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Affective Style and Affective Disorders: Perspectives from Affective Neuroscience

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Individual differences in emotional reactivity or affective style can be fruitfully decomposed into more elementary constituents. Several separable features of affective style are identified such as the *threshold* for reactivity, the *peak amplitude* of response, the *rise time to peak* and the *recovery time*. The latter two characteristics constitute components of *affective chronometry*. The circuitry that underlies two fundamental forms of motivation and emotion—approach and withdrawal-related processes—is described. Data on individual differences in functional activity in certain components of these circuits are next reviewed, with an emphasis on the nomological network of associations surrounding individual differences in asymmetric prefrontal activation. The relevance of such differences for understanding the nature of the affective dysfunction in affective disorders is then considered. The article ends by considering what the prefrontal cortex "does" in certain components of affective style and highlights some of the important questions for future research.

I. INTRODUCTION

Among the most striking features of human emotion is the variability that is apparent across individuals in the quality and intensity of dispositional mood and emotional reactions to similar incentives and challenges. The broad ranges of differences in these varied affective phenomena has been

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referred to as "affective style" (Davidson, 1992). Differences among people in affective style appear to be associated with temperament (Kagan, Reznick & Snidman, 1988), personality (Gross, Sutton, & Ketelaar, in press) and vulnerability to psychopathology (Meehl, 1975). Moreover, such differences are not a unique human attribute, but appear to be present in a number of different species (e.g. Davidson, Kalin, & Shelton, 1993; Kalin, 1993).

In the next section of this article, conceptual distinctions among the various components of affective style will be introduced and methodological challenges to their study will be highlighted. The third section will present a brief overview of the anatomy of two basic motivational/emotional systems—the approach and withdrawal systems. Section four will consider individual differences in these basic systems and indicate how such differences might be studied. The fifth section will address the relation between such individual differences and psychopathology. It is our intuition that some of the individual differences in basic processes of affective style are central to determining either resilience or vulnerability. Such differences can be conceptualised as diatheses which affect an individual's response to a stressful life event. Finally, the last section will consider some of the implications of this perspective for assessment, treatment and plasticity.

II. THE CONSTITUENTS OF AFFECTIVE STYLE

Many phenomena are subsumed under the rubric of affective style. A concept featured in many discussions of affective development, affective disorders and personality is "emotion regulation" (Thompson, 1994). Emotion regulation refers to a broad constellation of processes that serve to either amplify, attenuate, or maintain the strength of emotional reactions. Included among these processes are certain features of attention which regulate the extent to which an organism can be distracted from a potentially aversive stimulus (Derryberry & Reed, 1996) and the capacity for self-generated imagery to replace emotions that are unwanted, with more desirable imagery scripts. Emotion regulation can be both automatic and controlled. Automatic emotion regulation may result from the progressive automisation of processes that initially were voluntary and controlled and have evolved to become more automatic with practice. We hold the view that regulatory processes are an intrinsic part of emotional behaviour and rarely does an emotion get generated in the absence of recruiting associated regulatory processes. For this reason, it is often conceptually difficult to distinguish sharply between where an emotion ends and regulation begins. Even more problematic is the methodological challenge of operationalising these different components in the stream of affective behaviour.

When considering the question of individual differences in affective behaviour, one must specify the particular response systems in which the individual differences are being explored. It is not necessarily the case that the same pattern of individual differences would be found across response systems. Thus, for example, an individual may have a low threshold for the elicitation of the subjective experience (as reflected in self-reports) of a particular emotion but a relatively high threshold for the elicitation of a particular physiological change. It is important not to assume that individual differences in any parameter of affective responding will necessarily generalise across response systems, within the same emotion. Equally important is the question of whether individual differences associated with the generation of a particular specific emotion will necessarily generalise to other emotions. For example, are those individuals who are behaviourally expressive in response to a fear challenge also likely to show comparably high levels of expressivity in response to positive incentives? Although systematic research on this question is still required, initial evidence suggests that at least certain aspects of affective style may be emotion-specific, or at least valence-specific (e.g. Wheeler, Davidson, & Tomarken, 1993).

In addition to emotion regulation, there are probably intrinsic differences in certain components of emotional responding. There are likely individual differences in the *threshold* for eliciting components of a particular emotion, given a stimulus of a certain intensity. Thus, some individuals are likely to produce facial signs of disgust on presentation of a particular intensity of noxious stimulus, whereas other individuals may require a more intense stimulus for the elicitation of the same response at a comparable intensity. This suggestion implies that dose-response functions may reliably differ across individuals. Unfortunately, systematic studies of this kind have not been performed, in part because of the difficulty of creating stimuli that are graded in intensity and designed to elicit the same emotion. In the olfactory and gustatory modalities, there are possibilities of creating stimuli that differ systematically in the concentration of a disgust-producing component and then obtaining psychophysical threshold functions that would reveal such individual differences. However, the production of such intensity-graded stimuli in other modalities will likely be more complicated, although with the development of large, normatively rated complex stimulus sets, this may be possible. An example is the *International Affective Picture System* (Lang, Bradley, & Cuthbert, 1995) developed by Peter Lang and his colleagues. This set includes a large number of visual stimuli that have been rated on valence and arousal dimensions and that comprise locations throughout this two-dimensional space. The density of stimulus exemplars at all levels within this space allow for the possibility of selecting stimuli that are graded in intensity for the sort of dose-response studies described above.

There are also likely to be individual differences in the *peak* or *amplitude* of the response. On presentation of a series of graded stimuli that differ in intensity, the maximum amplitude in a certain system (e.g. intensity of a facial contraction, change in heart rate, etc.) is likely to differ systematically across subjects. Some individuals will respond with a larger amplitude peak compared with others. Again, such individual differences may well be quite specific to particular systems and will not necessarily generalise across systems, even within the same emotion. Thus, the individual who is in the tail of the distribution in his/her heart rate response to a fearful stimulus will not necessarily be in the tail of the distribution in his/her facial response.

Another parameter that is likely to differ systematically across individuals is the *rise time to peak*. Some individuals will rise quickly in a certain response system, whereas others will rise more slowly. There may be an association between the peak of the response and the rise time to the peak within certain systems for particular emotions. Thus, it may be the case that for anger-related emotion, those individuals with higher peak vocal responses also show a faster rise time, but to the best of my knowledge, there are no systematic data related to such differences.

Finally, another component of intrinsic differences across individuals is the *recovery time*. Following perturbation in a particular system, some individuals recover quickly and others recover slowly. For example, following a fear-provoking encounter, some individuals show a persisting heart rate elevation that might last for minutes, whereas other individuals show a comparable peak and rise time, but recover much more quickly. Of course, as with other parameters, there are likely to be differences in recovery time across different response systems. Some individuals may recover rapidly in their expressive behaviour, while recovering slowly in certain autonomic channels. The potential significance of such dissociations has not been systematically examined.

The specific parameters of individual differences that are delineated above describe *affective chronometry*—the temporal dynamics of affective responding. Very little is known about the factors that govern these individual differences and the extent to which such differences are specific to particular emotion response systems or generalise across emotions (e.g. is the heart rate recovery following fear similar to that following disgust?). Moreover, the general issue of the extent to which these different parameters that have been identified are orthogonal or correlated features of emotional responding is an empirical question that has yet to be answered. For reasons that I hope to make clear later, affective chronometry is a particularly important feature of affective style and is likely to play a key role in determining vulnerability to psychopathology. It is also a feature of affective style that is methodo-

logically tractable and can yield to experimental study of its neural substrates.

We also hold that affective style is critical in understanding the continuity between normal and abnormal functioning and in the prediction of psychopathology and the delineation of vulnerability. On the opposite side of the spectrum, such individual differences in affective style will also feature centrally in any comprehensive theory of resilience. The fact that some individuals reside "off the diagonal" and appear to maintain very high levels of psychological well-being despite their exposure to objective life adversity is likely related to their affective style (Ryff & Singer, in press). Some of these implications will be discussed at the end of this article.

We first consider some of the neural substrates of two fundamental emotion systems. This provides the foundation for a consideration of individual differences in these systems and the neural circuitry responsible for such differences.

III. THE ANATOMY OF APPROACH AND WITHDRAWAL

Although the focus of my empirical research has been on measures of prefrontal brain activity, it must be emphasised at the outset that the circuit instantiating emotion in the human brain is complex and involves a number of interrelated structures. Preciously few empirical studies using modern neuroimaging procedures that afford a high degree of spatial resolution have yet been performed (see George et al., 1995; Paradiso et al., 1997, for examples). Therefore, hypotheses about the set of structures that participate in the production of emotion must necessarily be speculative and based to a large extent on the information available from the animal literature (e.g. LeDoux, 1987), and from theoretical accounts of the processes involved in human emotion.

Based upon the available strands of theory and evidence, numerous scientists have proposed two basic circuits each mediating different forms of motivation and emotion (see e.g. Davidson, 1995; Gray, 1994; Lang, Bradley, & Cuthbert, 1990). The approach system facilitates appetitive behaviour and generates certain types of positive affect that are approach-related (e.g. enthusiasm, pride, etc., see Depue & Collins, in press for a review). This form of positive affect is usually generated in the context of moving toward a desired goal (see Lazarus, 1991 and Stein & Trabasso, 1992, for theoretical accounts of emotion that place a premium on goal states). The representation of a goal state in working memory is hypothesised to be implemented in dorsolateral prefrontal cortex. The medial prefrontal cortex seems to play an important role in maintaining

representations of behavioural-reinforcement contingencies in working memory (Thorpe, Rolls, & Maddison, 1983). In addition, output from the medial prefrontal cortex to nucleus accumbens (NA) neurones modulates the transfer of motivationally relevant information through the NA (Kalivas, Churchill, & Klitenick, 1993). The basal ganglia are hypothesised to be involved in the expression of the abstract goal in action plans and in the anticipation of reward (Schultz, Apicella, Romo, & Scarnati, 1995a; Schultz et al., 1995b). The NA, particularly the caudomedial shell region of the NA, is a major convergence zone for motivationally relevant information from a myriad of limbic structures. Cells in this region of the NA increase their firing rate during reward expectation (see Schultz et al., 1995a). There are probably other structures involved in this circuit which depend on a number of factors including the nature of the stimuli signalling appetitive information, the extent to which the behavioural-reinforcement contingency is novel or overlearned, and the nature of the anticipated behavioural response.

It should be noted that the activation of this approach system is hypothesised to be associated with one particular form of positive affect and not all forms of such emotion. It is specifically predicted to be associated with *pre-goal attainment positive affect*, that form of positive affect that is elicited as an organism moves closer toward an appetitive goal. *Post-goal attainment positive affect* represents another form of positive emotion that is not expected to be associated with activation of this circuit (see Davidson, 1994 for a more extended discussion of this distinction). This latter type of positive affect may be phenomenologically experienced as contentment and is expected to occur when the prefrontal cortex goes off-line after a desired goal has been achieved. Cells in the NA have also been shown to decrease their firing rate during post-goal consummatory behaviour (e.g. Henriksen & Giacchino, 1993).

Lawful individual differences can enter into many different stages of the approach system. Such individual differences and their role in modulating vulnerability to psychopathology will be considered in detail later. For the moment, it is important to underscore two issues. One is that there are individual differences in the tonic level of activation of the approach system which alters an individual's propensity to experience approach-related positive affect. Second, there are likely to be individual differences in the capacity to shift between pre- and post-goal attainment positive affect and in the ratio between these two forms of positive affect. On reaching a desired goal, some individuals will immediately replace the just-achieved goal with a new desired goal, and so will have little opportunity to experience post-goal attainment positive affect, or contentment. There may be an optimal balance between these two forms of positive affect, although this issue has not received systematic study.

There appears to be a second system concerned with the neural implementation of withdrawal. This system facilitates the withdrawal of an individual from sources of aversive stimulation and generates certain forms of negative affect that are withdrawal-related. Both fear and disgust are associated with increasing the distance between the organism and a source of aversive stimulation. From invasive animal studies and human neuroimaging studies, it appears that the amygdala is critically involved in this system (e.g. LeDoux, 1987). Using functional magnetic resonance imaging (fMRI) we have recently demonstrated for the first time activation in the human amygdala in response to aversive pictures compared with neutral control pictures (Irwin et al., 1996). In addition, the temporal polar region also appears to be activated during withdrawal-related emotion (e.g. Reiman, Fusselman, Fox, & Raichle, 1989; but see Drevets, Videen, MacLeod, Haller, & Raichle, 1992a). These effects, at least in humans, appear to be more pronounced on the right side of the brain (see Davidson, 1992, 1993 for reviews). In human electrophysiological studies, the right frontal region is also activated during withdrawal-related negative affective states (e.g. Davidson, Ekman, Saron, Senulis, & Friesen, 1990a). At present, it is not entirely clear whether this EEG change reflects activation at a frontal site or whether the activity recorded from the frontal scalp region is volume-conducted from other cortical loci. The resolution of this uncertainty must await additional studies using positron emission tomography (PET) or fMRI, which have sufficient spatial resolution to differentiate among different anterior cortical regions. In addition to the temporal polar region, the amygdala and possibly the prefrontal cortex, it is also likely that the basal ganglia and hypothalamus are involved in the motor and autonomic components, respectively, of withdrawal-related negative affect (see Smith, DeVito, & Astley, 1990).

The nature of the relation between these two hypothesised affect systems also remains to be delineated. The emotion literature is replete with different proposals regarding the interrelations among different forms of positive and negative affect. Some theorists have proposed a single bivalent dimension that ranges from unpleasant to pleasant affect, with a second dimension that reflects arousal (e.g. Russell, 1980). Other theorists have suggested that affect space is best described by two orthogonal positive and negative dimensions (e.g. Watson & Tellegen, 1985). Still other workers have suggested that the degree of orthogonality between positive and negative affect depends upon the temporal frame of analysis (Diener & Emmons, 1984). This formulation holds that when assessed in the moment, positive and negative affect are reciprocally related, but when examined over a longer time-frame (e.g. dispositional affect), they are orthogonal. It must be emphasised that these analyses of the relation between positive and negative affect are all based exclusively on measures

of self-report and therefore their generalisability to other measures of affect are uncertain. However, based on new data to be described later, we believe that a growing corpus of data does indeed indicate that one function of positive affect is to inhibit concurrent negative affect.

IV. INDIVIDUAL DIFFERENCES IN ASYMMETRIC PREFRONTAL ACTIVATION: WHAT DO THEY REFLECT?

This section will present a brief overview of recent work from my laboratory designed to examine individual differences in measures of prefrontal activation and their relation to different aspects of emotion, affective style, and related biological constructs. These findings will be used to address the question of what underlying constituents of affective style such individual differences in prefrontal activation actually reflect.

In both infants (Davidson & Fox, 1989) and adults (Davidson & Tomarken, 1989) we noticed that there were large individual differences in baseline electrophysiological measures of prefrontal activation and that such individual variation was associated with differences in aspects of affective reactivity. In infants, Davidson and Fox (1989) reported that 10-month-old infants who cried in response to maternal separation were more likely to have less left and greater right-sided prefrontal activation during a preceding resting baseline compared with those infants who did not cry in response to this challenge. In adults, we first noted that the phasic influence of positive and negative emotion elicitors (e.g. film clips) on measures of prefrontal activation asymmetry appeared to be superimposed on more tonic individual differences in the direction and absolute magnitude of asymmetry (Davidson & Tomarken, 1989).

During our initial explorations of this phenomenon, we needed to determine if baseline electrophysiological measures of prefrontal asymmetry were reliable and stable over time and thus could be used as a trait-like measure. Tomarken, Davidson, Wheeler, and Doss (1992) recorded baseline brain electrical activity from 90 normal subjects on two occasions separately by approximately three weeks. At each testing session, brain activity was recorded during eight 1-minute trials, four eyes open and four eyes closed, presented in counterbalanced order. The data were scored visually to remove artefact, and then Fourier-transformed. Our focus was on power in the apha band (8–13Hz), although we extracted power in all frequency bands (see Davidson, Chapman, Chapman, & Henriques, 1990 for a discussion of power in different frequency bands and their relation to activation). We computed coefficient alpha as a measure of internal consistency reliability from the data for each session. The coefficient alphas were quite high, with all values exceeding .85, indicating that the electro-

physiological measures of asymmetric activation indeed showed excellent internal consistency reliability. The test-retest reliability was adequate with intraclass correlations ranging from .65 to .75, depending on the specific sites and methods of analysis. The major finding of import from this study was the demonstration that measures of activation asymmetry based on power in the alpha band from anterior scalp electrodes showed both high internal consistency reliability and acceptable test-retest reliability to be considered a trait-like index.

The large sample size in the reliability study discussed above enabled us to select a small group of extreme left and extreme right-frontally activated subjects for magnetic resonance imaging (MRI) scans to determine if there existed any gross morphometric differences in anatomical structure between these subgroups. None of our measures of regional volumetric asymmetry revealed any difference between the groups (unpublished observations). These findings suggest that whatever differences exist between subjects with extreme left versus right prefrontal activation, those differences are likely functional and not structural.

On the basis of our prior data and theory, we reasoned that extreme left and extreme right frontally activated subjects would show systematic differences in dispositional positive and negative affect. We administered the trait version of the Positive and Negative Affect Scales (PANAS; Watson, Clark, & Tellegen, 1988) to examine this question and found that the left-frontally activated subjects reported more positive and less negative affect than their right-frontally activated counterparts (Tomarken et al., 1992; see Fig. 1, overleaf). More recently with Sutton (Sutton & Davidson, 1997) we showed that scores on a self-report measure designed to operationalise Gray's concepts of Behavioral Inhibition and Behavioral Activation (the BIS/BAS scales; Carver & White, 1994) were even more strongly predicted by electrophysiological measures of prefrontal asymmetry than were scores on the PANAS scales (see Fig. 2, situated on p. 337 of the Colour Plate Section). Subjects with greater left-sided prefrontal activation reported more relative BAS to BIS activity compared with subjects exhibiting more right-sided prefrontal activation.

We also hypothesised that our measures of prefrontal asymmetry would predict reactivity to experimental elicitors of emotion. The model that we have developed over the past several years (see Davidson, 1992, 1994, 1995 for background) features individual differences in prefrontal activation asymmetry as a reflection of a diathesis which modulates reactivity to emotionally significant events. According to this model, individuals who differ in prefrontal asymmetry should respond differently to an elicitor of positive or negative emotion, even when baseline mood is partialed out. We (Wheeler et al., 1993) performed an experiment to examine this question. We presented short film clips designed to

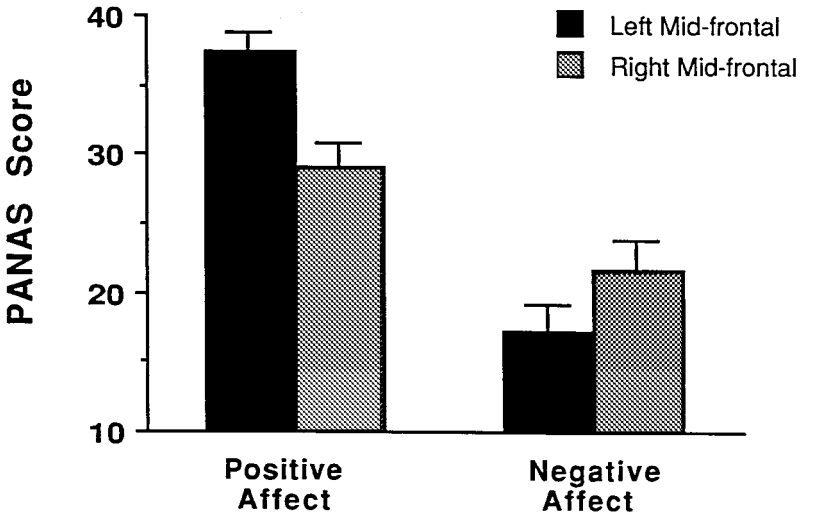

FIG. 1. Dispositional positive and negative affect (from scores on the PANAS-General Positive and Negative Affect Scale) in subjects who were classified as extreme and stable left-frontally active (N = 14) and extreme and stable right-frontally active (N = 13) on the basis of electrophysiological measures of baseline activation asymmetries on two occasions separated by three weeks. From Tomarken et al. (1992).

elicit positive or negative emotion. Brain electrical activity was recorded prior to the presentation of the film clips. Just after the clips were presented, subjects were asked to rate their emotional experience during the preceding film clip. In addition, subjects completed scales that were designed to reflect their mood at baseline. We found that individual differences in prefrontal asymmetry predicted the emotional response to the films even after the variance contributed by baseline mood was statistically removed. Those individuals with more left-sided prefrontal activation at baseline reported more positive affect to the positive film clips and those with more right-sided prefrontal activation reported more negative affect to the negative film clips. These findings support the idea that individual differences in electrophysiological measures of prefrontal activation asymmetry mark some aspect of vulnerability to positive and negative emotion elicitors. The fact that such relations were obtained following the statistical removal of baseline mood indicates that any difference between left and right frontally activated in baseline mood cannot account for the prediction of film-elicited emotion effects that were observed.

In a very recent study, we (Davidson, Dolski, Laron, & Sutton, in prep.) examined relations between individual differences in prefrontal activation asymmetry and the emotion-modulated startle. In this study, we presented

pictures from the *International Affective Picture System* (Lang et al., 1995) while acoustic startle probes were presented and the EMG-measured blink response from the orbicularis oculi muscle region was recorded (see Sutton, Davidson, Donzella, Irwin, & Dottl, 1997 for basic methods). Startle probes were presented both during the 6-second slide exposure as well as 500 milliseconds following the offset of the pictures, on separate trials.[1] We interpreted startle magnitude during picture exposure as providing an index related to the peak of emotional response, whereas startle magnitude following the *offset* of the pictures was taken to reflect the recovery from emotional challenge. Used in this way, startle probe methods can potentially provide new information on the time course of emotional responding. We expected that individual differences during actual picture presentation would be less pronounced than individual differences following picture presentation as an acute emotional stimulus is likely to pull for a normative response across subjects, yet individuals are likely to differ dramatically in the time to recover. Similarly, we predicted that individual differences in prefrontal asymmetry would account for more variance in predicting magnitude of recovery (i.e. startle magnitude post-stimulus) than in predicting startle magnitude during the stimulus. Our findings were consistent with our predictions and indicated that subjects with greater right-sided prefrontal activation show a larger blink magnitude following the offset of the negative stimuli, after the variance in blink magnitude *during* the negative stimulus was partialed out. Measures of prefrontal asymmetry did not reliably predict startle magnitude during picture presentation. The findings from this study are consistent with our hypothesis and indicate that individual differences in prefrontal asymmetry are associated with the time course of affective responding, particularly the recovery following emotional challenge.

In addition to the studies just described using self-report and psychophysiological measures of emotion, we have also examined relations

[1] In this initial study on the recovery function assessed with startle probe measures, we had only a single post-stimulus probe at 500ms following the offset of the picture. Readers may be surprised that the interval between the offset of the picture and the presentation of the probe was so short. However, it should be noted that these emotional pictures are not particularly intense and so the lingering effects of emotion following the presentation of such pictures is likely not to last very long in most individuals. Future studies will probe further out following the offset of the picture. Because, at most, only a single probe can be presented for each picture so that habituation effects are minimised, each new probe position requires a substantial increase in the overall number of pictures presented. There is a finite limit to the number of pictures contained in the IAPS. Even more importantly, we have found that it is critical to keep the picture viewing period to well under one hour to minimise fatigue and boredom.

between individual differences in electrophysiological measures of prefrontal asymmetry and other biological indices which in turn have been related to differential reactivity to stressful events. Two recent examples from our laboratory include measures of immune function and cortisol. In the case of the former, we examined differences between left- and right-prefrontally activated subjects in natural killer cell activity, because declines in NK activity have been reported in response to stressful, negative events (Kiecolt-Glaser & Glaser, 1991). We predicted that subjects with right prefrontal activation would exhibit lower NK activity compared with their left-activated counterparts because the former type of subject has been found to report more dispositional negative affect, to show higher relative BIS activity and to respond more intensely to negative emotional stimuli. We found that right-frontally activated subjects indeed had lower levels of NK activity compared to their left-frontally activated counterparts (Kang et al., 1991).

Recently, in collaboration with Kalin, our laboratory has been studying similar individual differences in scalp-recorded measures of prefrontal activation asymmetry in rhesus monkeys (Davidson, Kalin, & Shelton, 1992, 1993). Recently, we (Kalin, Larson, Shelton, & Davidson, in press) acquired measures of brain electrical activity from a large sample of rhesus monkeys (N = 50). EEG measures were obtained during periods of manual restraint. A subsample of 15 of these monkeys were tested on two occasions four months apart. We found that the test-retest correlation for measures of prefrontal asymmetry was .62, suggesting similar stability of this metric in monkey and man. In the group of 50 animals, we also obtained measures of plasma cortisol during the early morning. We hypothesised that if individual differences in prefrontal asymmetry were associated with dispositional affective style, such differences should be correlated with cortisol, because individual differences in baseline cortisol have been related to various aspects of trait-related stressful behaviour and psychopathology (see e.g. Gold, Goodwin, & Chrousos, 1988). We found that animals with right-sided prefrontal activation had higher levels of baseline cortisol than their left-frontally activated counterparts (see Fig. 3). Moreover, when blood samples were collected two years following our initial testing, animals classified as showing extreme right-sided prefrontal activation at age 1 year had significantly higher baseline cortisol levels when they were 3 years of age compared with animals who were classified at age 1 year as displaying extreme left-sided prefrontal activation. These findings indicate that individual differences in prefrontal asymmetry are present in nonhuman primates and that such differences predict biological measures that are related to affective style.

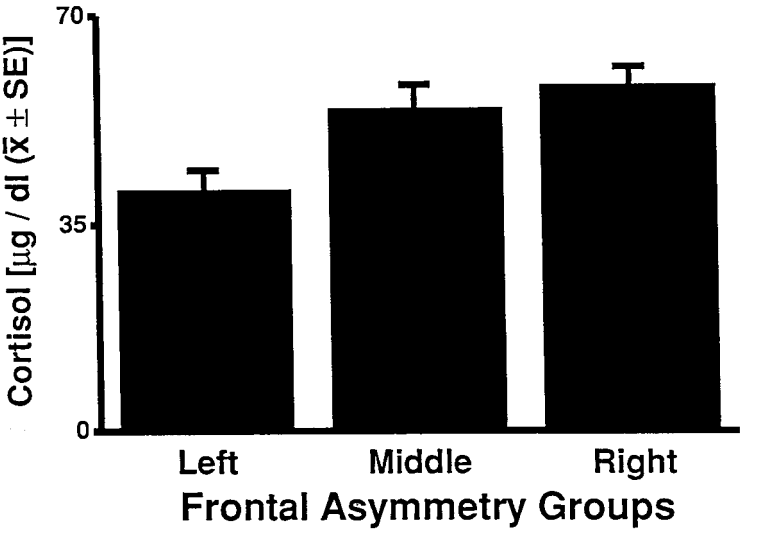

FIG. 3. Basal morning plasma cortisol from 1-year-old rhesus monkeys classified as left ($N = 12$), middle ($N = 16$), or right ($N = 11$) frontally activated based upon electrophysiological measurements. From Kalin et al. (in press).

V. AFFECTIVE STYLE AND PSYCHOPATHOLOGY

Virtually all forms of psychopathology involve some abnormality in emotional processes, although the nature of these abnormalities is likely to differ among different disorders. The study of precisely what is abnormal in the emotion-processing systems of individuals with different forms of psychopathology is very much at the earliest stages of investigation. We have used our findings in normal subjects as a foundation to probe the underlying neural substrates of affective and anxiety disorders with a major goal of understanding more precisely the nature of the abnormality in emotional-processing in affective disorders.

One of the important sources of data on relations between brain function and emotion has come from studies of the affective styles of patients with localised brain lesions (see Robinson & Downhill, 1995 for a review). Robinson and his colleagues have reported that damage to the left frontal region is more likely to be associated with depression than damage to any other cortical region. Moreover, among patients with left hemisphere damage, more severe depressive symptomatology is present in those patients whose damage is closer to the frontal pole (Robinson, Kubos, Starr, Rao, & Price, 1984). Studies of regional brain function with neuroimaging of patients with psychiatric depressions have fairly consistently revealed a pattern of decreased blood flow or metabolism in left prefrontal

regions at rest (Baxter et al., 1989; Bench et al., 1992; 1993; Martinot et al., 1990; see George, Ketter, & Post, 1994 for a review; see also Drevets et al., 1992b for a more complex pattern associated with pure familial depression).

We have conducted several studies examining regional brain electrical activity in depression. We hypothesised that most depression is fundamentally associated with a deficit in the approach/appetitive motivation system and should therefore be specifically accompanied by decreased activation in the left prefrontal region as measured by scalp electrophysiology. Henriques and Davidson (1991) obtained support for this hypothesis. Moreover, in another study, these authors demonstrated that the decrease in left prefrontal activation found among depressives was also present in recovered depressives who were currently euthymic, compared with never depressed controls who were screened for lifetime history of psychopathology in both themselves as well as their first degree relatives (Henriques & Davidson, 1990). Together the findings from patients with localised unilateral brain damage, as well neuroimaging and electrophysiology studies in psychiatric patients without frank lesions, converge on the notion that depression is associated with a deficit in at least the prefrontal component of the approach system. We view this pattern of left prefrontal hypoactivation as a neural reflection of the decreased capacity for pleasure, loss of interest, and generalised decline in goal-related motivation and behaviour.

Consistent with this notion are the data from another recent behavioural study from my laboratory where we demonstrated using signal detection methods that depressed subjects were specifically hyporeactive to reward incentives (Henriques, Glowacki, & Davidson, 1994). In this study, we administered a verbal memory task under reward, punishment, and neutral incentive conditions. The rewards and punishments were monetary. Signal detection measures of sensitivity and response bias were computed. Nondepressed control subjects exhibited a more liberal response bias under both reward and punishment incentives. In other words, they were more likely to consider a stimulus as a signal if they were rewarded for correct hits or punished for misses. Depressed subjects showed a pattern quite similar to the controls in response to the punishment contingency. However, they failed to modify their response bias during the reward condition. In other words, the depressed subjects were less responsive to rewards compared with controls, however, the groups showed no significant differences in response to punishment.

Based on the evidence reviewed earlier, we hypothesised that in contrast to depression, anxiety disorders would be associated with an increase in right-sided rather than a decrease in left-sided prefrontal activation, particularly during an acute episode of anxiety. To test this hypothesis, we (Davidson, Marshall, Tomarken, & Henriques, 1997) exposed social phobics who were particularly fearful of making public speeches to the

threat of having to make a public speech. We recorded brain electrical activity during an anticipation phase where subjects were presented with an audiotaped countdown that noted how much more time there was until they were to make their speech. The taped-recorded message was presented every 30 seconds for a total of 3 minutes. We found that the phobics showed a large and highly significant increase over baseline in right-sided prefrontal and right-sided parietal activation. During the same anticipation period, the controls showed a very different pattern of regional changes. The only change to reach significance was in the left posterior temporal region. We interpret this latter change as likely a consequence of verbal rehearsal in anticipation of making the public speech. No region in the right hemisphere exceeded an even liberal statistical threshold for increased activation relative to a baseline condition. The change in prefrontal activation among the phobics is consistent with our hypothesis of increased right-sided activation associated with an increase in anxiety. The increase in right parietal activation is consistent with Heller and Nitschke's (this Issue) hypothesis of increased right-sided activation associated with the arousal component of anxiety. Indeed, simultaneous measures of heart rate in this study indicated that the phobics had higher heart rate compared with the controls, particularly during the anticipation phase.

Research using self-report measures of positive and negative affect as well as experienced increases in autonomic arousal indicate that decreased positive affect is uniquely associated with depression, whereas increased autonomic arousal is uniquely associated with anxiety. However, reported negative affect is something that has been found to be common to both anxiety and depression (Watson et al., 1995). We have hypothesised that the decrease in left prefrontal activation may be specific to depression, whereas the increase in right-sided prefrontal activation (as well as right parietal activation) may be specific to certain components of anxiety. Considerably more research is required to understand the contribution being made by the activated right prefrontal region to negative affect. Other work (see Posner & Petersen, 1990 for a review) indicates that portions of the right prefrontal region are activated during certain types of vigilance and attention (e.g. Knight, 1991; see Posner & Petersen, 1990 for a review). Anxiety-related negative affect is accompanied by heightened vigilance (e.g. McNally, this Issue) which may be reflected in the right prefrontal increase.

One common region we believe to be associated with both anxiety and depression is the amygdala. Even though there is a burgeoning literature on the anatomy and function of the amygdala (see Aggleton, 1993 for a review), relatively little research has been conducted in intact humans, owing in large measure to the difficulty in imaging function in a structure that is relatively small (the adult human amygdala is approximately 1cm in

volume). However, from what is known from both the animal and human studies, it appears that the amygdala plays an important role in assigning affective significance, particularly of negative valence, to both sensory as well as cognitive input (see LeDoux, 1992 for a review). Using positron emission tomography (PET) to measure regional blood flow, several groups have reported increased blood flow in the amygdala in response to both behavioural (e.g. Schneider et al., 1995) and pharmacological (e.g. Ketter et al., 1996) elicitors of negative affect. We have recently reported activation in the human amygdala using functional magnetic resonance imaging (fMRI) in response to aversive pictures (Irwin et al., 1996). These studies suggest that activation in the human amygdala occurs in response to a broad range of elicitors of negative affect.

Both fMRI and ^{15}O PET are ill-suited, for different reasons, for examining individual differences in resting or baseline levels of activation in the amygdala. As it is currently used, fMRI requires that at least two conditions be compared. What is measured is a relative difference in MR signal intensity between two or more conditions. Currently, fMRI is not calibrated in real physiological units. Although ^{15}O PET can be calibrated in real units, it reflects activity over a very short period of time (approximately one minute) and thus, for psychometric reasons, is poorly suited to capture trait-like differences. (It would be the equivalent of developing a single-item self-report instrument for assessing individual differences.) PET used with fluorodeoxyglucose (FDG) as a tracer, on the other hand, is well-suited to capture trait-like effects because the period of active uptake of tracer in the brain is approximately 30 minutes. Thus, it is inherently more reliable as the data reflect activity aggregated over this 30-minute period. We have used resting FDG-PET to examine individual differences in glucose metabolic rate in the amygdala and its relation to dispositional negative affect in depressed subjects (Abercrombie et al., submitted). We acquired a resting FDG-PET scan as well as a structural MR scan for each subject. The structural MR scans are used for anatomical localisation by coregistering the two image sets. Thus, for each subject, we used an automated algorithm to fit the MR scan to the PET image. Regions of interest (ROIs) were then drawn on each subject's MR scan to outline the amygdala in each hemisphere. These ROIs were drawn on coronal sections of subjects' MR images and the ROIs were then automatically transferred to the coregistered PET images. Glucose metabolism in the left and right amygdala ROIs were then extracted. The inter-rater reliability for the extracted glucose metabolic rate is highly significant with intraclass correlations between two independent raters $\geq .97$. Figure 4 (situated on p. 338 of the Colour Plate Section) illustrates ROIs drawn around the amygdala on MR scans of three subjects and the associated coregistered PET images from the same subjects. We found that subjects with greater glucose

metabolism in both the right and left amygdala report greater dispositional negative affect on the PANAS scale (see Fig. 5). These findings indicate that individual differences in resting glucose metabolism in the amygdala are present and that they predict dispositional negative affect among depressed subjects. Most nondepressed controls score so low on the PANAS trait negative scale that it is not possible to examine the same relation in this group because of the severe truncation of range for the PANAS scores.

The findings reviewed in this section indicate that the framework adopted for the study of individual differences in fundamental approach and withdrawal-related processes can be usefully applied in the study of psychopathology. A deficit in the approach system is viewed as a unique attribute of depressive disorders that is reflected in decreased left prefrontal activation. The acute symptoms of anxiety, as was described in our study with social phobics, was associated with a pronounced increase in both right-sided prefrontal and parietal activation. From research conducted in our laboratory as well as recent findings in the literature, it appears that

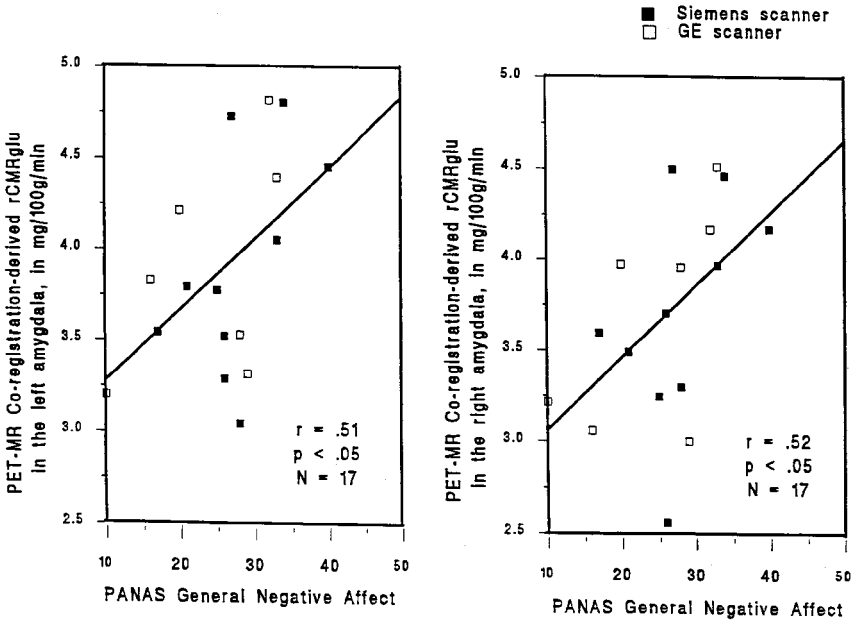

FIG. 5. Scatter plot of correlations between dispositional negative affect assessed with the PANAS-General Negative Affect Scale and PET MRI-coregistration-derived regional glucose metabolism in the left and right amygdalae for all subjects (N = 17). Subjects were tested on two different PET cameras. Those tested in a Siemens CTI 933/04 PET camera are displayed by closed squares and those tested in the GE Advance are depicted by the open squares. From Abercrombie et al. (submitted).

amygdala activation may be a generic component of negative affect that is present in both anxiety and depression. Thus, differences between these disorders may be more pronounced for *cortical* systems that are critically involved in affect regulation and affect-cognition interaction, whereas subcortical contribution (in particular, the amygdala) may be common to both types of disorders and may in part be responsible for the substantial comorbidity between these disorders (Watson et al., 1995).

VI. IMPLICATIONS AND CONCLUSIONS

Earlier in this article, the constituents of affective style were described. We considered individual differences in threshold, peak amplitude, rise time to peak, and recovery time. Together, these constitute parameters of affective chronometry and dictate important features of the time course of affective responding. Following a description of the functional neuroanatomy of the approach and withdrawal systems, individual differences in prefrontal activation asymmetry were discussed and their relation to affective style and psychopathology described. In the light of this information, we now return to the question posed in the title of Section IV: What do individual differences in prefrontal asymmetry reflect?

On the basis of findings from several new studies in my laboratory, I suggest that at least one important component of what prefrontal cortex "does" in affective responding is modulate the time course of emotional responding, particularly recovery time. There are several facts critical to making this claim. First, there are extensive reciprocal connections between amygdala and the prefrontal cortex (PFC), particularly the medial and orbital zones of the PFC (Amaral, Price, Pitkanen, & Carmichael, 1992). The glutamatergic efferents from the PFC likely synapse on GABA (gamma-aminobutyric acid) neurones (Amaral et al., 1992) and thus provide an important inhibitory input to the amygdala. Second, LeDoux and his colleagues (Morgan, Romanski, & LeDoux, 1993; but see Gewirtz, Falls, & Davis, 1997) demonstrated in rats that lesions of medial prefrontal cortex dramatically prolong the maintenance of a conditioned aversive response. In other words, animals with medial prefrontal lesions retain aversive associations for a much longer duration of time than normal animals. These findings imply that the medial PFC normally inhibits the amygdala as an active component of extinction. In the absence of this normal inhibitory input, the amygdala remains unchecked and continues to maintain the learned aversive response. Third, are the data from my laboratory cited in Section IV, indicating that individual differences in prefrontal activation asymmetry significantly predict the magnitude of the post-stimulus startle following removal of the variance attributable to startle magnitude during the presentation of the emotional

picture. In particular, left prefrontal activation appears to facilitate two processes simultaneously: (1) it maintains representations of behavioural-reinforcement contingencies in working memory (Thorpe et al., 1983); (2) it inhibits the amygdala. In this way, the time course of negative affect is shortened whereas the time course of positive affect is accentuated. Finally, fourth, new findings using PET from my laboratory indicate that in normal subjects, glucose metabolism in left medial and lateral prefrontal cortex is strongly associated reciprocally with glucose metabolic rate in the amygdala (Abercrombie et al., 1996). Thus, subjects with greater left-sided prefrontal metabolism have lower metabolic activity in their amygdala. These findings are consistent with the lesion study of LeDoux and colleagues and imply that prefrontal cortex plays an important role in modulating activity in the amygdala. At the same time, the left prefrontal cortex is also likely to play a role in the maintenance of reinforcement-related behavioural approach. Perhaps the damping of negative affect and shortening of its time course facilitates the maintenance of approach-related positive affect.

The questions that are featured in this article are more tractable now than ever before. With the advent of echoplanar methods for rapid functional magnetic resonance imaging (MRI), sufficient data can be collected within individuals to examine functional connections among regions hypothesised to constitute important elements of the approach and withdrawal circuits discussed earlier. Individual differences in different aspects of these systems can then be studied with greater precision. Functional magnetic resonance imaging (fMRI) methods also lend themselves to address questions related to affective chronometry. In particular, we can calculate that the slope of MRI signal intensity declines following the offset of an aversive stimulus to provide an index of the rapidity of recovery from activation in select brain regions. Positron emission tomography (PET) methods using new radioligands that permit quantification of receptor density for specific neurotransmitters in different brain regions is yielding new insights directly relevant to questions about affective style (see e.g. Farde, Gustavsson, & Jönsson, 1997). Trait-like differences in affective style are likely reflected in relatively stable differences in characteristics of the underlying neurochemical systems. Using PET to examine such individual differences promises to provide important syntheses between neurochemical and neuroanatomical approaches to understanding the biological bases of affective style.

Affective neuroscience seeks to understand the underlying proximal neural substrates of elementary constituents of emotional processing. In this article, I have provided a model of the functional neuroanatomy of approach and withdrawal motivational/emotional systems and illustrated the many varieties of individual differences that might occur in these

systems. Research on prefrontal asymmetries associated with affective style and psychopathology was used to illustrate the potential promise of some initial approaches to the study of these questions. Modern neuroimaging methods used in conjunction with theoretically sophisticated models of emotion and psychopathology offer great promise in advancing our understanding of the basic mechanisms giving rise to affective style and affective and anxiety disorders.

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REFERENCES

Abercrombie, H.C., Larson, C.L., Ward, R.T., Schaefer, S.M., Holden, J.E., Perlman, S.B., Turski, P.A., Krahn, D.D., & Davidson, R.J. (submitted). Metabolic rate in the amygdala predicts negative affect and depression severity in depressed patients: A FDG-PET Study.

Abercrombie, H.C., Schaefer, S.M., Larson, C.L., Ward, R.T., Holden, J.F., Turski, P.A., Perlman, S.B. & Davidson, R.J. (1996). Medial prefrontal and amygdalar glucose metabolism in depressed and control subjects: An FDG-PET study. *Psychophysiology*, *33*, S17.

Aggleton, J.P. (1993). The contribution of the amygdala to normal and abnormal emotional states. *Trends in Neuroscience*. *16*, 328–333.

Amaral, D.G., Price, J.L., Pitkanen, A., & Carmichael, S.T. (1992). Anatomical organization of the primate amygdaloid complex. In J.P. Aggleton (Ed.), *The amygdala: Neurobiological aspects of emotion, memory and mental dysfunction* (pp. 1–66). New York: Wiley-Liss.

Baxter, L.R., Schwartz, J.M., Phelps, M.E., Mazziota, J.C., Guze, B.H., Selin, C.E., Gerner, R.H., & Sumida, R.M. (1989). Reduction of prefrontal cortex glucose metabolism common to three types of depression. *Archives of General Psychiatry*, *46*, 243–252.

Bench, C.J., Friston, K.J., Brown, R.G., Frackowiak, R.S.J., & Dolan, R.J. (1993). Regional cerebral blood flow in depression measured by positron emission tomography: the relationship with clinical dimensions. *Psychological Medicine*, *23*, 579–590.

Bench, C.J., Friston, K.J., Brown, R.G., Scott, L.C., Frackowiak, S.J., & Dolan, R.J. (1992). The anatomy of melancholia-focal abnormalities of cerebral blood flow in major depression. *Psychological Medicine*, *22*, 607–615.

Carver, C.S., & White, T.L. (1994). Behavioral inhibition, behavioral activation and affective responses to impending reward and punishment: The BIS/BAS scales. *Journal of Personality and Social Psychology*, *67*, 319–333.

Davidson, R.J. (1992). Emotion and affective style: Hemispheric substrates. *Psychological Science*, *3*, 39–43.

Davidson, R.J. (1993). Cerebral asymmetry and emotion: Conceptual and methodological conundrums. *Cognition and Emotion*, *7*, 115–138.

Davidson, R.J. (1994). Asymmetric brain function, affective style and psychopathology: The role of early experience and plasticity. *Development and Psychopathology*, *6*, 741–758.

Davidson, R.J. (1995). Cerebral asymmetry, emotion and affective style. In R.J. Davidson & K. Hugdahl (Eds.), *Brain asymmetry* (pp. 361–387). Cambridge, MA: MIT Press.

Davidson, R.J., Chapman, J.P., Chapman, L.P., & Henriques, J.B. (1990). Asymmetrical brain electrical activity discriminates between psychometrically-matched verbal and spatial cognitive tasks. *Psychophysiology*, *27*, 528–543.

Davidson, R.J., Dolski, I., Laron, C., & Sutton, S.K. (in prep.). Electrophysiological measures of prefrontal asymmetry predict recovery of emotion-modulated startle.

Davidson, R.J., Ekman, P., Saron, C., Senulis, J., & Friesen, W.V. (1990a). Approach/withdrawal and cerebral asymmetry: Emotional expression and brain physiology: I. *Journal of Personality and Social Psychology*, *58*, 330–341.

Davidson, R.J., & Fox, N.A. (1989). Frontal brain asymmetry predicts infants' response to maternal separation. *Journal of Abnormal Psychology*, *98*, 127–131.

Davidson, R.J., Kalin, N.H., & Shelton, S.E. (1992). Lateralized effects of diazepam on frontal brain electrical asymmetries in rhesus monkeys. *Biological Psychiatry*, *32*, 438–451.

Davidson, R.J., Kalin, N.H., & Shelton, S.E. (1993). Lateralized response to diazepam predicts temperamental style in rhesus monkeys. *Behavioral Neuroscience*, *107*, 1106–1110.

Davidson, R.J., Marshall, J.R., Tomarken, A.J., & Henriques, J.B. (1997). While a phobic waits: Regional brain electrical and autonomic activity predict anxiety in social phobics during anticipation of public speaking. Submitted for publication.

Davidson, R.J., & Tomarken, A.J. (1989). Laterality and emotion: An electrophysiological approach. In F. Boller & J. Grafman (Eds.), *Handbook of neuropsychology*. Amsterdam: Elsevier.

Depue, R.A., & Collins, P.F. (in press). Neurobiology of the structure of personality: Dopamine, facilitation of incentive-reward motivation, and extraversion. *Behavioral and Brain Sciences*.

Derryberry, D., & Reed, M.A. (1996). Regulatory processes and the development of cognitive representations. *Development and Psychopathology*, *8*, 215–234.

Diener, V.E., & Emmons, R.A. (1984). The independence of positive and negative affect. *Journal of Personality and Social Psychology*, *47*, 1105–1117.

Drevets, W.C., Videen, T.O., MacLeod, A.K., Haller, J.W., & Raichle, M.E. (1992a). PET images of blood changes during anxiety: Correction. *Science*, *256*, 1696.

Drevets, W.C., Videen, T.O., Price, J.L., Preskorn, S.H., Carmichael, S.T., & Raichle, M.E. (1992b). A functional anatomical study of unipolar depression. *Journal of Neuroscience*, *12*, 3628–3641.

Farde, L., Gustavsson, J.P., & Jönsson, E. (1997). D2 dopamine receptors and personality. *Nature*, *385*, 590.

George, M.S., Ketter, T.A., Parekh, P.I., Horwitz, B., Hersovitch, P., & Post, R.M. (1995). Brain activity during transient sadness and happiness in healthy women. *American Journal of Psychiatry*, *152*, 341–351.

George, M.S., Ketter, K.A., & Post, R.M. (1994). Prefrontal cortex dysfunction in clinical depression. *Depression*, *2*, 59–72.

Gewirtz, J.C., Falls, W.A., & Davis, M. (1997). Normal conditioned inhibition and extinction of freezing and fear-potentiated startle following electrolytic lesions of medial prefrontal cortex in rats. *Behavioral Neuroscience*, *111*, 712–726.

Gold, P.W., Goodwin, F.K., & Chrousos, G.P. (1988). Clinical and biochemical manifestations of depression: Relation to the neurobiology of stress. *New England Journal of Medicine*, *314*, 348–353.

Gray, J.A. (1994). Three fundamental emotion systems. In P. Ekman & R.J. Davidson (Eds.), *The nature of emotion: Fundamental questions* (pp. 243–247). New York: Oxford University Press.

Gross, J.J., Sutton, S.K., & Ketelaar, T.V. (in press). Relations between affect and personality: Support for the affect-level and affective-reactivity views. *Personality and Social Psychology Bulletin*.

Henriksen, S.J., & Giacchino, J. (1993). Functional characteristics of nucleus accumbens neurons: Evidence obtained from *in vivo* electrophysiological recordings. In P.W. Kalivas

& Barnes, C.D. (Eds.), *Limbic motor circuits and neuropsychiatry* (pp. 101–124). Boca Raton, FL: CRC Press.

Henriques, J.B., & Davidson, R.J. (1990). Regional brain electrical asymmetries discriminate between previously depressed and healthy control subjects. *Journal of Abnormal Psychology*, *99*, 22–31.

Henriques, J.B., & Davidson, R.J. (1991). Left frontal hypoactivation in depression. *Journal of Abnormal Psychology*, *100*, 535–545.

Henriques, J.B., Glowacki, J.M., & Davidson, R.J. (1994). Reward fails to alter response bias in depression. *Journal of Abnormal Psychology*, *103*, 460–466.

Irwin, W., Davidson, R.J., Lowe, M.J., Mock, B.J., Sorenson, J.A., & Turski, P.A. (1996). Human amygdala activation detected with echo-planar functional magnetic resonance imaging. *NeuroReport*, *7*, 1765–1769.

Kagan, J., Reznick, J.S., & Snidman, N. (1988). Biological bases of childhood shyness. *Science*, *240*, 167–171.

Kalin, N.H. (1993). The neurobiology of fear. *Scientific American*, *268*, 94–101.

Kalin, N.H., Larson, C., Shelton, S.E., & Davidson, R.J. (in press). Asymmetric frontal brain activity, cortisol, and behaviour associated with fearful temperament in Rhesus monkeys. *Behavioral Neuroscience*.

Kalivas, P.W., Churchill, L., & Klitenick, M.A. (1993). The circuitry mediating the translation of motivational stimuli into adaptive motor responses. In P.W. Kalivas & Barnes, C.D. (Eds.), *Limbic motor circuits and neuropsychiatry* (pp. 237–287). Boca Raton, FL: CRC Press.

Kang, D.H., Davidson, R.J., Coe, C.L., Wheeler, R.W., Tomarken, A.J., & Ershler, W.B. (1991). Frontal brain asymmetry and immune function. *Behavioral Neuroscience*, *105*, 860–869.

Ketter, T.A., Andreason, P.J., George, M.S., Lee, C., Gill, D.S., Parekh, P.I., Willis, M.W., Herscovitch, P., & Post, R.M. (1996). Anterior paralimbic mediation of procaine-induced emotional and psychosensory experiences. *Archives of General Psychiatry*, *53*, 59–69.

Kiecolt-Glaser, J.K., & Glaser, R. (1991). Stress and immune function in humans. In R. Ader, D.L. Felten, & N. Cohen (Eds.), *Psychoneuroimmunology* (2nd ed.) (pp. 849–868). San Diego, CA: Academic Press.

Knight, R.T. (1991). Evoked potential studies of attention capacity in human frontal lobe lesions. In H.S. Levin, H.M. Eisenberg, & A.L. Benton (Eds.), *Frontal lobe function and dysfunction* (pp. 139–153). New York: Oxford University Press.

Lang, P.J., Bradley, M.M., & Cuthbert, B.N. (1990). Emotion, attention and the startle reflex. *Psychological Review*, *97*, 377–398.

Lang, P.J., Bradley, M., & Cuthbert, B. (1995). *International Affective Picture System: Technical manual and affective ratings*. Gainesville FL: Center for Research in Psychophysiology, University of Florida.

Lazarus, R.S. (1991). *Emotion and adaptation*. Oxford, UK: Oxford University Press.

LeDoux, J.E. (1987). Emotion. In V.B. Mountcastle (Ed.), *Handbook of physiology, Section 1: The nervous system: Vol. V. Higher functions of the brain* (pp. 419–459). Bethesda, MD: American Physiological Society.

LeDoux, J.E. (1992). Emotion and the amygdala. In J.P. Aggleton (Ed.), *The amygdala: Neurobiological aspects of emotion, memory and mental dysfunction* (pp. 339–351). New York: Wiley-Liss.

Martinot, J.L., Hardy P., Feline, A., Huret, J.D., Mazoyer, B., Attar-Levy, D., Pappata, S., & Syrota, A. (1990). Left frontal glucose hypometabolism in the depressed state: A confirmation. *American Journal of Psychiatry*, *147*, 1313–1317.

Meehl, P.E. (1975). Hedonic capacity: Some conjectures. *Bulletin of the Menninger Clinic*, *39*, 295–307.

Morgan, M.A., Romanski, L., & LeDoux, J.E. (1993). Extinction of emotional learning: Contribution of medial prefrontal cortex. *Neuroscience Letters*, *163*, 109–113.

Paradiso, S., Robinson, R.G., Andreason, N.C., Downhill, J.E., Davidson, R.J., Kirchner, P.T., Watkins, G.L., Boles, L.L., & Hichwa, R.D. (1997). Emotional activation of limbic circuitry in elderly and normal subjects in a PET study. *American Journal of Psychiatry*, *154*, 382–389.

Posner, M.I., & Petersen, S.E. (1990). The attention system of the human brain. *Annual Review of Neuroscience*, *13*, 25–42.

Reiman, E.M., Fusselman, M.J.L., Fox, B.J., & Raichle, M.E. (1989). Neuroanatomical correlates of anticipatory anxiety. *Science*, *243*, 1071–1074.

Robinson, R.G., & Downhill, J.E. (1995). Lateralization of psychopathology in response to focal brain injury. In R.J. Davidson & K. Hugdahl (Eds.), *Brain asymmetry* (pp. 693–711). Cambridge, MA: MIT Press.

Robinson, R.G., Kubos, K.L., Starr, L.B., Rao, K., & Price, T.R. (1984). Mood disorders in stroke patients: Importance of location of lesion. *Brain*, *107*, 81–93.

Russell, J.A. (1980). A circumplex model of emotion. *Journal of Personality and Social Psychology*, *39*, 1161–1178.

Ryff, C.D., & Singer, B. (in press). The contours of positive human health. *Psychological Inquiry*.

Schneider, F., Gur, R.E., Mozley, L.H., Smith, R.J., Mozley, P.D., Censitis, D.M., Alavi, A., & Gur, R.C. (1995). Mood effects on limbic blood flow correlate with emotional self-rating: A PET study with oxygen-15 labeled water. *Psychiatric Research: Neuroimaging*, *61*, 265–283.

Schultz, W., Apicella, P., Romo, R., & Scarnati, E. (1995a). Context-dependent activity in primate striatum reflecting past and future behavioral events. In J.C. Houk, J.L. Davis, & Beiser, D.G. (Eds.), *Models of information processing in the basal ganglia* (pp. 11–28). Cambridge, MA: MIT Press.

Schultz, W., Romo, R., Ljungberg, T., Mirenowicz, J., Hollerman, J.R., & Dickinson, A. (1995b). Reward-related signals carried by dopamine neurons. In J.C. Houk, J.L. Davis, & Beiser, D.G. (Eds.), *Models of information processing in the basal ganglia* (pp. 233–248). Cambridge, MA: MIT Press.

Smith, O.A., DeVito, J.L., & Astley, C.A. (1990). Neurons controlling cardiovascular responses to emotion are located in lateral hypothalamus-perifornical region. *American Journal of Physiology*, *259*, R943–R954.

Stein, N.L., & Trabasso, T. (1992). The organization of emotional experience: Creating links among emotion, thinking, language and intentional action. *Cognition and Emotion*, *6*, 225–244.

Sutton, S.K., & Davidson, R.J. (1997). Prefrontal brain asymmetry: A biological substrate of the behavioral approach and inhibition systems. *Psychological Science*, *8*, 204–210.

Sutton, S.K., Davidson, R.J., Donzella, B., Irwin, W., & Dottl, D.A. (1997). Manipulating affective state using extended picture presentation. *Psychophysiology*, *34*, 217–226.

Thompson, R.A. (1994). Emotion regulation: A theme in search of definition. In N.A. Fox (Ed.), *The development of emotion regulation: Biological and behavioral aspects. Monographs of the Society for Research in Child Development*, *59*, (Serial No. 240), 25–52.

Thorpe, S., Rolls, E., & Maddison, S. (1983). The orbitofrontal cortex: Neuronal activity in the behaving monkey. *Experimental Brain Research*, *49*, 93–113.

Tomarken, A.J., Davidson, R.J., Wheeler, R.E., & Doss, R.C. (1992). Individual differences

in anterior brain asymmetry and fundamental dimensions of emotion. *Journal of Personality and Social Psychology*, *62*, 676–687.

Watson, D., Clark, L.A., Weber, K., Assenheimer, J.S., Strauss, M.E., & McCormick, R.A. (1995). Testing a tripartite model: I. Evaluating the convergent and discriminant validity of anxiety and depression symptom scales. *Journal of Abnormal Psychology*, *104*, 3–14.

Watson, D., Clark, L.A., & Tellegen, A. (1988). Developmental and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology*, *54*, 1063–1070.

Watson, D., & Tellegen, A. (1985). Toward a consensual structure of mood. *Psychological Bulletin*, *98*, 219–235.

Wheeler, R.E., Davidson, R.J., & Tomarken, A.J. (1993). Frontal brain asymmetry and emotional reactivity: A biological substrate of affective style. *Psychophysiology*, *30*, 82–89.

Woods, R.P., Mazziotta, J.C., & Cherry, S.R. (1993). MRI-PET registration with automated algorithm. *Journal of Computer Assisted Tomography*, *17*, 536–546.