Anger: A review of human electrophysiology and functional neuroimaging research

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Evidence from a variety of research approaches has pointed to the importance of asymmetrical frontal cortical activity in emotional/motivational processes. Much of this evidence has been obtained with electroencephalographic (EEG) measures of brain activity, or more specifically, alpha frequency band activity derived from the EEG. Research has revealed that alpha power is inversely related to regional brain activity using hemodynamic measures (Cook, O’Hara, Uijtdehaage, Mandelkern, & Leuchter, 1998) and behavioral tasks (Davidson, Chapman, Chapman, & Henriques, 1990). Additional data from individuals with brain damage supports the research with EEG (e.g., Robinson & Downhill, 1995).

In the EEG research, depression has been found to relate to resting frontal asymmetrical activity, with depressed individuals showing relatively less left than right frontal brain activity (Jacobs & Snyder, 1996; Schaffer, Davidson, & Saron, 1983). Moreover, relatively less left frontal activity has been found in individuals who were previously clinically depressed but were in remission status (Henriques & Davidson, 1990).

Other research has revealed that trait positive affect is associated with greater left than right frontal brain activity, whereas trait negative affect is associated with greater right than left frontal brain activity (e.g., Tomarken, Davidson, Wheeler, & Doss, 1992). Still other research has found that trait behavioral activation sensitivity (BAS) relates to greater left than right frontal brain activity (Harmon-Jones & Allen, 1997; Sutton & Davidson, 1997).
In addition to the research that suggests that resting baseline frontal asymmetrical activity relates to other measures of trait emotion and motivation, research has found that resting baseline frontal asymmetrical activity predicts emotional responses. For example, individuals with relatively greater right than left frontal activity during baseline recording sessions report larger negative affective responses to negative emotion-inducing films (fear and disgust) and smaller positive affective responses to positive emotion-inducing films (happiness) (Tomarken, Davidson, & Henriques, 1990; Wheeler, Davidson, & Tomarken, 1993). Moreover, relative right frontal activity at baseline predicts crying in response to maternal separation in 10-month-old infants (Davidson & Fox, 1989).

Research has also demonstrated that asymmetrical frontal brain activity is associated with state emotional responses. For instance, Davidson and Fox (1982) found that 10-month-old infants exhibited increased left frontal activation in response to a film clip of an actress generating a happy facial expression as compared to a sad facial expression. Frontal brain activity has been found to relate to facial expressions of positive and negative emotions, as well. For example, Ekman and Davidson (1993) found increased left frontal activation during voluntary facial expressions of smiles of enjoyment. More recently, Coan, Allen, and Harmon-Jones (2001) found that voluntary facial expressions of fear produced relatively less left frontal activity.

Finally, biofeedback training has been used to manipulate asymmetrical frontal cortical activity and the effects of this manipulation on emotional responses have been observed (Allen, Harmon-Jones, & Cavender, 2001). These results suggest that the frontal asymmetry can be altered using biofeedback training and that this alteration can affect emotional responses, with an increase in left frontal cortical activity causing more
happy emotional facial expressions and an increase in relative right frontal cortical 
activity causing more sad emotional facial expressions. Taken together, this research 
suggests that asymmetrical frontal cortical activity is causally involved in emotional 
responses (for a more detailed review, see Coan & Allen, 2003).

Explanations of the Relationship between Asymmetrical Frontal Activity and 
Emotion/Motivation

All of this past evidence can be summarized within one of three theoretical 
models. According to the valence model, the left frontal brain region is involved in the 
experience and expression of positive emotion and the right frontal brain region is 
involved in the expression and experience of negative emotion (e.g., Ahern & Schwartz, 
1985; Gotlib, Ranganath, & Rosenfeld, 1998; Heller, 1990; Heller & Nitschke, 1998; 
Silberman & Weingartner, 1986). Indeed, research is consistent with this model and it is 
widely accepted (e.g., Oatley & Jenkins, 1996; Zajonc & McIntosh, 1992).

According to the motivational direction model, the left frontal brain region is 
involved in expression of approach-related emotions and the right frontal brain region is 
involved in expression withdrawal-related emotions (Fox, 1991; Harmon-Jones & Allen, 
1997; Sutton & Davidson, 1997). Again, the obtained results can be accommodated by 
this model. That is, the affects and emotions that have been examined in the research are 
also associated with approach or withdrawal motivation. The approach-related emotions 
have been found to be associated with relatively greater left frontal activity, whereas the 
withdrawal-related emotions have been found to be associated with relatively greater 
right frontal activity.
According to the valenced motivation model, the left frontal brain region is involved in the expression and experience of positive, approach-related emotions and the right frontal brain region is involved in the expression and experience of negative, withdrawal-related emotions (Davidson, 1998; Tomarken & Keener, 1998). The obtained results can also be accommodated by this model. That is, the positive affects that have been examined in the research are all associated with approach motivation, and the negative affects that have been examined are all associated with withdrawal motivation.

Because the previously conducted research confounded the valence of the emotion with the direction of motivation, it had been unable to address whether the frontal asymmetry reflects the valence of the emotion, the direction of the motivation, or a combination of valence and motivation. Often, positive emotion is associated with approach-related motivation, whereas negative emotion is associated with withdrawal-related motivation. Indeed, most contemporary theories of emotion posit that positive emotion is always associated with approach motivation and that negative emotion is always associated with negative emotion (Gray, 1994a, 1994b; Watson, 2000; for a different point of view, see Carver, 2001). However, not all emotions behave in accord with this assumed relationship between the valence of emotion and direction of motivation. Anger is one of the best examples of a violation of the relationship, because anger is negative in valence (e.g., Lazarus, 1991; Watson, 2000), but it often evokes approach motivation (e.g., Berkowitz, 1999; Darwin, 1872/1965; Plutchik, 1980; Young, 1943).

In addressing the exact emotional/motivation functions of asymmetrical frontal brain activity, my colleagues and I have examined the emotion of anger, as it is a
negative emotion that often evokes approach motivational tendencies. In support of the motivational direction model over the other two models, recent evidence has suggested that anger and aggression may be associated with greater left than right frontal cortical activity. In this chapter, I will review the evidence supportive of such a relationship. Then, I will briefly consider evidence, seemingly inconsistent with the aforementioned research, that suggests that aggression is associated with decreased frontal cortical activity. In the end, I will offer some resolutions to these apparent discrepancies and suggest some further empirical tests of the relationship between anger, aggression, and frontal cortical activity.

Anger and Approach Motivation

Before reviewing the research on anger and asymmetrical frontal activity, it is important to consider whether anger is associated with approach motivation. Several lines of research suggest that anger elicits behavioral approach or approach motivation tendencies.

Behavioral Evidence

In the animal behavior literature, a distinction has been made between offensive or irritable aggression and defensive aggression (Flynn, Vanegas, Foote, & Edwards, 1970; Moyer, 1976). It has been posited that irritable aggression results from anger and that pure irritable aggression “involves attack without attempts to escape from the object being attacked” (Moyer, 1976, p. 187). A number of aggression researchers have suggested that offensive aggression is associated with anger, attack, and no attempts to escape, whereas defensive aggression is associated with fear, attempts to escape, and attack only if escape is impossible (Blanchard & Blanchard, 1984; Lagerspetz, 1969;
Moyer, 1976). In demonstrating that organisms evidence offensive aggression and that this is an approach behavior, Lagerspetz (1969) found that under certain conditions mice would cross an electrified grid to attack another mouse.

With adult humans, Baron (1977) demonstrated that signs of their tormentor’s pain reinforce angry persons positively. The participants who had been deliberately provoked by another individual then had a sanctioned opportunity to assault him. Indications that their first attacks were hurting their target led to intensified aggression even though the unprovoked participants reduced the intensity of their punishment at learning of the other’s pain. The initial signs of their victim’s suffering showed the angry persons they were approaching their aggressive goal and evoked even stronger assaults from them (see also, Berkowitz, Cochran, & Embree, 1981).

Subsequent to frustrating events, anger may maintain and increase task engagement and approach motivation. Lewis, Sullivan, Ramsay, and Alessandri (1992) found that infants who expressed anger during extinction maintained interest during subsequent relearning, whereas infants who expressed sadness during extinction evidenced decreased interest during relearning.

**Subjective Evidence**

Additional support for the idea that anger is associated with approach motivation comes from research testing the conceptual model that integrated reactance theory with learned helplessness theory (Wortman & Brehm, 1975). According to this model, how individuals respond to uncontrollable outcomes depends on their expectation of being able to control the outcome and the importance of the outcome. When an individual expects to be able to control outcomes that are important, and those outcomes are found
to be uncontrollable, psychological reactance should be aroused. Thus, for individuals who initially expect control, the first few bouts of uncontrollable outcomes should arouse reactance, a motivational state aimed at restoring control. After several exposures to uncontrollable outcomes, these individuals should become convinced that they cannot control the outcomes and should show decreased motivation (i.e., learned helplessness). In other words, reactance will precede helplessness for individuals who initially expect control. In one study testing this model, individuals who exhibited angry feelings (a manifestation of reactance) in response to one unsolvable problem had better performance and more approach motivation on a subsequent cognitive task than did participants who exhibited less anger (Mikulincer, 1988).

Other research has revealed that state anger relates to high levels of self-assurance, physical strength, and bravery (Izard, 1991), inclinations associated with approach motivation. Additionally, Lerner and Keltner (2001) found that anger (both trait and state) is associated with optimistic expectations, whereas fear is associated with pessimistic expectations. Moreover, happiness was associated with optimism, making anger and happiness appear more similar to each other in their relationship with optimism than fear and anger. Although Lerner and Keltner (2001) interpreted their findings as being due to the appraisals associated with anger, it seems equally plausible that it was the approach motivational character of anger that caused the relationship of anger and optimism. That is, anger creates optimism because anger engages the approach motivational system and produces greater optimistic expectations.

*Hormonal and Physiological Evidence*
Further evidence supporting the conceptualization of anger as involving approach and not withdrawal comes from research on testosterone, which has been found to be associated with anger and aggression in humans (e.g., Olweus, 1986). In this research, testosterone treatments have been found to decrease withdrawal (fear) responses in a number of species (e.g., Boissy & Bouissou, 1994; Vandenheede & Bouissou, 1993). Other research has demonstrated that damage to the amygdala, a brain region involved in defensive behavior, has no effect on offensive aggression but reduces reactivity to nonpainful threat stimuli (Blanchard & Takahashi, 1988; Busch & Barfield, 1974).

**Individual Differences Evidence**

Other evidence supporting the idea that anger is associated with an approach-orientation comes from research on bipolar disorder. The emotions of euphoria and anger often occur during manic phases of bipolar disorder (Cassidy, Forest, Murry, & Carroll, 1998; Depue & Iacono, 1989; Tyrer & Shopsin, 1982). Both euphoria and anger may be approach-oriented processes, and a dysregulated or hyperactive approach system may underlie mania (Depue & Iacono, 1989; Fowles, 1993). Research suggests that hypomania/mania involves increased left frontal brain activity and approach motivational tendencies. In this research, it has been found that individuals who have suffered damage to the right frontal cortex are more likely to evidence mania (see review by Robinson & Downhill, 1995). Thus, this research is consistent with the view that mania may be associated with increased left frontal activity and increased approach tendencies, because the approach motivation functions of the left frontal cortex are released and not restrained by the withdrawal system in the right frontal cortex. Furthermore, lithium carbonate, a treatment for bipolar disorder, reduces aggression (Malone, Delaney, Luebbert, Cater, &
Anger, as measured by the Buss and Perry (1992) anger subscale, has been found to relate to trait BAS, as measured by Carver and White’s (1994) questionnaire (Harmon-Jones, in press-a).

While individuals with relatively low left frontal activation are at risk for deficits in approach motivation and depression, those with relatively high left frontal activation may evidence excessive approach motivation, leading to increased anger and aggression.

**Asymmetrical Frontal Activity and Trait Anger**

In all past research on the frontal asymmetry, the valence of the affective style (positive vs. negative) was confounded with the direction of the motivation (approach vs. withdrawal). Consequently, scientists have concluded that the frontal asymmetry reflects differences in emotional valence (e.g., Ahern & Schwartz, 1985; Gotlib, Ranganath, & Rosenfeld, 1998; Heller, 1990; Heller & Nitschke, 1998). To address this confound, Harmon-Jones and Allen (1998) assessed the relationship between resting frontal asymmetrical activity and anger, an emotion that is negatively valenced but approach-related. Results indicated that trait anger related to increased left frontal activity and decreased right frontal activity.

More recently, Harmon-Jones (in press-b) addressed an alternative explanation for the results of Harmon-Jones and Allen (1998). The alternative explanation suggested that persons with high levels of trait anger might experience anger as a positive emotion, and this positive feeling or attitude toward anger could be responsible for anger being associated with relative left frontal activity. Anger might have been regarded positively
because of the subjective feel or evaluation of the emotion. After conducting three studies that developed a valid and reliable assessment of attitude toward anger, a study was conducted to assess whether resting baseline asymmetrical activity related to trait anger and attitude toward anger. Results indicated that anger related to relative left frontal activity and not attitude toward anger. Moreover, further analyses revealed that the relationship between trait anger and left frontal activity was not due to anger being associated with a positive attitude toward anger.

**Asymmetrical Frontal Activity and State Anger**

Although the Harmon-Jones and Allen (1998) and the Harmon-Jones (in press-b) studies suggest that anger is related to relative left frontal activity, both studies are correlational and subject to the interpretational limitations associated with correlational studies (e.g., a third variable causes the observed relationship). To address these limitations, experiments have been conducted in which anger is manipulated and its effects on regional brain activity are examined.

*State Anger Induced via Interpersonal Insult and Asymmetrical Frontal Activity*

Harmon-Jones and Sigelman (2001) conducted an experiment to assess whether situationally induced anger would increase relative left frontal activity. Participants were randomly assigned to a condition in which another person insulted them or to a condition in which another person treated them in a neutral manner. Immediately following the treatment, EEG was collected. As predicted, individuals who were insulted evidenced greater relative left frontal activity than individuals who were not insulted. Additional analyses revealed that within the insult condition, reported anger and aggression were positively correlated with relative left frontal activity. Neither of these correlations was
significant in the no-insult condition. These results suggest that relative left-frontal activation was associated with more anger and aggression in the condition in which anger was evoked. This research thus provides the first demonstration of a relationship between state anger and relative left frontal activation, a result predicted by models that posit that the frontal asymmetry reflects motivational direction but not predicted by models that posit that the frontal asymmetry reflects emotional valence.

*The Effect of Coping Potential on Anger-Related Left Frontal Cortical Activity*

In the experiments reviewed thus far, it was assumed that anger related to left frontal cortical activity because anger was associated with approach motivation. In Harmon-Jones and Sigelman (2001), the experiment was designed in a manner to evoke anger that was approach oriented. Although most instances of anger involve approach inclinations, not all forms of anger are associated with approach motivation. To manipulate approach motivation independently of anger, Harmon-Jones, Sigelman, Bohlig, and Harmon-Jones (2003) performed an experiment in which the ability to cope with the anger-producing event was manipulated. Based on past research that has revealed that coping potential affects motivational intensity (Brehm & Self, 1996), it was predicted that the expectation of being able to take action to resolve the anger-producing event would increase approach motivational intensity relative to expecting to be unable to take action.

In the experiment, university students opposed to a tuition increase were exposed to an editorial that argued for a tuition increase. They were exposed to this counterattitudinal message, as a large body of research has suggested that exposure to such messages evokes negative affect (for a review, see Harmon-Jones, 2000).
Conditions differed with regard as to whether it was possible for participants to act to change the likelihood that tuition will be increased, to manipulate coping potential or the expectation of acting to change the situation. In the action-possible condition, participants were told that the increase may occur in the future and that petitions were being circulated to attempt to prevent the increase. In the action-impossible condition, participants were told that the tuition increase would definitely occur.

Both conditions evoked significant increases in anger (over baseline) and they were not significantly different from each other. More importantly and consistent with predictions, results indicated that participants who expected to engage in the approach-related action of signing a petition to ameliorate the tuition-increase situation (action-possible condition) evidenced greater left frontal activity than participants who expected to be unable to engage in approach-related action. Moreover, within the action-possible condition, participants who evidenced greater left frontal activity in response to the tuition increase message also evidenced greater self-reported anger, providing support for the idea that anger is often an approach-related emotional response. In the condition where action was not possible, greater left frontal activity did not relate to greater anger. This is because, although anger usually leads to approach motivation, when action is not possible, approach motivation should remain low, even if angry feelings are high. Finally, within the action-possible condition, participants who evidenced greater left frontal activity in response to the tuition increase message were more likely to engage in behaviors that would reduce the possibility of the tuition increase (i.e., they were more likely to sign the petition and to take petitions with them for others to sign). This finding
suggests that greater approach motivation, as reflected in greater left frontal cortical activity, was associated with more action to correct the negative situation.

The research of Harmon-Jones, Sigelman et al. (2003) supports the hypothesis that the left frontal cortical region is involved in approach motivation rather than positive affect. Moreover, the results suggest that the left frontal region is most accurately described as a region sensitive to motivational intensity. That is, it was only when anger was associated with an opportunity to behave in a manner to resolve the anger-producing event that participants evidenced the increased relative left frontal activation.

Proneness toward Hypomania/Mania and Anger-Related Left Frontal Cortical Activity

The reviewed research suggests that anger is related to relative left frontal cortical activity because anger is associated with approach motivation. Consequently, individuals with greater trait approach motivation may be particularly likely to evidence greater left frontal activity in response to an anger-provoking situation, as they feel motivated to redress the anger-provoking situation. In contrast, individuals with lower trait approach motivation may be particularly unlikely to evidence greater left frontal activity and may instead respond with lower left frontal activity, as they feel hopeless to redress the anger-provoking situation. To examine these ideas, Harmon-Jones, Abramson, Sigelman, Bohlig, Hogan, and Harmon-Jones (2002) exposed individuals with high and low trait approach motivation to an anger-producing situation. Based on the observed link between hypomania/mania and increased approach motivation (Depue & Iacono, 1989; Meyer et al., 1999), we predicted that proneness toward mania would be related to increased relative left frontal activity in response to an anger-evoking event. In contrast, based on the link between depression and decreased approach motivation (Depue & Iacono, 1989;
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Fowles, 1993; Henriques & Davidson, 1990), we predicted that proneness toward unipolar depression would be related to decreased relative left frontal activity in response to the anger-invoking event. To assess these individual differences characteristics among a sample of unselected undergraduate students, we used the General Behavior Inventory, which was developed to identify individuals who are at risk for developing these disorders (Depue & Klein, 1988; Depue, Krauss, Spoont, & Arbisi, 1989). Results indicated that tendencies toward hypomania/mania related to increased left frontal activity, and that tendencies toward unipolar depression related to decreased left frontal activity following exposure to the anger-provoking radio editorial. In these analyses, resting, baseline relative left frontal activity was statistically controlled, suggesting that the effects were specific to when anger was aroused.

Sympathy Reduces Anger-Related Left Frontal Activity

Whereas the reviewed evidence links approach anger to relative left frontal activity, it is important to establish that manipulations that reduce angry approach behaviors also reduce relative left frontal activity. To address this issue, we tested whether sympathy would reduce the relative left frontal activity typically observed during anger. Past research has suggested that experiencing sympathy for another individual can reduce aggression toward that individual (e.g., see review by Miller & Eisenberg, 1988). We hypothesized that sympathy may reduce aggression by reducing the relative left frontal activity associated with anger. To test this hypothesis, college students were told that the study concerned personality, perception, and brain activity, and that they and another student would be writing essays and evaluating each other based on the essays. Participants then wrote a persuasive essay arguing either for or against a 10% tuition
increase. Then, the experimenter returned to the participants’ room and handed them a folder containing a reading perspective, an essay, and a questionnaire.

The reading perspective instructions asked participants to remain completely objective (low sympathy) or to try to imagine how the other person must feel (high sympathy), as in much past sympathy research (Batson, 1991, 1998; Harmon-Jones, Peterson, & Vaughn, 2003; Stotland, 1969). The participant then read the essay ostensibly written by the other participant. In the essay, the other participant described his/her difficulties with having Multiple Sclerosis.

Following the reading of the essay, the participant received an evaluation of his/her essay ostensibly written by other participant. The evaluation contained either neutral ratings and comments (no insult) or insulting ratings and comments (insult). Immediately after feedback manipulation, EEG was collected. Then, the participant completed questionnaires assessing impressions of the other participant and emotions.

Results indicated that the insult evoked greater left frontal activity but only when high levels of sympathy were not first evoked for the insulting person. Additional comparisons revealed that the high sympathy/insult condition produced greater relative left frontal activity than every other condition. Thus, when participants first experienced sympathy for the target person, they did not evidence increased left frontal activity when insulted. The experiment thus suggested that the alteration of relative left frontal activity via sympathy can reduce angry aggression.

**Manipulation of Left Frontal Cortical Activity and Attentional Processing of Anger**

In addition to the reviewed evidence, other research is consistent with the hypothesis that anger is associated with left frontal activity. For example, d’Alfonso, van
Honk, Hermans, Postma, and de Haan (2000) recently used slow repetitive transcranial magnetic stimulation (rTMS) to inhibit the left or right prefrontal cortex. They found that rTMS applied to the right prefrontal cortex caused selective attention towards angry faces whereas rTMS applied to the left prefrontal cortex caused selective attention away from angry faces. Because slow rTMS produces inhibition of cortical excitability, these results suggests that the rTMS applied to the right prefrontal cortex decreased its activation and caused the left prefrontal cortex to become more active. The same holds true for the rTMS applied to the right prefrontal cortex and activation of the left prefrontal cortex. The increase in left prefrontal activity led participants to attentionally approach angry faces, as in an aggressive confrontation. In contrast, the increase in right prefrontal activity led participants to attentionally avoid angry faces, as in a frightening confrontation. The interpretation of these results, which d’Alfonso et al. advanced, concurs with other research that has demonstrated that attention toward angry faces is associated with high levels of self-reported anger and that attention away from angry faces is associated with high levels of cortisol (van Honk, Tuiten, de Haan, van den Hout, & Stam, 2001; Van Honk, Tuiten, Van den Hout, Koppeschaar, Thijssen, & de Haan, 1998; van Honk, Tuiten, Verbaten, van den Hout, Koppeschaar, Thijssen, & de Haan, 1999), which is associated with fear.

**Research on Anger Using Other Brain Imaging Methods**

Whereas the above-reviewed research has revealed that the left frontal cortical region is involved in approach motivation and anger, it is limited in that EEG is the sole imaging method used. While EEG possesses excellent temporal resolution, its spatial resolution is limited. A search of the literature revealed two experiments that had
examined the effects of anger on brain activity measured with brain imaging methods other than EEG. One experiment utilized positron emission tomography (PET). One used oxygen-15-labeled carbon dioxide to study normalized regional cerebral blood flow during anger as compared to a neutral control state (Dougherty et al., 1999). In the experiment, eight healthy men provided a written description of a time when they were the most angry they had been in their life. The neutral scripts were generated by the experimenters (i.e., going for a walk, cooking dinner). Based on the anger material provided by the participant and the experimenter-generated neutral information, the experimenter created a script in the second person and then audiotaped it in a neutral voice for playback in the lab. The scripts were 30-40 sec long. Other emotions were activated in a similar manner but the results were not published in the report. Emotion induction time was counterbalanced across participants. Before each scan, the participant was told to close his eyes, listen to the script, and “imagine the event portrayed as vividly as possible, as if he was actually participating in the event, rather than just ‘watching himself’ in it.” (p. 467). Participants were asked to recall and imagine the event for 60 sec following the script audiotape. Positron emission tomography (PET) data were collected during this time period. The anger and neutral conditions did not differ on heart rate, skin conductance, or frontalis muscle activity, even though past research would suggest that differences between conditions should emerge (e.g., Jaencke, 1996; Lavoie, Miller, Conway, & Fleet, 2001). Perhaps anger was not evoked or perhaps the anger was not sufficiently strong to affect these variables. However, the anger condition reported greater anger than the neutral condition. The PET results revealed that as compared to neutral imagery, anger imagery caused an increase in the left orbital frontal cortex, the
right anterior cingulate cortex, the bilateral anterior temporal poles, left precentral gyrus, bilateral medial frontal cortex, and bilateral cerebellum. No significant differences emerged between conditions in the amygdala or insular cortex.

Thus, the increase in activity in the left orbital frontal cortex is consistent with the anger research results obtained using EEG. However, Dougherty et al. (1999) interpreted the increase in left orbital frontal cortical activity as corresponding “to inhibition of aggressive behavior in the face of anger.” (p. 471). While this interpretation is consistent with some speculations of the role of the left orbital frontal cortex in response inhibition (Mega et al., 1997), it is inconsistent with the EEG results showing that increased left frontal activity is associated with increased aggression and approach behavior (e.g., Harmon-Jones & Sigelman, 2001; Harmon-Jones et al., 2003). The interpretation that the left frontal cortical region is involved in the inhibition of anger and aggression is also inconsistent with lesion data suggesting that mania results from damage to the right frontal region (e.g., Robinson & Downhill, 1995) and results obtained when the left relative to right frontal cortex is activated and angry attentional processes are measured (e.g., d’Alfonso et al., 2000). However, it is possible that the EEG is assessing dorsolateral frontal cortical activity and not orbital frontal activity, and that left orbital frontal activity is involved in the inhibition of anger, whereas left dorsolateral frontal activity is involved in approach motivations like anger.

In another experiment (Kimbrell et al., 1999), using H\textsubscript{2}^{15}O PET, 18 healthy participants were instructed to recall anxious, angry, or neutral events and then “recall the emotion they felt during that time and to try to experience it that way again.” (p. 455). Affect-congruent faces were displayed to participants during the recall “to help subjects
re-experience and sustain the emotion.” (p. 455). Compared to the neutral recall task, the anger recall task evoked increased activity in the left superior temporal gyrus, left inferior frontal cortex, right thalamus, and right posterior cingulate. Anger also evoked decreased regional cerebral blood flow in the right superior temporal gyrus, inferior parietal cortex, and right middle frontal gyrus. However, when anger and anxiety were compared, anger was associated with greater activity in the brainstem, right medial frontal gyrus, and right inferior frontal gyrus. Thus, these results suggest that while both anxiety and anger caused increases in some areas of the left frontal region (as compared to neutral), anger caused greater activations in some area of the right frontal cortex and brainstem activity than anxiety. Based on research suggesting that retrieval of personally relevant, time-specific memories activates the left temporal pole (Maguire et al., 1999), Kimbrell et al. (1999) suggested “that the common activations by anxiety and anger in the left anterior temporal and inferior frontal cortical area relate to the nonspecific aspects of recall of negative emotion…” (p. 461). Clearly, the results of Kimbrell et al. (1999) are inconsistent with the EEG results reviewed herein and the results of Dougherty et al. (1999).

As Kimbrell et al. (1999) noted, there were a number of limitations to the experiment, including the variety of past events recalled and whether the recall task evoked the actual emotion (the same limitation apply to Dougherty et al., 1999). Consistent with their concerns about comparing actual emotional experience to imagined emotional experience, research has demonstrated that moving a thumb activates primary motor cortex (Rao et al., 1995), whereas imagining moving a thumb activates supplemental motor cortex (Parsons et al., 1995).
Of course, it may be difficult to compare anger induced by imagery to anger induced by insulting feedback or goal blocking, as in Harmon-Jones and Sigelman (2001) and Harmon-Jones, Sigelman et al. (2003). In the imagery experiments, there was no report of a significant association between reported anger and regional brain activity. In the EEG experiments using means other than imagery to induce anger, self-reported anger has been found to correlate significantly with relative left frontal activity (Harmon-Jones & Sigelman, 2001; Harmon-Jones, Sigelman et al., 2003). Examination of correlations between reported emotion and physiological measures assists in determining whether the brain activation is related to emotional experience or some other non-emotional variable.

**Comparisons of Violent to Non-Violent Individuals on Frontal Lobe Function**

The results indicating that relatively greater left frontal cortical activity is associated with increased approach-oriented anger and behavior are seemingly inconsistent with evidence suggesting that violent individuals have reduced frontal lobe function (e.g., Amen et al., 1996; Raine, Stoddard, Bihrle, & Buchsbaum, 1998; Raine, Meloy et al., 1998). These results, and others, have led some to conclude that the prefrontal cortex, particularly the left orbital frontal cortex (and frontal activations derived from EEG), is involved in the regulation of negative affects like anger (Davidson, Putnam, & Larson, 2000).

However, other research has more strongly implicated right frontal regions in violence. For example, Raine, Stoddard et al. (1998) found that murderers who came from relatively good home backgrounds showed reduced prefrontal functioning, compared to murderers from relatively bad home backgrounds and normal controls. In
particular, the greatest reduction in prefrontal functioning was found in the right orbitofrontal cortex. Raine, Park et al. (2001) provided further support for this interpretation in a continuous performance task study that assessed fMRI in violent offenders. Results indicated that violent offenders who had suffered severe child abuse evidenced reduced right hemispheric functioning, particularly in the right temporal cortex. In contrast, individuals who had suffered severe child abuse and had refrained from violence evidenced relatively lower left but higher right activity in the temporal lobe. These results suggest that the reduced right temporal activity coupled with severe child abuse was associated with being violent.

These findings are consistent with the reviewed EEG research (Harmon-Jones & Allen, 1998; Harmon-Jones et al., 2002; Harmon-Jones et al., 2003), which found that approach-oriented anger was associated with reduced right frontal activity (in addition to increased left frontal activity). Other research has revealed that increased activity in the right frontal cortex is associated with withdrawal motivation. Perhaps the violent individuals who showed reduced right frontal activity in the studies of Raine and colleagues (1998, 2001) lack the behavioral constraints engendered by the withdrawal motivation system that may be partially instantiated in the right frontal cortex.

However, other studies have implicated reduced activity in both left and right frontal cortices in violence and aggression. For instance, Raine, Meloy et al. (1998) found in a PET study that affective murderers, as compared to predatory murderers and normal controls, evidenced reduced lateral and medial prefrontal activity in both hemispheres during a continuous performance task.
Of course, differences in participant samples may explain the differences in results. That is, most of the anger studies have involved normal individuals, whereas the studies on violence have involved extremely violent individuals. However, in the Harmon-Jones and Allen (1998) study, seven of the participants were adolescents who were in an in-patient psychiatric unit for impulse control disorders. But even among this sample, trait anger was related to greater left frontal activity and reduced right frontal activity at rest. These results suggest that the samples may not be the source of the differences. However, the Harmon-Jones and Allen (1998) samples was much younger than samples used in other studies comparing frontal lobe function in violent and non-violent individuals (e.g., Raine, Maloy et al., 1998). The longer lifetime of violence in adults may cause the reductions in frontal cortical activity.

The studies comparing brain function of violent and non-violent individuals typically assess frontal lobe function at rest or during a cognitive task and not during anger-arousing situations. For example, Raine, Maloy et al. (1998) measured PET during a continuous performance task. However, it is not clear that reduced frontal lobe function measured during these tasks causes violence. The violent individuals (as compared to the non-violent individuals) who display less prefrontal activity during cognitive tasks may simply be less motivationally/emotionally engaged by the relatively unemotional nature of the tasks. However, violent individuals may not demonstrate reduced frontal lobe function during a more emotionally engaging situation, such as an interpersonal provocation. It seems that the brain activation during such events would be more predictive of violent behavior.
Another difficulty emerges when attempting to compare studies of violent offenders with the studies on anger: anger can be manipulated in the lab, whereas being a violent offender cannot be manipulated. Thus, in the latter type of studies, there are the omnipresent difficulties associated with correlational studies. For instance, the violence may have caused the reduction in frontal activity. Longitudinal studies are needed in which brain function and violence are measured at several time points, starting in youth and through adulthood. Such a design would allow researchers to more conclusively infer whether brain function predicts violence.

In future research on the role of the frontal cortex in anger and violence, it will be important to distinguish whether the effects of violence on prefrontal activity are due to anger, impulsivity, or some other variable. In other words, do the causes of the violence play an important role in the relationship of violence with prefrontal activity?

Importantly, the recent work by Raine and colleagues has begun this type of research as they have examined differences between affective and predatory murderers, and how socialization affects relationships between violence and prefrontal activity. Because the left prefrontal region is supplied with a high density of serotonin type 2 receptors (e.g., Mann et al., 1996), and because serotonin has been found to relate to impulsivity (e.g., Soloff et al., 2000), it is possible that the reductions in prefrontal activity are due to impulsivity and not necessarily anger and violence.

**Conclusion**

In sum, the reviewed experimental research suggests that increased activation of the left frontal cortical region is associated with approach-oriented anger, whereas decreased activation of the right frontal cortical region is associated with approach-
oriented anger. Evidence also suggests that this pattern of frontal cortical activation is associated with approach behaviors, some of which can be destructive – aggression against another person (Harmon-Jones & Sigelman, 2001), and some of which can be constructive – action taken to resolve a perceived social injustice (Harmon-Jones, Sigelman et al., 2003). Future research will benefit the understanding of anger by using brain imaging methodologies with greater spatial resolution to examine neural correlates of actual outbursts of anger that lead to constructive as well as destructive behaviors. Moreover, examinations of the neural circuitry of non-violent and violent individuals during outbursts of anger will assist in understanding one of society’s most destructive emotions.
References


Footnotes

1. While there have been several studies examining neural responses to photographs of angry faces, there have only been a very few studies examining neural activity associated with the experience or expression of anger. Because the former type of studies are likely assessing neural processes associated with the perception of emotional stimuli and not necessarily the experience or expression of emotion, these studies are not reviewed.