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Well-being and affective style: neural substrates and biobehavioural correlates

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One of the most salient features of emotion is the pronounced variability among individuals in their reactions to emotional incentives and in their dispositional mood. Collectively, these individual differences have been described as affective style. Recent research has begun to dissect the constituents of affective style. The search for these components is guided by the neural systems that instantiate emotion and emotion regulation. In this article, this body of research and theory is applied specifically to positive affect and well-being. The central substrates and peripheral biological correlates of well-being are described. A resilient affective style is associated with high levels of left prefrontal activation, effective modulation of activation in the amygdala and fast recovery in response to negative and stressful events. In peripheral biology, these central patterns are associated with lower levels of basal cortisol and with higher levels of antibody titres to influenza vaccine. The article concludes with a consideration of whether these patterns of central and peripheral biology can be modified by training and shifted toward a more salubrious direction.

Keywords: affective neuroscience; resilience; prefrontal cortex; brain asymmetry; emotion regulation; affective style

1. INTRODUCTION

One of the most salient characteristics of emotion is the extraordinary heterogeneity in how different individuals respond to the same emotionally provocative challenge. Such differences in patterns of emotional reactivity play a crucial role in shaping variations in well-being. Although individual differences in emotion processing can be found at many levels of phylogeny, they are particularly pronounced in primates and probably are most extreme in humans. A number of evolutionary theorists have speculated on the adaptive significance of such individual differences (Wilson 1994). Although these arguments have never been applied to the domain of emotion and affective style, it is not difficult to develop hypotheses about how such differences might provide advantages to individuals living in groups. However, rather than focus on the distal causes of such individual differences which are so difficult to subject to rigorous test, I wish only to call attention to the possibility that variability in characteristics such as 'fearfulness' or 'cheerfulness' might provide some adaptive benefit to individuals living together in groups. Instead, this article examines the proximal mechanisms that underlie such individual differences, with a focus on well-being. The central substrates of individual differences in components of well-being will be described. The possible influence of the central circuitry of emotion on peripheral biological indices that are relevant to physical health and illness will also be considered. It is helpful to contrast well-being with specific types of psychopathology that involve dysfunctions in the circuitry of adaptive emotional responding. Accordingly, some mention of recent work on the neurobiology of mood and anxiety disorders will be made. Finally, plasticity in the underlying brain circuitry that instantiates affective style will be described and its role in promoting resilience will be considered.

Affective style refers to consistent individual differences in emotional reactivity and regulation (see Davidson 1998*a*; Davidson *et al.* 2000*a*,*b*). It is a phrase that is meant to capture a broad array of processes that, either singly or in combination, modulate an individual's response to emotional challenges, dispositional mood and affect-relevant cognitive processes. Affective style can refer to valence-specific features of emotional reactivity or mood, or it can refer to discrete emotion-specific features. Both levels of analysis are equally valid and the choice of level should be dictated by the question posed.

Rapid developments in our understanding of emotion, mood and affective style have come from the study of the neural substrates of these phenomena. The identification of the brain circuitry responsible for different aspects of affective processing has helped to parse the domain of emotion into more elementary constituents in a manner similar to that found in cognitive neuroscience, where an appeal to the brain has facilitated the rapid development of theory and data on the subcomponents of various cognitive processes (e.g. Kosslyn & Koenig 1992).

This article will highlight some of the advances that have been made in our understanding of the brain mechanisms that underlie affective style. These advances have emerged from three major sources: studies of patients with discrete lesions of the brain; neuroimaging studies of normal indivi-

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duals; and studies of pathologies of brain function in patients with various psychiatric and neurological disorders that involve abnormalities in emotion. I will use the material on pathology to help to identify the neural circuitry crucial to certain forms of positive affect so that we can begin to place well-being squarely within a neurobiological framework.

Both lesion and neuroimaging studies provide information primarily on the 'where' question; that is, where in the brain are computations related to specific aspects of affective processing occurring. It is important at the outset to consider both the utility of knowing 'where' and how such information can provide insight into the 'how' question; that is, how might a particular part of the brain instantiate a specific process that is essential to affective style. The brain sciences are now replete with information on the essential nature of specific types of information processing in different regions of the brain. For example, there is evidence to suggest that the DLPFC is important for maintaining a representation of information online in the absence of immediate cues. The neurophysiological basis of this type of information processing has been actively studied in the animal laboratory (e.g. Goldman-Rakic 1996, 2000). If this region of the brain is activated at certain times in the stream of affective information processing, we can develop hypotheses on the basis of extant work about what this territory of PFC might be doing during the affective behaviour and how it might be doing it. A related consideration is the network of anatomical connectivity to and from a particular brain region. From a consideration of connectivity, insights may be gleaned as to how a particular brain region might react during a particular form of emotional processing. For example, we know that regions of the amygdala have extensive connectivity with cortical territories that can become activated following activation of the amygdala. In this way, the amygdala can issue a cortical call for further processing in response to potentially threatening stimuli, which must be processed further to assess danger. Other regions of the amygdala have extensive connections to limbic and brainstem circuits that can modulate behavioural and autonomic outflow. Adjustments in autonomic responses and action tendencies are typical components of emotion.

2. CONCEPTUAL AND METHODOLOGICAL CONSIDERATIONS IN THE STUDY OF AFFECTIVE STYLE

Current research on well-being is based largely on the use of self-report measures to make inferences about variation among individuals in type and magnitude of well-being. One important component of neurobiological research on well-being is to begin to dissect well-being into more specific constituents that may underlie the coarse phenomenological descriptions provided by subjects. In addition, research on the neural correlates of well-being may provide an independent biological measure sensitive to variations in well-being that are not subject to the kinds of reporting and judgemental biases commonly found in the self-report measures. For example, researchers have found that questions that precede items asking about well-being can influence a subject's report of well-being. Variations in the weather can similarly affect such reports. These examples illustrate the fact that when subjects are queried about global well-being, they frequently use convenient heuristics to answer such questions and typically do not engage in a systematic integration of utility values over time. It may be that certain parameters of brain function are better repositories of the cumulative experiences that inevitably shape well-being. At the present point in the development of this science, these are mere speculations in search of evidence but the time is ripe for such evidence to be gathered.

The status of research on well-being is now at a point occupied about a decade ago or more by research on mood and anxiety disorders, though it continues to suffer from some of the same problems. Mood and anxiety disorders are generally conceptualized as being caused, or at least accompanied by, dysfunctions of emotion. However, what specific affective process is dysfunctional is rarely, if ever, delineated, and nosological schemes for categorizing these disorders do not rely upon the specific nature of the affective dysfunction in question, but rather are based upon phenomenological description. Research in my laboratory over the past 15 years has been predicated on the view that more meaningful and rapid progress in understanding the brain bases of mood and anxiety disorders can be achieved if we move to an intermediate level of description that penetrates below the categorical, phenomenologically based classifications of the diagnostic and statistical manual (DSM) and seeks to characterize the specific nature of the affective styles that are associated with vulnerability to these forms of psychopathology.

Many of the parameters of affective style, such as the threshold to respond, magnitude of response, latency to peak of response and recovery function, are features that are often opaque to conscious report, though they may influence the subjective experience of emotion. These parameters of responding can be measured in many different response systems including both central and peripheral systems. For example, magnitude of response can be measured in a peripheral measure such as the emotion-modulated startle (Lang 1995) or in a central measure such as activation in the amygdala assessed with fMRI. The extent to which coherence across response systems in these parameters is present has not yet been systematically addressed. In previous work, we have argued that variations in some of these parameters in particular response systems are especially relevant to vulnerability to mood, anxiety and other disorders and also to resilience (e.g. Davidson 2000*a*,*b*). One of the important developments in emotion research in general, and in affective neuroscience in particular, is the capacity to objectively measure these parameters of responding. For example, in several studies we have used the emotion-modulated startle to capture the time-course of valence-specific emotion responding (Larson *et al.* 1998; Jackson *et al.* 2000). The startle reflex is controlled by a brainstem circuit that is influenced by activity in forebrain structures. Davis (1992) elegantly dissected the circuitry through which the magnitude of this reflex is modulated during the arousal of fear in rodents. He demonstrated that it is via a descending pathway from the central nucleus of the amygdala to the nucleus pontine reticularis in the brainstem that the magnitude of startle is enhanced in response to a conditioned fear cue. Lesions of the central nucleus of the amygdala abolish the fear potentiation of the startle but do not affect the magnitude

of the baseline startle. Lang and his colleagues (Vrana *et al.* 1988) were the first to show systematically that in humans, the same basic phenomenon can be produced. They took advantage of the fact that brief acoustic noise bursts produce the eyeblink component of the startle and little else, thus enabling their presentation as innocuous stimuli in the background. By measuring electromyographic activity from the orbicularis oculi muscle with two miniature electrodes under one eye, they were able to quantify the strength of the blink response and show that the magnitude of the blink was greater when subjects were presented with unpleasant pictures in the foreground, compared with the presentation of neutral pictures. Moreover, when subjects were exposed to positive stimuli, the magnitude of startle was actually attenuated relative to a neutral condition (Vrana *et al.* 1988). This same basic effect has now been reported with many different types of foreground stimuli in several modalities (see Lang (1995) for a review).

We have exploited the emotion-modulated startle to begin to characterize the time-course of affective responding, or what I have referred to as affective chronometry (Davidson 1998*a*). By inserting acoustic noise probes at different latencies before and after a critical emotional stimulus is presented, both the anticipatory limb and the recovery limb of the response can be measured. By using paradigms in the MRI scanner that were first studied in the psychophysiology laboratory, the neural circuitry underlying the different phases of affective processing can be interrogated with fMRI. Our current work in this area has emphasized the importance of the recovery function following negative events for vulnerability to certain forms of psychopathology as well as for resilience. We have argued that the failure to recover rapidly following a negative event can be a crucial ingredient of vulnerability to both anxiety and mood disorders, particularly when such a style is combined with frequent exposure to negative events over a sustained period of time. The failure to recover adequately would result in sustained elevations in multiple systems that are activated in response to negative events. By contrast, the capacity for rapid recovery following negative events may define an important ingredient of resilience. We have defined resilience as the maintenance of high levels of positive affect and well-being in the face of significant adversity. It is not that resilient individuals never experience negative affect, but rather that the negative affect does not persist. Such individuals are able to profit from the information provided by the negative affect and their capacity for 'meaning making' in response to such events may be part and parcel of their ability to show rapid decrements in various biological systems following exposure to a negative or stressful event (see Giese-Davis & Spiegel 2003).

3. NEURAL SUBSTRATES OF EMOTION AND AFFECTIVE STYLE

In the following three sections, a brief overview is provided of core components of the circuitry that instantiates some important aspects of emotion and affective style, with an emphasis on PFC and the amygdala. It is not meant to be an exhaustive review, but rather will present selected highlights to illustrate some of the key advances that have been made in the recent past.

Emotion and affective style are governed by a circuit that includes the following structures, and probably also others: DLPFC, vmPFC, OFC, amygdala, hippocampus, ACC and insular cortex. It is argued that different subprocesses are instantiated in each of these structures, and that they normally work together to process, generate and regulate emotional information and emotional behaviour.

4. PREFRONTAL CORTEX

A large corpus of data at both the animal and human levels implicate various sectors of the PFC in emotion. The PFC is not a homogeneous zone of tissue but, rather, has been differentiated on the basis of both cytoarchitectonic and functional considerations. The three subdivisions of the primate PFC that have been consistently distinguished include the DLPFC, vmPFC and OFC. In addition, there appear to be important functional differences between the left and right sides within some of these sectors.

The case for the differential importance of left and right PFC sectors for emotional processing was first made systematically in a series of studies on patients with unilateral cortical damage (Gainotti 1972; Sackeim *et al.* 1982; Robinson *et al.* 1984). Each of these studies compared the mood of patients with unilateral left- or right-sided brain damage and found a greater incidence of depressive symptoms following left-sided damage. In most cases, the damage was fairly substantial, and probably included more than one sector of PFC and often also included other brain regions. The general interpretation that has been placed upon these studies is that depressive symptoms are increased following left-sided anterior PFC damage because this brain territory participates in certain forms of positive affect and when damaged leads to deficits in the capacity to experience positive affect, a hallmark feature of depression (Watson *et al.* 1995). It should be noted that not all studies support this conclusion. In a recent meta-analysis of lesion studies, Carson *et al.* (2000) failed to find support for this hypothesis. Davidson (1993) has previously reviewed many of these studies and has addressed a number of critical methodological and conceptual concerns in this literature. The most important of these issues is that according to the diathesis-stress model of anterior activation asymmetry proposed by Davidson (1995, 1998*b*) and colleagues (Henriques & Davidson 1991), individual differences in anterior activation asymmetry, whether lesion-induced or functional, represent a diathesis. As such, they alter the probability that specific forms of emotional reactions will occur in response to the requisite environmental challenge. In the absence of such a challenge, the pattern of asymmetric activation will simply reflect a propensity but will not necessarily culminate in differences in mood or symptoms. In a study with the largest sample size to date ($n = 193$) for a study of mood sequelae in patients with unilateral lesions, Morris *et al.* (1996) found that among stroke patients, it was only in those with small lesions that the relation between left PFC damage and depressive symptoms was observed. It is likely that larger lesions intrude on other brain territories and mask the relation between left PFC damage and depression.

A growing corpus of evidence in normal intact humans is consistent with the findings derived from the lesion evi-