tone of voice (e.g., happy, sad, angry, or indifferent). Typically, right-brain-damaged patients are impaired in their prosodic expression (Borod, 1993). Thus, although there are some inconsistencies in the literature that need to be better understood, it appears that the right hemisphere is especially important for expressing emotion, as well as for processing incoming emotional information.

**Clinical Implications of Right-Hemisphere Specialization for Emotional Information Processing and Expression**

Understanding the lateralized organization of emotional information processing and expression has helped neuropsychologists and developmental psychologists to understand the behavioral effects of right-hemisphere damage and dysfunction, with important consequences for diagnosis and treatment. Damage to the right hemisphere in adults has been associated with remarkable difficulties in social and emotional function. The patient's difficulties in decoding emotional signals and comprehending emotional experience must be taken into account if rehabilitation is to be successful.

These findings have also provided insight into an important consequence of acquired or congenital right-hemisphere dysfunction in childhood. Researchers have identified and described nonverbal learning disability (NVLD) as being characterized by poor visual-spatial information processing despite fluent language abilities (e.g., Rourke, 1988). Individuals with NVLD often show a relative weakness in left-sided motor skills, also a sign of right-hemisphere dysfunction. These behavioral deficits, revealed by neuropsychological assessment, may or may not be accompanied by evidence of brain damage on a neurological exam. NVLD is also accompanied by great difficulty understanding interpersonal and social processes. Most likely, these deficits have their origin in very early childhood (Semrud & Hynd, 1990). Preverbal skills in infancy, including such right-hemisphere functions as the ability to comprehend and express emotion via facial signals, tone of voice, and gesture, have been shown to play a critical role in the development of infant-caregiver attachment, which in turn strongly influences later social adjustment. If these normative processes are disrupted, children are at great risk for later problems, including problematic peer relations and subsequent anxiety and depression. Ongoing difficulties processing emotional information may then build on earlier disruptions in social development to produce more severe manifestations of various types of psychopathology.

The explication of this type of learning disability has benefited many individuals who would previously have been misdiagnosed. In less severe cases, they might have been viewed as behavior disordered, or perceived as lazy, obnoxious, and uncaring. More severe cases may have been misdiagnosed with labels such as psychopathy (a pathological lack of empathy and feeling for other human beings) or pervasive developmental disorder (a category that includes autism and other disorders in which social behavior is disturbed). NVLD can even be mistaken for attention deficit hyperactivity disorder (ADHD), as these children (and adults) are typically quite disorganized and have difficulty regulating and structuring their attention and activities. Given the vastly different therapeutic approaches that are best suited for these diverse conditions, the appropriate diagnosis is critical. For example, children with NVLD typically do not benefit from stimulant medication, as do children with ADHD.

**BEYOND THE RIGHT HEMISPHERE: BRAIN SYSTEMS IN EMOTIONAL EXPERIENCE**

Research on the role of the hemispheres in emotion has also underscored the importance of differentiating various aspects of emotion in both theory and practice (Davidson, 1992; Heller & Nitsche, 1997). For example, the results from a variety of studies converge to suggest that the experience of emotion involves very different neuropsychological mechanisms than either the interpretation or the expression of emotional information.

Sporadic case studies describing different emotional experiences after right- and left-hemisphere brain damage led Gainotti (1972) to study systematically the effects of lateralized lesions on emotional behavior. He described dramatic differences between patients with right-brain damage, who displayed cheerful, even euphoric emotions (the "indifference reaction"), and patients with left-brain damage, who were distressed and fearful (the "catastrophic reaction"). These results were subsequently confirmed and extended in a series of studies by Robinson and his colleagues (e.g., Robinson, Kubos, Starr, Rao, & Price, 1984), who found that clinical depression was more common after left-brain damage than after right-brain damage, particularly when the lesion was in the most anterior part of the frontal cortex. Gainotti, Caltagirone, and Zoccoliotti (1993) suggested that the differences between patients might reflect the fact that people with left-brain damage lose their ability to speak, and a negative emotional reaction to this loss is not surprising.
However, numerous studies examining electrical and metabolic activity in the brain during different emotions suggest a different explanation. These studies have found that when non-brain-damaged people are sad, they show decreased left- and increased right-hemisphere activity (Davidson, 1995). Based on these data, Davidson has hypothesized that the left and right anterior regions of the brain are key components of an affective regulatory system that mediates approach and avoidance behavior. Activation of the left hemisphere is associated with approach, response to reward, and positive affect. Activation of the right hemisphere, in contrast, is associated with avoidance, withdrawal from aversive stimuli, and negative affect.

Furthermore, there appear to be stable individual differences in asymmetric brain activity across the life span that predict important biases in emotional responses to stress or challenge. Fox and Davidson (1988) found that infants who tended to cry when faced with maternal separation displayed less left and more right anterior activity than those who were not distressed in this situation. In addition, adults who show greater left anterior activity report more positive affect, engage in more approach behaviors, and respond more intensely to positive than negative stimuli, whereas those who show greater right anterior activity report more negative affect, engage in more avoidance behaviors, and respond more to negative than positive stimuli (for a review, see Davidson, 1995). These differences are even related to immune function: People with more right anterior activity show a diminished immune response, as measured by activity of natural killer cells, than those with more left anterior activity (Kang et al., 1991).

DISTINGUISHING ASPECTS OF EMOTION AND EMOTIONAL DISORDERS

Research in our lab has also highlighted the importance of distinguishing aspects of emotion and decomposing emotional experience into more fundamental components. We have relied on a particular model of emotion (the circumplex model) that is based on factor analytic studies of self-reported emotions. This model defines affective space using two primary dimensions, valence (pleasant or unpleasant) and arousal (high or low). Most emotions fall somewhere in the four quadrants delineated by these axes (e.g., elation is located between the pleasant-valence and high-arousal poles). The psychological dimensions of valence and arousal have been shown to correspond to specific and distinct physiological response systems (Lang, Bradley, & Cuthbert, 1990). For example, valence is related to heart rate, whereas self-reported arousal is associated with skin conductance, a measure of sweat-gland activity. These dimensions are also characterized by distinct patterns of cortical brain activity. On the basis of studies reviewed elsewhere (Heller, Nitschke, & Lindsay, 1997), we hypothesized that the anterior regions of the brain are associated with the valence dimension of the circumplex model, with more left anterior activity reflecting pleasant emotions, and more right anterior activity reflecting unpleasant emotions. The right posterior region is involved in arousal-related aspects of emotional experience, with more activity related to higher arousal (Heller, 1990; Heller & Nitschke, 1998).

These hypotheses led to several specific predictions about regional brain activity during depression and anxiety. Depression and anxiety both entail unpleasant valence and avoidance behavior. Therefore, we predicted that depression and anxiety would both be associated with increased activity in anterior regions of the right hemisphere. However, self-reported depression and anxiety tend to fall at opposite ends of the arousal dimension, with depression linked to low arousal and anxiety to high arousal. Therefore, depression and anxiety should be associated with opposing directions of activity in the right posterior region (decreased activity in depression, increased activity in anxiety). If depression and anxiety co-occur (as is very common), it is possible that the effects in the right posterior region would cancel each other.

Results from several recent studies are consistent with our prediction that activity in the right posterior region differentiates depression and anxiety. We have examined depressed inpatients, depressed outpatients, and students with high scores on self-report measures of depression (e.g., Heller, Etienne, & Miller, 1995). In each study, we administered a face-processing task that measures the degree to which an individual displays an attentional bias toward the left versus right side of space (a hemispatial bias). This hemispatial bias is thought to be produced by an orienting response toward the side of space opposite the more active hemisphere. Although a group difference in hemispatial bias is not specific as to which hemisphere is more or less active than in control subjects (e.g., a smaller left hemispatial bias could indicate either more left- or less right-hemisphere activity than normal), it is often possible to infer the lateralization of activity based on other neuropsychological data.

In our task, subjects are asked to indicate which of two faces looks happier; one has a smile in left...
hemisphere, whereas the other has a smile in right hemispace. Most people think the face whose smile is positioned in their left hemispace looks happier, but there are large differences among individuals in the magnitude of the bias. We found that depressed people had smaller left hemispatial biases than control subjects, suggesting, on the basis of these and other data, reduced right-hemisphere activity. In contrast, anxiety was associated with larger left hemispatial biases, suggesting increased right-hemisphere activity. Furthermore, these effects emerged only when shared characteristics of depression and anxiety were removed either statistically or via experimental design (e.g., Heller et al., 1995).

Lateralization of brain activity not only differentiates depression and anxiety, but also appears to distinguish different types of anxiety. Psychological theories have distinguished anxious apprehension (worry), which involves verbal rumination about possible negative outcomes of future events, from anxious arousal (panic), a more immediate fear response that involves physiological hyperarousal. A review of the literature suggested to us that when brain activity has been measured in subjects characterized by anxious apprehension, asymmetries in favor of the left hemisphere have been reported, but when brain activity has been measured in subjects characterized by anxious arousal, asymmetries in favor of the right hemisphere have been reported.

Electroencephalographic (EEG) research in our lab has supported our hypothesis that neurophysiological patterns distinguish anxious apprehension from anxious arousal (Heller, Nitschke, Etienne, & Miller, 1997). Electrical activity of the brain is measured by placing electrodes on the scalp, recording electrical activity, and calculating amplitude (size of signal, measured as voltage) and frequency (cycles per second, measured in Hertz). Amplitude and frequency vary depending on a person’s behavior. Typically, when people are drowsy or relaxed, slower frequencies (8–13 Hz), known as alpha, are present. In experimental paradigms, a decrease in alpha is presumed to indicate an increase in the activity of the brain region near the electrode.

We selected a group of participants who scored high on measures of trait anxiety. The questionnaire items used to classify participants suggest that trait anxiety is likely to reflect anxious apprehension. In addition, by definition, trait-anxious people are expected to respond to stress with increased anxious arousal (Spielberger, 1968). Therefore, we measured EEG during a resting baseline condition and while subjects listened to unpleasant and arousing emotional narratives. As predicted, compared with control subjects, trait-anxious participants showed a larger asymmetry in favor of the left hemisphere, particularly for anterior regions of the brain. This asymmetry was present across all conditions. In addition, trait-anxious participants showed a selective increase in right posterior activity while listening to highly arousing, negatively valenced narratives, whereas control subjects showed nonsignificant increases for both right and left posterior regions. These results are consistent with our interpretation of the patterns of brain activity reported elsewhere.

In a subsequent study, we used specific questionnaires to select people characterized by anxious apprehension and people characterized by anxious arousal, and measured EEG activity at rest (Nitschke, Heller, Palmieri, & Miller, 1998). We found that the two groups differed significantly in their hemispheric asymmetries, consistent with predictions of increased left-hemisphere activity in anxious apprehension and increased right-hemisphere activity in anxious arousal. Thus, lateralized brain activity differentiated people with a tendency toward one type of anxiety from people with a tendency toward the other. The fact that these two types of anxiety are distinguished neurophysiologically supports the psychological and physiological evidence suggesting that they are distinct constructs and highlights the need to consider the presence of both in diagnostic, treatment, and research procedures.

Research in lateralization has also helped to distinguish between subtypes of depression. Bruder and his colleagues (e.g., Bruder, 1995) have found that melancholic depression (distinguished by an inability to experience pleasure), but not atypical depression (in which mood can brighten in response to pleasurable events), is characterized by poor right-hemisphere performance on auditory tasks, suggesting deficits in right posterior function. Possibly, our findings with regard to anxious apprehension and anxious arousal will also prove to aid in the discrimination of different anxiety disorders, because various diagnoses differ in the degree to which these kinds of anxiety are present. For example, anxious apprehension is particularly salient in generalized anxiety disorder, whereas anxious arousal predominates in panic disorder.

IMPLICATIONS FOR COGNITION

Perhaps one of the most important contributions understanding lateralization in emotional experience can provide is insight into the cognitive capabilities and styles of
people with emotional disorders. Numerous studies have shown that if a region of the cortex is specialized for a particular mode of information processing, activity in that region covaries with performance on tasks that benefit from that type of computation. In the vast majority of studies, increased activity is associated with better performance (for a review, see Heller & Nitschke, 1997), whereas deficient activity is associated with decrements in performance. For example, reduced activity in right posterior regions, reflected in left-ear deficits and in reduced left hemispatial biases on the face-processing task mentioned earlier, is also manifested in poor performance on tests of visuospatial information processing (e.g., manipulating blocks to make a design). Similar deficits are likely to appear on a variety of tasks that draw on other specialized capacities of the right hemisphere, including important aspects of language (see Beevers & Chiarello, this issue).

The cognitive characteristics of depression and anxiety can be anchored to corresponding levels of activity in critical regions of the cortex, including anterior and right posterior regions (Heller & Nitschke, 1997; Nitschke, Heller, & Miller, in press). A variety of cognitive skills mediated by anterior brain regions are impaired in depression, including memory on tasks that require or benefit from information-organizing strategies, the ability to access errors accurately, problem solving, and cognitive flexibility. Anxiety, in contrast, is associated with attentional biases toward threat-related stimuli that dovetail with specializations of the right hemisphere for visual and spatial attention, vigilance, and physiological arousal. These attentional biases are likely to reflect the heightened activation of the right hemisphere in anxious arousal.

In summary, the present brief review has surveyed the growing literature on regional brain specialization, and especially lateralization, in both normal emotion and psychological dysfunction. With the proper methodological and substantive caveats, such as distinctions between types of anxiety, this literature shows striking consistency, with left-right anterior balance associated with the experienced valence of a stimulus and with right posterior activity associated both with experienced arousal and with accuracy in the interpretation of emotional information. These findings have enabled us to refine our understanding of the functional organization of the brain regions subserving normal emotional processing. In addition, these data have provided important insights into the neurophysiological substrates and cognitive concomitants of clinical disorders such as depression and anxiety.

Notes

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2. Except for the far periphery, all visual information reaches both eyes. However, the inside half of each retina projects to the opposite side of the brain, whereas the outside halves project to the same side of the brain. When the eyes are fixated on a point straight ahead, the information to the right of fixation (right visual field) projects to the left half of the retina of both eyes. Information to the left of fixation (left visual field) projects to the right half of the retina of both eyes. Thus, information in the left visual field is carried to the right hemisphere via the inner retina of the left eye and the outer retina of the right eye. Similarly, information in the right visual field is carried to the left hemisphere via the inner retina of the right eye and the outer retina of the left eye.

References


Integration of Information Between the Cerebral Hemispheres

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Despite 30 years of research clearly demonstrating the complementary functions of the cerebral hemispheres, we have little information about how these two relatively distinct portions of the brain interact to provide the seamless behavior we all exhibit in everyday life. So striking are some of the demonstrations of lateralization of function in split-brain patients (i.e., individuals in whom the corpus callosum, which connects the cerebral hemispheres, has been severed) that philosophers and neuroscientists alike have paused to consider whether humans might have two separate and unique consciousneses, rather than a single mind. Recent work has helped to expand our understanding of the exquisite interplay between the hemispheres that provides us with unified thought. It has become clear that interhemispheric interaction has some unanticipated functions, such as playing a role in perceptually binding together disparate parts of an object or modulating attentional ability. Furthermore, interhemispheric interaction appears to have emergent properties, in that under certain conditions, one cannot deduce how the hemispheres interact based solely on how each hemisphere operates in isolation.

Researchers attempting to understand interhemispheric interaction have generally concentrated on two major lines of inquiry. The first examines how information is represented as it is transferred from one hemisphere to the other. Thought of differently, this line of inquiry attempts to understand the “language” that the hemispheres use to communicate with one another. The second line of inquiry examines how transfer between the hemispheres affects the brain’s information processing capacities and strategies. That is, this line of research attempts to understand what mental processes are modulated or influenced by interhemispheric interaction.

Most interaction between the cerebral hemispheres occurs via a very large neural band of fibers known as the corpus callosum (see Fig. 1), which is composed of more than 200 million nerve fibers. Although there are other neural pathways by which information can be transferred between the hemispheres (see Fig. 1), the vast major-

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