Received: 16 May 2016 | Revised: 21 December 2016 | Accepted: 21 March 2017

DOI: 10.1111/psyp.12879

ORIGINAL ARTICLE

WILEY PSYCHOPHYSIOLOGY SPR

On the role of asymmetric frontal cortical activity in approach and withdrawal motivation: An updated review of the evidence

Eddie Harmon-Jones[1] | **Philip A. Gable[2]**

[1] School of Psychology, The University of New South Wales, Sydney, New South Wales, Australia

[2] Department of Psychology, University of Alabama, Tuscaloosa, Alabama

Correspondence
Eddie Harmon-Jones, School of Psychology, The University of New South Wales, Sydney, New South Wales 2052, Australia.
Email: eddiehj@gmail.com

Funding information
Australian Research Council grant (DP150104514)

Abstract

We review conceptual arguments and research on the role of asymmetric frontal cortical activity in emotional and motivational processes. The current article organizes and reviews research on asymmetrical frontal cortical activity by focusing on research that has measured trait (baseline) frontal asymmetry and related it to other individual differences measures related to motivation (e.g., anger, bipolar disorder). The review also covers research that has measured state frontal asymmetry in response to situational manipulations of motivation and emotion and as an intervening variable in motivation-cognition interactions. This review concludes that much research supports the view that greater left than right frontal cortical activity is associated with greater positively or negatively valenced approach motivation. The view that greater right than left frontal cortical activity is associated with withdrawal motivation, although supported, has received less empirical attention. In addition to reviewing research on the emotive functions of asymmetric frontal cortical activity, the reviewed research illustrates the need to consider motivational direction as separate from affective valence in conceptual models of emotional space.

KEYWORDS
emotion, frontal asymmetry, motivation

1 | INTRODUCTION

Over the last two decades, research on asymmetric frontal cortical activation and emotion and motivation has flourished, as evidenced by several published reviews (e.g., Coan & Allen, 2004; Harmon-Jones, 2003a; Harmon-Jones, Gable, & Peterson, 2010; Rutherford & Lindell, 2011). In our own work, we have focused on a conceptual question regarding the emotive correlates of asymmetric frontal cortical activity. Specifically, we have sought to address whether asymmetric (left vs. right) frontal cortical activity is related to affective valence (positive vs. negative affect) or motivational direction (approach vs. withdrawal). Consequently, we focus this review primarily on research related to this conceptual question.

2 | DEFINITIONS

As recommended by others (Izard, 2010), we believe it important to clearly define the scientific concepts we will use. For us, affect is a broad term that encompasses emotions and moods and it reflects the subjective experience of the organism. Affective valence—whether an affect is positive or negative—is frequently used as a concept but infrequently defined. Lazarus (1991) suggested there are three ways researchers often (implicitly) define affective valence: (a) the emotion's adaptive consequences, (b) the conditions that evoked the emotion, or (c) the emotion's subjective feel. The first definition is based on the consequences of the affect, so if the affect produces positive consequences like good health, it is a positive affect, and if it produces negative consequences like bad health, it is a negative affect. We find this definition problematic for several reasons. Perhaps most importantly, many emotions that are commonly thought of as negative are often involved in producing positive consequences. Consider the child who experiences fear when she sees a reckless car approaching and consequently stays out of the street to avoid getting hit. In addition, what may be positive in the short term may be negative in the long term. Consider the angry man who gets his immediately desired goal but causes all of his coworkers to dislike him, resulting in him losing his job. A second definition of affective valence is based on whether the affect results from a situation that is considered positive (congruent with one's goals) or negative (incongruent with one's goals). Thus, positive affects are evoked by events that are viewed or appraised as positive to the organism. We have no problems with this definition, but we do believe that most researchers and laypersons do not use it in their own implicit theories of affect. The third definition concerns the subjective feel of the affective experience. The affects that organisms like to experience are positive affects, and the affects that organisms dislike are negative affects (Harmon-Jones, Harmon-Jones, Amodio, & Gable, 2011). Emotion theorist Paul Ekman (2003, p. 190) also seemed to prefer this definition when he suggested that the liking or enjoyment of emotions underlies which emotions are considered as positive or negative: “Just as there is a set of distinctive emotions that we usually don't enjoy feeling, there is a set of distinctive emotions that we do enjoy feeling.” When discussing affective valence, we use this last definition.

For us, motivation is an internal state of the organism that reflects the amount of energy or effort the organism will expend to accomplish something; this is motivational intensity. Motivational intensity should be distinguished from motivational potential. Motivational intensity is the amount of energy exerted, whereas motivational potential is the upper limit of energy the organism would exert (Brehm & Self, 1989). This distinction is important and may assist in understanding why certain stimuli may not always influence measures of motivation. Motivational potential is related to the benefits expected, such as the value of the reward and the need for it. When the difficulty of instrumental behavior is known (or perceived), perceived task difficulty will relate to motivational intensity in a nonmonotonic way (in the shape of a wedge). That is, the difficulty of exerting the behavior interacts with potential motivation to influence motivational intensity. If it is easy to obtain the reward, motivational intensity will be low, because little effort is needed to accomplish the goal. If it is moderately difficult to obtain the reward, motivational intensity will be higher if the reward is perceived as valuable and needed (i.e., if motivational potential is high). If, however, the reward is not perceived as valuable and needed (i.e., if motivational potential is low), motivational intensity will be low for this moderately difficult task. Finally, if it is impossible to obtain the reward, motivational intensity will be low (regardless of the level of potential motivation), because no amount of effort will gain the reward. This theoretical model of motivation has been supported in much past research (e.g., Brehm & Self, 1989; Gendolla, Wright, & Richter, 2012; Wright, Tunstall, Williams, Goodwin, & Harmon-Jones, 1995), and it has guided some research on asymmetric frontal cortical activity (as we review below).

Motivational direction refers to where the organism is motivated to go. It can be motivated to go toward (approach) or to go away (avoid or withdraw) from something (Harmon-Jones, Harmon-Jones, & Price, 2013). Most theories that consider motivational direction specify the “something” by positing that the organism is motivated to go toward rewards, desired outcomes, or positive goals, and that the organism is motivated to go away from punishments, undesired outcomes, or negative goals. We believe that organisms are indeed often motivated to approach or avoid based on these anticipations, but we do not believe that these anticipations should be part of the definition of motivational direction. Much evidence suggests that approach motivation can occur in the absence of any anticipated outcomes. For example, an individual in a manic episode can be very approach motivated or oriented to go toward things in the environment and exactly what she approaches will depend on what is available or present in the environment (e.g., sex or drugs). In this case, the manic “mood,” not the anticipated outcome, caused the approach motivation. That is, this person could be approach motivated long before she finds a goal to go toward.

3 | THE RELATIONSHIP OF ASYMMETRIC FRONTAL CORTICAL ACTIVITY WITH AFFECTIVE VALENCE

The interest in asymmetric frontal cortical activity and its relationship with affective variables goes back almost a century. Starting in the 1930s, clinicians observed that individuals who had suffered damage to the left frontal cortex were more likely to suffer depression as a result of the damage (Goldstein, 1939). Additional studies replicated these results and found that individuals who had suffered damage or lesions to the left frontal cortex started to have depressive symptoms (Black, 1975; Gasparrini, Satz, Heilman, & Coolidge, 1978; Gainotti, 1972; Robinson & Price, 1982), whereas individuals who had suffered lesions to the right frontal cortex started to have manic symptoms (Gainotti, 1972; Robinson & Price, 1982; Sackeim et al., 1982).

Other research along these lines used the Wada test; it injects amytal, a barbiturate derivative, into one of the internal carotid arteries, causing a suppression of the activity of one brain hemisphere. Injection of amytal into the left side produced depressed affect, whereas injection of amytal into the right side produced euphoria (Alema, Rosadini, & Rossi, 1961; Perria, Rosadini, & Rossi, 1961; Rossi & Rosadini, 1967; Terzian & Cecotto, 1959). These effects probably reflect the release of one hemisphere from contralateral inhibitory forces (Schutter & Harmon-Jones, 2013). Thus, when the left hemisphere was deactivated by amytal, the right hemisphere became more uninhibited and more active, which caused depressed affect. Conversely, when the right hemisphere was deactivated by amytal, the left hemisphere became more uninhibited and more active, which caused euphoria.

Interest in asymmetric frontal cortical activity has received much empirical attention from EEG research. In this research, asymmetric frontal cortical activity is often measured by comparing alpha power (8–13 Hz) activity levels between areas on the left and right. Alpha power is inversely related to regional brain activity as suggested by research that has combined EEG with hemodynamic measures (Cook, O'Hara, Uijtdehaage, Mandelkern, & Leuchter, 1998) and behavioral tasks (Davidson, Chapman, Chapman, & Henriques, 1990). The EEG frontal asymmetry research generally uses difference scores, and the use of difference scores is justified by the amytal and lesion research that suggests that asymmetry may be the critical variable; that is, one hemisphere may be inhibiting the opposite hemisphere. Studies using transcranial magnetic stimulation (Schutter, 2009; Schutter, van Honk, d'Alfonso, Postma, & de Haan, 2001) are also consistent with this view. In particular, the corpus callosum may play an important role in the asymmetric functioning of the frontal cortices (Schutter & Harmon-Jones, 2013). The corpus callosum is the largest white matter bundle connecting the left and right hemispheres. It provides interhemispheric functional connectivity, which may aid in the hemispheric cross-talk associated with approach or withdrawal motivation. Because of these considerations, researchers often subtract left frontal alpha power from right frontal alpha power (after log-transforming the values to normalize the distributions, e.g., log F4 minus log F3), and then refer to the obtained result as relative left or relative right frontal activity, depending on whether the result is a more positive (relative left) or a more negative (relative right) numeric value.

3.1 | Resting asymmetric frontal activity and trait affect

Several early EEG frontal asymmetry studies examined EEG in individuals while they simply sat quietly in the lab for 4 to 8 min. This resting, baseline EEG was assumed to reflect something like a personality trait and it was related to other personality trait or individual difference measures. The first set of studies followed the lead of the lesion studies and focused primarily on depression. These studies revealed that depression was associated with relatively low left frontal activity (e.g., Allen, Iacono, Depue, & Arbisi, 1993; Henriques & Davidson, 1990; Jacobs & Snyder, 1996; Schaffer, Davidson, & Saron, 1983; see meta-analysis by Thibodeau, Jorgensen, & Kim, 2006). Subsequent studies revealed that greater relative right frontal activity is associated with more negative affect, whereas higher relative left frontal activity is associated with more trait positive affect (Tomarken, Davidson, Wheeler, & Doss, 1992).

However, some studies have failed to replicate some of the results concerning correlations between individual differences measures and resting, baseline frontal asymmetry (Reid, Duke, & Allen, 1998). Consequently, researchers examined several resting, baseline EEG sessions from a large group of individuals and found that approximately half of the variance in a resting, baseline session is due to trait influences, whereas the remaining half of the variance is due to state influences (Hagemann, Hewig, Seifect, Naumann, & Bartussek, 2005; Hagemann, Naumann, Thayer, & Bartussek, 2002). With so much variance in the resting, baseline EEG measure being due to state or situational influences, it is not surprising that the correlations between this EEG measure and other trait measures do not always replicate. That is, situational variables, particularly strong ones, may overwhelm the influence of a particular trait relationship with the resting, baseline EEG measure. For instance, two studies found that time of day and time of year correlated with asymmetric frontal cortical activity (Peterson & Harmon-Jones, 2009). Specifically, both studies revealed that relative right frontal activity was highest during fall mornings. This time of year is associated with more depression (e.g., Magnusson, 2000) and this time of day is associated with higher cortisol levels (e.g., King et al., 2000), and cortisol has been linked with withdrawal motivation. Perhaps greater resting relative right frontal activity occurred during fall mornings because of the combination of variables associated with decreased approach motivation (depression) and increased withdrawal motivation (cortisol).

Other variables are also likely to influence relationships between resting asymmetric frontal cortical activity and other trait variables. For instance, research has revealed that characteristics of the experimenter may influence these relationships (Wacker, Mueller, Pizzagalli, Hennig, & Stemmler, 2013). We return to this issue later. In any event, relationships between resting asymmetric frontal activity and other personality traits are not invariant and may be influenced by certain situational variables, but there does appear to be sufficient evidence to suggest that the "trait" relationships are indeed present. But exactly how trait frontal asymmetry occurs is unknown. At least three possible explanations exist. First, trait frontal asymmetry could simply reflect individuals' frontal asymmetry at rest, in a completely neutral state. This explanation seemed to be the guiding principle (at least implicitly) in the early trait frontal asymmetry studies. Second, the lab context in which the frontal asymmetry is measured is typically a relatively novel situation, and individual differences in response to this situation may "cause" the observed resting frontal asymmetry. That is, individuals with positive (or approach) temperaments may respond to the novel lab situation with greater relative left frontal activity, whereas individuals with negative (or withdrawal) temperaments may respond to the novel lab situation with greater relative right frontal activity. Third, the psychological processes of the individuals sitting in a resting baseline session may underlie their frontal asymmetry scores. That is, individuals who are daydreaming about their hopes and aspirations may have greater relative left frontal activity, whereas individuals who are worrying about their fears may have greater relative right frontal activity. Research is needed to better understand state and trait variance in resting baseline EEG measures.

Up to this point in the history of research on asymmetric frontal cortical activity and emotion-related variables, several studies had suggested that, when measured during a resting baseline, relative left frontal activity was associated with traits associated with more positive affect, whereas relative right frontal activity was associated with traits associated with more negative affect (e.g., see reviews by Coan & Allen, 2004; Rutherford & Lindell, 2011; Thibodeau et al., 2006). However, these results could be interpreted in another way. That is, because most positive affective traits are directly associated with approach motivation traits, and most negative affective traits are directly associated with withdrawal motivation traits, approach versus withdrawal motivation (motivational direction) could also explain the obtained results. A similar interpretation could be made for depression and anxiety, as depression has been associated with decreased approach motivation and increased withdrawal motivation, and anxiety has been associated with increased withdrawal motivation (see review by Shankman & Klein, 2003).

3.2 | Resting asymmetric frontal activity and affective reactions to stimuli

Another body of early studies examined whether resting asymmetric frontal cortical activity would predict affective reactions to situations or stimuli. For instance, studies found that, relative to individuals with greater relative left frontal activity, individuals with greater relative right frontal activity reported greater negative affective responses to negative emotion-inducing films (fear and disgust) and lesser positive affective responses to positive emotion-inducing films (happiness; Tomarken, Davidson, & Henriques, 1990; Wheeler, Davidson, & Tomarken, 1993). Conceptually similar results were also discovered in 10-month-old infants. That is, infants with greater relative right frontal activity were more likely to cry in response to maternal separation (Davidson & Fox, 1989).

Much like the resting asymmetric frontal activity and trait affect research, these studies can be explained by an affective valence or motivational direction conceptual model. That is, because the negative affective situations likely evoked withdrawal motivation (e.g., fear is often associated with withdrawal) and the positive affective situations likely evoked approach motivation (e.g., happiness is often associated with approach), either conceptual model can explain the observed relationships.

3.3 | Manipulations of asymmetric frontal cortical activity and affective reactions

The studies described above using resting baseline asymmetric frontal cortical activity were correlational, and consequently it is impossible to know whether asymmetric frontal cortical activity was causally involved in the affective variables. To provoke more causal evidence, researchers have attempted to manipulate asymmetric frontal cortical activity and examine this manipulation's influence on affective variables.

3.3.1 | Neurofeedback

To test the causal influence of asymmetric frontal cortical activity on affective responses to situational evocations, some studies have used neurofeedback training to manipulate asymmetric frontal cortical activity (e.g., Allen, Harmon-Jones, & Cavender, 2001; Harmon-Jones, Harmon-Jones et al., 2008). With neurofeedback, participants are presented with tones or some other type of feedback that corresponds to their currently occurring brain wave activity at certain regions. If the brain wave activity is consistent with that desired by the experiment, some type of "reward" feedback is presented; if the brain wave activity is not consistent with that desired, "punishment" or no feedback is presented. The rewards could simply be the presentation of a tone that informs the participant that the desired brain change has occurred. These neurofeedback-induced changes in brain wave activity are the result of operant conditioning. The changes occur without participants being aware of how they occurred (Kamiya, 1979; Siniatchkin, Kropp, & Gerber, 2000); with extensive practice, participants can gain awareness of how to intentionally cause changes in brain wave activity (e.g., 8 weeks of practice; Kotchoubey, Kübler, Strehl, Flor, & Birbaumer, 2002).

In one example experiment, participants were trained to increase relative right versus relative left frontal activity for 30 min a day for several days (Allen et al., 2001). Participants were simply told to try to make a high-pitched tone play as much as possible. During the first second of each 2-s time period, an asymmetric frontal cortical activity index was computed (i.e., alpha power at F4 and F3), and this index was compared against a criterion value that had been established for that training session. If the asymmetry index exceeded the criterion value in the desired direction, a higher pitched (300 Hz) reward tone was played; if the criterion was not exceeded, a lower pitched (150 Hz) nonreward tone was played. On the last day of the study for each participant, immediately following the training session, participants viewed film clips designed to evoke emotions while zygomatic and corrugator muscle region activity was recorded.

Results indicated that the neurofeedback training had successfully altered asymmetric frontal activity. That is, participants who received neurofeedback training to increase relative right frontal activity showed a significant increase in relative right frontal activity from Day 1 to Day 3 and 4. In contrast, individuals who received training to increase relative left frontal activity did not show a significant increase in relative left frontal activity, but they did differ significantly from those who had received relative right frontal training (for a replication, see Quaedflieg et al., 2016). As predicted, this manipulated change in asymmetric frontal cortical activity caused changes in affective responses. In particular, participants who received training to increase relative right frontal cortical activity had less zygomatic and more corrugator muscle region activity in response to all film clips than participants in the increase left frontal cortical activity condition. These results provided some of the first evidence to suggest that asymmetric frontal cortical activity is causally involved in affective responses.

3.3.2 | Unilateral hand contractions

Other research has used unilateral hand contractions as a way to manipulate asymmetric frontal cortical activity and examine its influence on affective responses. Unilateral hand or body contractions (Hellige, 1993) and unilateral contraction of the facial muscles in the lower third of the face (Rinn, 1984) cause increased activation of the contralateral brain hemisphere, because innervation of these muscles is contralateral. These unilateral body contractions likely influence emotive outcomes due to the spread of activation to, or recruitment of, contralateral frontal areas (Schiff & Lamon, 1989, 1994).

Previous behavioral research has found that contractions of the left hand and of the left side of the lower third of the face cause individuals to report feeling more sad and to have more negative perceptions and judgments; on the other hand, contractions of the right hand and of the right side of the lower third of the face cause individuals to report feeling more positive affect and to have more positive perceptions and judgments (Schiff & Lamon, 1989, 1994).

The first experiment to use unilateral body contractions to examine their influence on EEG and emotive outcomes had participants contract their left or right hand by squeezing a ball for approximately 4 min (Harmon-Jones, 2006). Then, participants listened to a radio editorial about options for apartments in the city in which the participants lived. EEG was measured, and participants completed a self-report scale that contained items that measure positive activation (Watson, Wiese, Vaidya, & Tellegen, 1999). Results indicated that the unilateral contraction of one hand caused greater activation of the contralateral hemisphere (as measured by EEG alpha suppression) over the central and frontal regions (see Gable, Poole, & Cook, 2013, for replication). The unilateral hand contraction manipulation also influenced positive activation: Right-hand contractions caused greater positive activation to the radio editorial than the left-hand contractions. Moreover, within the right-hand condition, self-reported positive activation correlated with greater relative left frontal activity at midfrontal sites, but not at other sites.

Much like the evidence reviewed in the previous sections, the studies that manipulated asymmetric frontal cortical activity and examined its influence on positive and negative affective responses can be explained by an affective valence or motivational direction conceptual model. That is, this past research used negative affective situations that were likely also evoking withdrawal motivation and positive affective situations that were likely also evoking approach motivation.

3.4 | The influence of situational manipulations of positive and negative affect on asymmetric frontal cortical responses

Another line of research suggesting more of a causal relationship between asymmetric frontal cortical activity and positive and negative affect involved manipulating positive and negative affective states and measuring the resulting asymmetric frontal cortical activity. In one early experiment along these lines, Davidson and Fox (1982) had 10-month-old infants view film clips of an actress displaying happy or sad facial expressions. They found that the infant had greater relative left frontal activity to the happy face film clip as compared to the sad face film clip.

Other experiments have manipulated positive and negative emotions by having participants form facial expressions of discrete emotions and measuring asymmetric frontal cortical activity during the posing of these facial expressions. In one early experiment, Ekman and Davidson (1993) found that, compared to facial expressions of nongenuine smiles of joy, facial expressions of genuine smiles of enjoyment caused greater relative left frontal activity. Another experiment by Coan, Allen, and Harmon-Jones (2001) found that when individuals posed facial expressions of fear they had less relative left frontal activity as compared to when they posed several other types of facial expressions.

Other experiments have produced conceptually similar results but have extended the previous experiments by examining asymmetric frontal cortical activity using ERPs. For example, Graham and Cabeza (2001) found that individuals had larger left frontal ERPs (positive slow waves; 750 ms to 1,250 ms after event onset) when viewing unfamiliar happy faces and larger right frontal ERPs when viewing unfamiliar neutral faces.

Again, the evidence reviewed in this section uses affective situations that also likely evoked motivational responses. As such, these results can be explained by an affective valence or motivational direction conceptual model.

4 | ASYMMETRIC FRONTAL CORTICAL ACTIVITY AND MOTIVATIONAL DIRECTION

A large number of studies have found that the left frontal cortical region is involved in the experience of positive affect, whereas the right frontal cortical region is involved in the experience of negative affect. This line of research suggested a conceptual interpretation of asymmetric frontal cortical activity that focused on the experience of positive or negative affect, or affective valence. Alongside this conceptual view, researchers occasionally suggested that asymmetric frontal cortical activity was related to approach versus withdrawal motivation, or motivational direction.

4.1 | Resting frontal asymmetry and trait motivation

Two of the earliest studies to test the idea that motivational direction was related to asymmetric frontal cortical activity observed that individual differences in self-reported trait approach motivation related to greater relative left frontal cortical activity during resting baseline (Harmon-Jones & Allen, 1997; Sutton & Davidson, 1997). Of these two studies, one found that trait "withdrawal" motivation correlated with greater relative right frontal activity at baseline (Sutton & Davidson, 1997), whereas the other found no significant correlation between trait withdrawal and relative right frontal activity (Harmon-Jones & Allen, 1997).

4.1.1 | Behavioral activation/behavioral inhibition

In these studies, approach and withdrawal motivation were assessed with the behavioral inhibition/behavioral activation system (BIS/BAS) questionnaires developed by Carver and White (1994). The approach motivation (BAS) questionnaire includes items such as "I go out of my way to get things I want"; "I crave excitement and new sensations." The withdrawal motivation (BIS) questionnaire includes items such as "I worry about making mistakes" and "I have very few fears compared to my friends (reverse scored)." Carver and White's BIS/BAS questionnaire was based on Gray's (1987) theory of motivation, not on Gray's updated theory of reinforcement sensitivity (Gray & McNaughton, 2000). In Gray's original theory, BAS was conceived as a motivational system sensitive to signals of conditioned reward, nonpunishment, and escape from punishment. Gray posited that the BAS caused movement toward goals. Gray's original BIS was conceived as a motivational system sensitive to signals of conditioned punishment, nonreward, novelty, and innate fear stimuli. Gray posited that the BIS inhibits behavior, increases arousal, prepares for vigorous action, and increases attention toward aversive stimuli. Interestingly, Carver (2009) has tended to refer to BAS as reward/incentive sensitivity and BIS as punishment/threat sensitivity.

Other studies have found that trait approach motivation is related to greater relative left frontal activity at baseline but that trait withdrawal motivation is not significantly correlated with relative right frontal activity (Amodio, Master, Yee, & Taylor, 2008; Coan & Allen, 2003). De Pascalis, Cozzuto, Caprara, and Alessandri (2013) found that greater BAS was associated with greater left-sided activation in the middle frontal gyrus (BA11). Other studies have conceptually replicated the relationship of BIS/BAS with asymmetric frontal cortical activity by examining ERPs (Peterson, Gable, & Harmon-Jones, 2008).

Conceptually similar results have been found using implicit measures of motivational systems of promotion and prevention. These systems have been described as being similar to approach and avoidance motivation (Higgins, 1997) but somewhat different: Promotion is a need for growth and advancement, whereas prevention is a need for safety and security (Molden, Lee, & Higgins, 2008). In this study (Amodio, Shah, Sigelman, Brazy, & Harmon-Jones, 2004), promotion and prevention regulatory focus were measured using a reaction time task that involved lexical decisions. Participants listed four words that represented attributes to which they aspired (which are related to promotion focus) and four words that represented attributes they felt they ought to possess (which are related to prevention focus). After listing these attributes, they performed a lexical decision task (word/nonword decisions) that included their individual words as well as filler words and nonwords. Reaction times to the words were used to assess the strength of promotion and prevention focus. Results revealed that a stronger promotion focus was associated with greater relative left frontal activity, whereas a stronger prevention focus was associated with greater relative right frontal activity.

Other research has found that greater relative left frontal activity is associated with higher trait impulsivity, a trait related to a diminished supervisory control system and heightened approach motivation (Gable, Mechin, Hicks, & Adams, 2015; Santesso et al., 2008). Similarly, attention-deficit/hyperactivity disorder (ADHD) has been found to be associated with greater relative left frontal activity in both pediatric and adult samples (e.g., Keune et al., 2011; Keune, Wiedemann, Schneidt, & Schönenberg, 2015), presumably because ADHD is associated with increased approach motivation (Mitchell, 2010). Neal and Gable (2016) examined whether multiple facets of impulsivity related to greater relative left frontal activity during a resting, baseline session. A sample of 150 participants completed the UPPS-P scale assessing negative urgency, positive urgency, lack of premeditation, and lack of perseverance (Cyders & Smith, 2007; Whiteside, Lynam, Miller, & Reynolds, 2005). Negative and positive urgency assess the tendency toward rash behavior in intense positive and negative states. Lack of premeditation and lack of perseverance assess cognitive tendencies of impulsivity. Each of these facets of impulsivity related to greater resting left frontal activity (and reduced right frontal activity), suggesting that greater left frontal asymmetry relates to trait impulsivity.

However, some research has failed to replicate the relationship of relative left frontal activity measured at resting baseline with trait BAS, even among large samples (Gable, Mechin, Hicks, & Adams, 2015; Neal & Gable, 2016; Wacker, Chavanon, & Stemmler, 2010). Some researchers have suggested that the correlation of trait BAS and relative left frontal activity measured at baseline may be influenced by situational variables. In one important test of this idea, Wacker and colleagues (2013) found that the significant correlation between trait BAS and greater relative left frontal cortical activity occurred primarily when male participants interacted with attractive female experimenters. This finding suggests that the association between relative left frontal activity and trait BAS may be most easily detected when individuals are in situations that arouse approach motivation.

Other research supports the hypothesis that situational contexts may enhance the link between trait approach motivation and resting left frontal activity. For example, research has linked trait positive arousal—a component of the approach system—with individual differences in left nucleus accumbens activity during anticipation of large gains (Wu, Samanez-Larkin, Katovich, & Knutson, 2014). Hughes, Yates, Morton, and Smillie (2015) had participants complete a task varying in effort expenditure and rewards, in which participants chose to complete low-reward low-effort trials or high-reward high-effort trials. Greater resting left frontal activity related to greater effort in the pursuit of high-reward high-effort trials, but not low-reward low-effort trials. Baseline frontal activity appears to be more strongly associated with approach-motivated traits and states during incentive anticipation.

4.1.2 | Bipolar disorder

Another individual difference that has been linked to asymmetric frontal cortical activity via motivational direction is bipolar disorder. Individuals with bipolar disorder exhibit increased approach motivation during episodes of hypomania and mania and decreased approach motivation during episodes of depression. This observation led clinical psychological scientists to posit that individuals with bipolar disorder may have particularly high levels of approach motivation when exposed to events such as rewards, goal striving, and frustrations, but particularly low levels of approach motivation when exposed to events such as definite failure. Research has supported these predictions. Compared with individuals with no affective disorders, individuals who have Bipolar I disorder (Meyer, Johnson, & Winters, 2001) and individuals who are prone to hypomanic symptoms (Meyer, Johnson, & Carver, 1999) have higher scores on self-report measures of BAS sensitivity (Carver & White, 1994), activation (subscale from Internal State Scale; Bauer et al., 1991), and achievement motivation (Johnson, Ruggero, & Carver, 2005). Moreover, hypomanic/manic, but not depressive, episodes have been found to be associated with goal-striving (Nusslock, Abramson, Harmon-Jones, Alloy, & Hogan, 2007) and goal-attainment (Johnson et al., 2000) life events.

Research using measures of asymmetric frontal cortical activity has also provided evidence consistent with this theory. For instance, greater relative right frontal activity, measured in EEG resting baseline measurements, has been found in bipolar depression (Allen et al., 1993), whereas greater relative left frontal activity has been found in mania (Kano, Nakamura, Matsuoka, Iida, & Nakajima, 1992). Moreover, proneness to hypomania/mania symptoms is correlated with greater relative left frontal cortical activity in response to anger-evoking events (Harmon-Jones et al., 2002).

This BAS theory of bipolar disorder also posits that if an event is appraised as a challenge and evokes approach-motivated perceptions of successful coping, approach motivation should be increased and hypomania/mania symptoms may result for individuals with bipolar disorder. One study (Harmon-Jones, Abramson et al., 2008) tested part of this prediction by providing individuals with a bipolar spectrum diagnosis and individuals without any affective disorder anagram tasks that varied in difficulty (i.e., easy, medium, and hard) and also varied in whether a reward or punishment could be expected (i.e., individuals could gain or avoid losing money on each trial). EEG activity was recorded as individuals prepared to solve each trial type. Compared to individuals without any affective disorder, individuals with bipolar disorder were predicted to have greater relative left frontal cortical activity while preparing for the hard tasks because these tasks were the most challenging. This prediction was based in part on motivational intensity theory (Brehm & Self, 1989; Wright et al., 1995), which posits that individuals (generally) should disengage when tasks are more difficult than the effort or outcome is worth. In contrast, individuals with bipolar disorder were predicted to be motivated even when confronted with very difficult tasks and thus not show the generally adaptive, energy-conserving response of disengagement. Moreover, individuals with bipolar disorder were predicted to be even more motivated by the reward (gain) trials, especially when they were hard, because these individuals are particularly sensitive to reward. Results supported these predictions, revealing that individuals with bipolar disorder, as compared to other individuals, had greater relative left frontal cortical activity to the hard/rewarding task. In addition, among individuals with bipolar disorder, their self-reported hypomanic state correlated with greater left frontal activity to the tasks. Taken together, these results suggest that bipolar disorder partially influenced left frontal activity to the challenging and rewarding task via hypomanic state at the time of EEG recording.

Other trait variables relate to resting frontal asymmetry. For instance, Nash, Inzlicht, and McGregor (2012) found that greater relative right frontal activity related to increased error monitoring as measured by the ERP referred to as the error-related negativity. These results suggest that individuals with greater relative right frontal activity may be more concerned with making mistakes and with punishment. Similarly, other research has revealed that greater relative right frontal activity is associated with less risk taking (Gianotti et al., 2009).

4.2 | The influence of situational manipulations of motivation on asymmetric frontal cortical activity

4.2.1 | Pictures of motivationally significant stimuli

Some experiments have not found expected effects of affective/motivationally significant pictures on asymmetric frontal cortical activity (Elgavish, Halpern, Dikman, & Allen, 2003; Hagemann, Naumann, Becker, Maier, & Bartussek, 1998; see reviews by Murphy, Nimmo-Smith, & Lawrence, 2003; Pizzagalli, Schackman, & Davidson, 2003). These failures may have been due to the fact that the pictures evoked different levels of motivation across participants. That is, some participants may have responded with little to no motivation, while others responded with much more motivation (Harmon-Jones, 2007). In tests of this idea, studies first measured participants' self-reported liking for dessert and the time since they had last eaten; these measures served as assessments of individual differences in emotion and motivation. Then, participants viewed dessert pictures and neutral pictures while EEG was recorded. Results indicated that individuals with stronger emotive tendencies (longer time since eaten, more liking for dessert) toward pictures of desserts had greater relative left frontal activity to dessert stimuli but not to neutral stimuli (Gable & Harmon-Jones, 2008; Harmon-Jones & Gable, 2009). In these studies, the emotive pictures alone did not cause significant shifts in asymmetric frontal cortical activity; in other words, there was no main effect of picture type on asymmetry.

These results suggest that relative left frontal activity measured in the lab is at least partially dependent on individual differences that persons have toward the stimuli (e.g., liking of desserts) and have as a result of when they last satisfied a particular motive (e.g., time since last eating). Of course, some stimuli may be sufficiently strong such that they activate approach (or withdrawal) motivation in all participants. Along these lines, Schöne, Schomberg, Gruber, and Quirin (2016) found that erotic stimuli evoked relative left frontal activity in all of their participants.

The above experiments measured EEG alpha power. Other experiments have measured asymmetric frontal cortical activity using ERPs to affective/motivationally significant pictures. For example, van de Laar, Licht, Franken, and Hendriks (2004) found that individuals addicted to cocaine had larger positive slow wave responses over the left (but not right) frontal region when viewing cocaine-related photographs as compared to neutral photographs. In another experiment (Gable & Harmon-Jones, 2010), participants viewed pictures designed to evoke low (neutral rocks) or high (desserts for persons who reported liking desserts) approach motivation. Late positive potential (LPP) amplitudes to dessert pictures were larger in left hemisphere frontal-lateral sites than right hemisphere frontal-lateral sites, but these hemispheric differences did not occur for neutral pictures (for a replication, see Gable & Harmon-Jones, 2013). Similar effects have been found when pictures of alcohol cues are presented to individuals who like alcohol (Gable, Mechin, & Neal, 2016).

4.2.2 | Positive affects varying in approach and asymmetric frontal cortical activity

If relative left frontal cortical activity reflects the intensity of approach motivation rather than positive affect per se, then it should be possible to manipulate the intensity of approach motivation within positive affect while holding positive affect constant to test this proposition. In other words, positive affects high in approach motivation should evoke greater relative left frontal cortical activity than positive affects low in approach motivation even when both types of positive affect are equal in positivity.

One of the first experiments to test this idea had participants describe the steps needed to obtain a desired goal (positive action-oriented), describe a normal day (neutral), or describe a past event that made them feel good without personal action (positive, inaction-oriented; E. Harmon-Jones, C. Harmon-Jones, Fearn, Sigelman, & Johnson, 2008, experiment 2). Results revealed that self-reported positivity (*enthusiastic*, *interested*, *happy*, *proud*, and *feel good about myself*) was greater in the action- and inaction-oriented positive conditions as compared to the neutral condition, suggesting that the two positive affect conditions evoked equal levels of positivity. Moreover and consistent with predictions, participants in the positive action-oriented condition evidenced greater relative left frontal cortical activity relative to participants in the other two conditions. That is, high approach positive affect caused greater relative left frontal cortical activity than low approach positive affect.

4.2.3 | Facial expressions of approach-motivated positive affect

Facial expressions are another way that different levels of approach-motivated positive affect have been manipulated. First, research was needed to discover which positive emotions were associated with low versus high approach-motivated positive affect. So, in one experiment, participants were instructed to complete the action-orientation writing task manipulation described in the previous paragraph; then, the participants simply wrote one word that best described how they felt during the situation described (C. Harmon-Jones, Schmeichel, Mennit, & Harmon-Jones, 2011). Participants were most likely to write "determined," which is also a word on the positive activation scale of the PANAS (Watson, Clark, & Tellegen, 1988). In the next experiment, participants were simply asked to make a facial expression that best expressed "determination" or a low approach-motivated positive emotional facial expression of "satisfaction" or a neutral facial expression (Price, Hortensius, & Harmon-Jones, 2013). Finally, in this same experiment, participants completed a task to measure behavioral persistence. Results revealed that participants who made the facial expression of high approach-motivated positive affect had greater relative left frontal activity than participants in the other two facial expression conditions. Moreover, within this key condition, greater relative left frontal cortical activity was correlated with greater behavioral persistence, suggesting that the greater relative left frontal cortical activity was associated with more behavioral approach.

4.2.4 | Using body posture to manipulate approach motivation

Another experiment conceptually replicated these effects using a different manipulation of high and low approach-motivated positive affect. Based on previous research (e.g., Harmon-Jones & Peterson, 2009; Price & Harmon-Jones, 2011), this manipulation had two levels: high approach motivation was manipulated by having sitting participants lean forward, as though they were reaching out for a desired object; low approach motivation was manipulated by having participants recline backward in a reclining chair (Harmon-Jones, Gable, & Price, 2011). While sitting in a chair in one of these two postures, participants viewed appetitive (dessert) and neutral (rock) pictures through video glasses in order to maintain a consistent viewing distance. Results revealed that participants in the high approach leaning-forward posture had greater relative left frontal activity to appetitive dessert as compared to neutral rock pictures. In contrast, participants in the low approach reclining-backward posture did not have a difference in relative left frontal activity to appetitive versus neutral pictures. Thus, this manipulation of body posture influenced relative left frontal cortical activity to appetitive versus neutral pictures, suggesting that this manipulation influenced approach motivation (see Price, Dieckman, & Harmon-Jones, 2012, for additional evidence consistent with this interpretation).

4.2.5 | Approach motivation and dissonance reduction

The above studies focused primarily on positive affect, but approach motivation can also occur during the experience of negative affect, as we review more fully below when we consider anger (see also Harmon-Jones et al., 2013). Another situation in which approach motivation can occur during the experience of negative affect is during the experience of cognitive dissonance. The action-based model of cognitive dissonance proposes that, following a decision, organisms are poised for action, and this action-oriented state is an approach-motivated one. In other words, once an individual makes a decision or a commitment to an action, she should be approach motivated to enact that decision or follow through with that commitment (Harmon-Jones, 1999; Harmon-Jones & Harmon-Jones, 2002; Harmon-Jones, Amodio, & Harmon-Jones, 2009; Harmon-Jones, Harmon-Jones, & Levy, 2015). Because the commitment should increase approach motivation, it should also enhance relative left frontal cortical activity. In addition, the increase in approach motivation should assist with cognitive dissonance reduction.

In one of the first tests of these ideas, participants were randomly assigned to a low choice or a high choice writing condition in which they wrote a counterattitudinal essay (increase tuition at their university; Harmon-Jones, Gerdjikov et al., 2008). This choice manipulation has been used since the 1960s by researchers to induce cognitive dissonance. Essentially, it gives individuals in the low choice condition a feeling or perception of having no choice but to write the counterattitudinal essay as part of the experiment (i.e., the instructions indicate that the participant has been randomly assigned to write the essay). Or it gives individuals in the high choice condition a feeling or perception of having freely chosen to write the same counterattitudinal essay (i.e., the instructions give the participants a plausible reason that the experiment needs the essay but then remind the participants that it is their choice to write the essay). Immediately after participants started to write the counterattitudinal essay, EEG activity was recorded. Results revealed that participants in the high-choice condition had greater relative left frontal activation than participants in the low-choice condition. Harmon-Jones, Harmon-Jones, Serra, and Gable (2011) replicated this effect, and also found that greater relative left frontal cortical activity occurred even when participants were given high choice to write proattitudinal essays. These latter results suggest that the high choice or commitment to action is the critical variable causing the increase in relative left frontal cortical activity.

Another experiment (Harmon-Jones, Harmon-Jones et al., 2008) used neurofeedback of asymmetric frontal cortical activity and found that the neurofeedback reduced relative left frontal activity, replicating previous results (Allen et al., 2001). Moreover, this manipulated reduction in relative left frontal activity produced less cognitive dissonance reduction, as predicted by the action-based model (Harmon-Jones, Harmon-Jones et al., 2008). More specifically, the neurofeedback-induced decrease in relative left frontal activity caused less attitude change following a difficult decision as compared to the condition in which neurofeedback was used to attempt to increase relative left frontal activity (although the neurofeedback did not successfully increase relative left frontal activity). This postdecisional attitude change has been referred to as spreading of alternatives because, after a difficult decision, individuals increase their liking of their chosen alternative and decrease their liking of their rejected alternative. That is, individuals spread their attitudes toward the decision alternatives farther apart from each other after a difficult decision compared to prior to the decision. According to the action-based model, this spreading of alternatives should assist with translating the decision into an effective decision or effective course of action. In other words, the increased spreading of alternatives should make the individual less conflicted about which alternative is best, and this should cause the individual to no longer vacillate between the decision options. That the manipulated decrease in relative left frontal activity caused a decrease in the spreading of alternatives suggests that decreasing approach motivation decreases cognitive dissonance reduction (see C. Harmon-Jones, Schmeichel, Inzlicht, & Harmon-Jones, 2011, and Harmon-Jones, Price, & Harmon-Jones, 2015, for other behavioral evidence linking approach motivation with dissonance reduction).

4.2.6 | Ego depletion increases approach motivation

A large body of research has suggested that, immediately after individuals engage in a bout of effortful self-control (e.g., inhibiting the desire to eat a tasty dessert), they suffer a reduction in self-control, so that they are more likely to fail at other types of self-control (e.g., react more aggressively to an insult; Stucke & Baumeister, 2006). This effect, referred to as ego depletion, was originally predicted and explained by the strength model of self-control, which posits that self-control is a limited resource or strength (Muraven & Baumeister, 2000). If an individual has recently engaged in self-control, then this limited resource or strength may be depleted and subsequent efforts at self-control may fail.

However, in the majority of studies testing this ego-depletion effect, the initial acts of self-control caused increases in subsequent approach-motivated behaviors (e.g., food consumption, impulsive aggression). Thus, these results could instead indicate that exercising self-control causes an increase in approach motivation. Some studies have supported this interpretation by finding that exercising self-control increases self-reported approach motivation, approach-motivated behavior, and perception of reward-relevant symbols (Schmeichel, Harmon-Jones, & Harmon-Jones, 2010). Taken together, these results suggest that failures of self-control that follow from prior self-control efforts (i.e., ego depletion) may be explained partially by increased approach motivation.

A study examining asymmetric frontal cortical activity to pictures that evoke affective responses provided further evidence along these lines. In this study, individuals who exercised self-control on a first task (i.e., an essay-writing task in which certain letters could not be used) had increased relative left frontal cortical activity while viewing pictures that evoked affective states. This effect was particularly evident among individuals with higher BAS than BIS, and particularly during positive picture viewing (Schmeichel, Crowell, & Harmon-Jones, 2016).

4.2.7 | Summary of section

Taken together, these studies suggest that relative left frontal cortical activity is associated with approach motivation even when the approach motivation is not perfectly related with positive affect. For instance, relative left frontal activity is greater when individuals are experiencing positive affective states that are high versus low in approach motivation, even when the two positive affective states are equivalent in general positivity (e.g., feelings of good mood or happiness). In addition, relative left frontal activity is also increased by manipulations that have no impact on positive affect but if anything increase negative affect. The cognitive dissonance experiments showing that commitments to chosen courses of action increase relative left frontal cortical activity provide evidence that shows that even when the motivational manipulations do not influence positive affect, they still influence relative left frontal cortical activity.

5 | ASYMMETRIC FRONTAL CORTICAL ACTIVITY AND ANGER

Perhaps even more compelling evidence for the idea that relative left frontal cortical activity is associated with approach motivation independent of positive affect comes from research on anger. Anger is often considered to be a negatively valenced emotion that evokes behavioral tendencies of approach (e.g., Darwin, 1872; Ekman & Friesen, 1975; Plutchik, 1980; Young, 1943). Anger is often associated with attack and offensive aggression (e.g., Berkowitz & Harmon-Jones, 2004; Blanchard & Blanchard, 1984; Lagerspetz, 1969). Offensive aggression can be distinguished from defensive aggression, which is associated with fear instead of anger. Offensive aggression is associated with attacks without attempts to escape, whereas defensive or fear-based aggression is associated with attacks only when escape is not possible.

Research with young children has revealed that anger is associated with approach motivation (e.g., Izard, 1991; Lewis, Alessandri, & Sullivan, 1990; Lewis, Sullivan, Ramsay, & Alessandri, 1992). Research with adults has revealed that individual differences in trait behavioral approach sensitivity (BAS) are associated with anger-related responses. For instance, trait BAS, as assessed by Carver and White's (1994) scale, is positively correlated with trait anger (Harmon-Jones, 2003b; Smits & Kuppens, 2005). Trait BAS is also correlated with more intense anger in response to situational anger manipulations (Carver, 2004). And trait BAS sensitivity is correlated with more aggressive inclinations particularly when approach motivation is first activated (Harmon-Jones & Peterson, 2008). In addition, trait BAS is correlated with more vigilant attention to angry faces presented out of conscious awareness; this finding is consistent with the idea that attention toward angry faces is involved in an approach-based dominance confrontation (Putman, Hermans, & van Honk, 2004).

Given this and other evidence linking anger with approach motivation (see Carver & Harmon-Jones, 2009; Harmon-Jones, Harmon-Jones, Abramson, & Peterson, 2009; Harmon-Jones et al., 2013, for reviews), research has examined the relationship between anger and relative left frontal cortical activity, to attempt to provide even more compelling evidence that relative left frontal activity is associated with approach motivation even when the affect associated with the approach motivation is not positive.

5.1 | Resting asymmetric frontal cortical activity and trait anger

In one of the first tests of the relationship between anger and relative left frontal cortical activity, trait anger was measured with the Buss and Perry (1992) Aggression Questionnaire, and relative left frontal activity was measured by examining baseline, resting EEG activity (Harmon-Jones & Allen, 1998). In this study of adolescents, trait anger correlated with greater relative left frontal activity. Trait anger did not relate to asymmetric cortical activity in other nonfrontal regions. This specificity of anger to asymmetric activity in frontal regions but not in other regions has been observed consistently in studies on anger.

This finding has been replicated in adult populations. For instance, one study with university students found that trait anger related to greater relative left frontal activity during a resting baseline session (Harmon-Jones, 2004). The same study also measured attitudes toward anger and found that, although individuals generally dislike anger, trait anger correlated directly with attitudes toward anger, such that individuals who scored high in trait anger liked anger more. However, attitudes toward anger did not correlate with relative left frontal cortical activity, suggesting that the relationship between anger and relative left frontal activity was not due to anger being regarded as a positive affect. In another study, relative left frontal activity correlated with trait anger (using the Buss and Perry [1992] Aggression Questionnaire) in incarcerated violent offenders (Keune et al., 2012). Likewise, greater relative left frontal activity has been found to be correlated with aggression in adults with ADHD (Keune et al., 2011).

5.2 | Manipulation of asymmetric frontal cortical activity and anger reactions

To test whether the manipulation of asymmetric frontal cortical activity would influence anger-related responses, several different methods have been used. In one of the first experiments of this sort, slow repetitive transcranial magnetic stimulation (rTMS) was used to inhibit the left or right prefrontal cortex (d'Alfonso, van Honk, Hermans, Postma, & de Haan, 2000). Because slow rTMS inhibits cortical excitability, rTMS applied to the right frontal cortex should decrease its activation and cause the left frontal cortex to become more active. Conversely, rTMS applied to the left frontal cortex should increase activation of the right frontal cortex. This research found that rTMS applied to the right frontal cortex increased selective attention toward angry faces, whereas rTMS applied to the left frontal cortex increased selective attention away from angry faces. In other words, increased left frontal cortical activity caused participants to be more attentionally engaged toward approach angry faces, in a manner similar to an aggressive confrontation. In contrast, increased right frontal cortical activity caused participants to be more attentionally avoidant of angry faces, in a manner similar to fear-based avoidance. These results have been conceptually replicated (van Honk & Schutter, 2006).

In an extension of this research, we tested whether manipulating asymmetric frontal cortical activity would influence behavioral aggression. To manipulate asymmetric frontal cortical activity, unilateral hand contractions were used. Their use was based on research that had found that contraction of the left hand increases relative right frontal cortical activity and that contraction of the right hand increases relative left frontal cortical activity (Harmon-Jones, 2006). In this experiment on aggression, participants first contracted their right or left hand by squeezing a rubber ball for approximately 4 min. Participants then received insulting interpersonal feedback. Next, participants played a reaction time game against the other (ostensible) participant who had insulted them. This game provided a measure of behavioral aggression. In the game, participants could deliver to the other participant a noise blast (60 to 100 dB of white noise) for up to 10 s if they responded faster than the other participant when an image appeared on the computer screen. As predicted, participants who contracted their right hand had greater relative left central and frontal cortical activity than participants who contracted their left hand. Moreover, those who contracted their right hand gave louder and longer noise blasts to the other participant than those who contracted their left hand (Peterson, Shackman, & Harmon-Jones, 2008). Finally, within the right-hand contraction condition, greater relative left frontal activity correlated with more behavioral aggression.

In a subsequent experiment, unilateral hand contractions were again manipulated, and anger was induced with social rejection or ostracism (Peterson, Gravens, & Harmon-Jones, 2011). Replicating the previous results, right-hand contractions caused greater relative left frontal cortical activation than left-hand contractions did. Moreover, as compared to left-hand contractions, right-hand contractions also caused greater self-reported anger in response to being ostracized.

Another study used transcranial direct current stimulation (tDCS) to manipulate relative left versus relative right frontal activity (Hortensius, Schutter, & Harmon-Jones, 2012). tDCS typically uses two electrodes—an anodal and a cathodal one—to administer weak electrical currents that induce changes in cortical excitability; these changes are thought to result from changes in the membrane potential (Nitsche & Paulus, 2000). Anodal tDCS increases cortical excitability, whereas cathodal tDCS decreases cortical excitability (Nitsche & Paulus, 2000). The use of these two tDCS electrodes over the frontal cortex allows simultaneous manipulation of the left and right frontal cortex; activity in one hemisphere is increased while activity in the corresponding contralateral hemisphere is decreased. In this study on anger and aggression, participants were randomly assigned to one of three conditions: one designed to increase relative right frontal activity, one designed to increase relative left frontal activity, and one that served as a sham control condition (i.e., participants received only a few seconds of tDCS in the sham condition but received 15 min of tDCS in the other two conditions). After receiving tDCS, participants received insulting interpersonal feedback and then were given an opportunity to act aggressively against the "person" who had insulted them, as in the study by Peterson, Shackman, and Harmon-Jones (2008). Results indicated that, within the increase-left-frontal-activity condition, those who reported feeling the angriest about the insulting feedback engaged in the most aggression. In other words, self-reported anger was correlated with more aggression. Within the other conditions, no significant correlation between anger and aggression emerged. Taken together, these results suggest that anger is most likely to lead to aggression when relative left frontal cortical activity is greatest.

5.3 | Influence of state anger on asymmetric frontal cortical activity

Experiments have been conducted to test the effects of manipulated anger on relative left frontal cortical activity. In one of the first such experiments, individuals who were given an interpersonal insult (i.e., insulting feedback on an essay they had written) had greater relative left frontal activity than individuals who were not insulted (i.e., given mildly positive feedback; Harmon-Jones & Sigelman, 2001). Within the insult condition, results revealed that self-reported anger and behavioral aggression were positively correlated with relative left frontal activity. Jensen-Campbell, Knack, Waldrip, and Campbell (2007) and Verona, Sadeh, and

Curtin (2009) conceptually replicated the above results, using different designs.

In another experiment, some participants were first induced to feel sympathy for a person who insulted them, and some were not. This manipulation of sympathy influenced relative left frontal activity to the interpersonal insult, such that sympathy reduced the effect of insult on relative left frontal activity (Harmon-Jones, Vaughn-Scott, Mohr, Sigelman, & Harmon-Jones, 2004), consistent with the idea that sympathy reduces aggressive impulses (Miller & Eisenberg, 1988).

Subsequent experiments have conceptually replicated these results. In one experiment, a social rejection experience was developed and found to increase self-reported anger and jealousy; moreover, the social rejection increased relative left frontal cortical activity, which was correlated with anger and jealousy correlated with anger and jealousy (Harmon-Jones, Peterson, & Harris, 2009). A subsequent experiment using this same jealousy-evoking paradigm found that participants who were induced to have increased relative left frontal cortical activity via tDCS reported feeling more jealousy than participants in a sham-control condition and participants induced to have increased relative right frontal activity (Kelley, Eastwick, Harmon-Jones, & Schmeichel, 2015). Similarly, 1-year-old infants who had greater relative left frontal activity at baseline displayed more jealousy-related responses when their mothers attended to a social rival (Mize & Jones, 2012).

Another study recorded asymmetric frontal cortical activity when individuals with borderline personality disorder, major depressive disorder, or no disorder were subjected to a social rejection using Cyberball (Beeney, Levy, Gatzke-Kopp, & Hallquist, 2014). Compared to individuals with no disorder, individuals with borderline personality disorder showed greater relative left frontal activity to the social rejection, whereas individuals with major depressive depression showed greater relative right frontal activity. These results are consistent with other research that suggests that individuals with major depressive disorder are more likely to respond with withdrawal and isolation to social rejection, whereas individuals with borderline personality disorder are more likely to respond with increased approach behaviors and hostility to social rejection.

Individual differences in trait BAS have also been found to relate to relative left frontal cortical activity to anger inductions (Gable & Poole, 2014). In this study, Carver and White's BIS/BAS scales were used to measure trait withdrawal/approach sensitivities. Anger was induced using pictures, particularly those displaying anti-American images such as flag burning (as used in Harmon-Jones, Harmon-Jones, Amodio, & Gable, 2011). Individual differences in BAS correlated with greater relative left frontal cortical activity (measured using EEG alpha power) to anger pictures controlling for relative left frontal activity to neutral pictures. In addition, BAS correlated with larger LPPs to anger pictures, but not to neutral pictures. Finally, larger LPP amplitudes to anger pictures related to greater relative left frontal cortical activity during anger pictures.

5.4 | Independent manipulation of approach motivation within anger

Anger is often associated with approach motivation. However, there may be occasions in which anger is not associated with approach motivation. For instance, some situations may make it impossible to act on angry urges and thus reduce the approach motivation of anger. Past theory and research suggest that when individuals believe that it is impossible to act, or when they expect to have low coping potential, they should have low motivational intensity (Brehm, 1999; Brehm & Self, 1989).

Using these theoretical inspirations, research has attempted to manipulate approach motivation independently of the anger experience by manipulating the possibility of action. In one of the first experiments testing these ideas, participants were angered and prior to being angered led to believe they could or could not act on their anger by taking actions that might resolve the anger-inducing event (i.e., sign petitions to prevent a tuition increase at their university; Harmon-Jones, Sigelman, Bohlig, & Harmon-Jones, 2003). As predicted, participants who were angered and expected to be able to engage in the approach-related action had greater relative left frontal activity than participants who were angered and expected to be unable to engage in approach-related action. In addition, within the action-possible condition (but not within the other condition), participants who had greater relative left frontal activity in response to the angering event also reported more anger and engaged in more approach-related behavior (i.e., signed the petition and took more petitions to have others sign them).

This effect of manipulated approach motivation associated with anger influencing relative left frontal activity has been conceptually replicated using pictorial stimuli (Harmon-Jones, Lueck, Fearn, & Harmon-Jones, 2006). In this study, individuals who scored low in racial prejudice viewed photographs designed to evoke feelings of anger, fear/disgust, positivity, or neutrality. The photographs designed to evoke anger depicted instances of racism and hatred (e.g., neo-Nazis, Ku Klux Klan). Before participants viewed the photographs, half of them were told that they would be asked to compose an essay on why racism is immoral, unjust, and unfair at the end of the experiment, and that this essay would be shown to other participants in a prejudice-reduction experiment. The other half of the participants were not given this instruction. This manipulation was designed to increase anger-related approach motivation for those who expected to write the essay. As predicted, participants who expected to act on their anger had greater relative left frontal activity to racist photographs than other photographs; participants who did not expect to act on their anger did not respond differently to the different types of photographs.

The results described above may seem to suggest that greater relative left frontal cortical activity will only occur in response to anger-evoking situations when explicit approach motivational opportunities exist. Research, however, suggests this not to be the case. That is, explicit opportunities to approach intensify relative left frontal activity, but they are not necessary for it to occur. For example, one study found that, when participants were shown anger-evoking pictures (and other pictures) and given no explicit manipulations of approach behavioral opportunities, those who scored higher in trait anger had greater relative left frontal activity to anger pictures compared to other pictures (Harmon-Jones, 2007). These results suggest that the explicit opportunity for approach-motivated behavior increases the effects of anger on relative left frontal activity but is not necessary to evoke relative left frontal activity during anger.

Another experiment provided support for the idea that the approach motivational intensity associated with anger influences relative left frontal activity. In this experiment, whole body posture was manipulated to influence approach motivational intensity (Harmon-Jones & Peterson, 2009). The idea that whole body postures can influence approach motivational intensity is supported by past research that has found that slumped postures can cause more "helpless behaviors" (Riskind & Gotay, 1982). Building on this research, we surmised that a supine body posture is antithetical to approach motivation, or the urge to move toward something (Harmon-Jones et al., 2013). In the experiment, after being randomly assigned to an upright or reclined (supine) body position, participants heard neutral or insulting interpersonal feedback, as in previous research (Harmon-Jones & Sigelman, 2001). Replicating past research, participants who received insulting feedback while sitting upright had greater relative left frontal activity than participants who received neutral feedback while sitting upright. More important, participants who received insulting feedback while in a reclined position had relative left frontal activity equal to participants in the neutral feedback/upright condition and lower than participants in the insulting feedback/upright condition. Thus, these results provide further evidence suggesting that anger relates to relative left frontal activity because of approach motivation—when approach motivation was reduced, anger did not cause greater relative left frontal activity.

5.5 | Anger and withdrawal motivation

The available evidence suggests that greater relative left frontal activity is correlated with anger because anger is often associated with approach motivation. However, if anger is not invariably correlated with approach motivation, is it possible for anger to be associated with withdrawal motivation and an increase in right frontal activation?

In one of the first experiments designed to test this idea, Wacker, Heldmann, and Stemmler (2003) had soccer players imagine that they were unfairly prevented from playing a soccer game by the coach. In the condition designed to evoke anger with approach motivational inclinations, the players imagined approaching the coach and protesting. In the condition designed to evoke anger with withdrawal motivational inclinations, they imagined backing out of the locker room and swearing silently at the coach. Both conditions evoked self-reported anger and increased relative left frontal cortical activity, but the two conditions did not differ from each other.

In another correlational study, Hewig, Hagemann, Seifert, Naumann, and Bartussek (2004) used the trait anger-out, trait anger-in, and trait anger-control scales of the State-Trait Anger Expression Questionnaire (Spielberger, 1988) to assess the relationships of these variables with resting baseline asymmetric frontal cortical activity. Trait anger-out likely taps approach-motivated anger as it is characterized as "expressing angry feelings in aggressive verbal or motor behavior directed toward other people or objects in the environment" (e.g., "When angry or furious, I lose my temper"; Spielberger, Reheiser, & Sydeman, 1995, p. 57). Trait anger-in taps the degree to which persons hold in anger (e.g., "When angry or furious, I keep things in"); and trait anger-control taps the degree to which persons control their anger (e.g., "When angry or furious, I control my angry feelings"). Consistent with previous results with approach-motivated anger, trait anger-out correlated with greater relative left frontal activity. In a novel extension of previous research, trait anger-control was found to be correlated with greater relative right frontal activity. Finally, trait anger-in was not correlated with asymmetric frontal cortical activity. Hewig et al. (2004) interpreted these results by positing that anger-control correlated to relative right frontal activity because individuals who score high in anger-control also score high in withdrawal motivation.

Anger may be associated with withdrawal motivational tendencies, but the evidence collected thus far provides mixed support for the idea. Anger may be most likely to be associated with withdrawal motivation when the situation evokes the feeling of anger along with concerns about being punished and anxiety. One situation in which this type of mixed state may occur is one in which a person is angry about a social policy that most other persons accept, and thus he worries about expressing anger about the policy. In such a situation, the angry person may be motivated to withdraw so as to avoid social punishments that might occur if others noticed the anger.

A social situation in which this type of anger may occur is one in which some individuals are angry about the pressure to act in accord with norms that encourage political correctness and discourage public expressions of racial prejudice (Plant & Devine, 1998). If an individual feels angry because of such, he may be motivated to withdraw even though he feels angry (and probably anxious about the social pressure). Consistent with these ideas, research has revealed that some individuals feel angry when socially pressured to respond without racial prejudice (Plant & Devine, 2001).

In the study by Zinner, Brodish, Devine, and Harmon-Jones (2008), White participants were told they were going to interact with a Black participant (as in Plant & Devine, 2003). To increase the chance that some participants would feel angry, pressure to act in a politically correct manner was applied by emphasizing the social importance of having harmonious interracial interactions. Once participants were told they would interact with a Black person, their EEG was assessed as they were asked to "mentally prepare" for the interaction. After this EEG recording and just prior to the expected interaction, participants reported their affective state concerning the upcoming interaction. As expected, self-reported anger correlated with greater relative right frontal cortical activity (controlling for baseline measurements of both variables). In other words, White individuals who felt more anger about the upcoming interaction with a Black person also had greater relative right frontal activity. Anger also correlated with greater skin conductance levels; these results suggest that individuals who felt more anger had more sympathetic nervous system activity. In addition, anger correlated with more spontaneous eye blinking, which has been found to be correlated with efforts at suppressing emotions (Gross & Levenson, 1993). These results suggest that the angered participants may have been trying to suppress their anger because they were concerned about being socially inappropriate. Finally, self-reported anger correlated with self-reported anxiety, suggesting that this social situation had also evoked punishment concerns for those individuals who were angry. Taken together, these results are consistent with the idea that anger may be correlated with relative right frontal cortical activity when individuals are motivated to withdraw.

Anger may also be associated with withdrawal motivation when anger is associated with rumination. When individuals are inhibited from acting on their anger, they may ruminate about it; that is, they may have repetitive thoughts about their angry situation that are difficult to inhibit and are associated with a passive focus on the anger (e.g., Nolen-Hoeksema, 2000). Consistent with the idea that rumination is associated with withdrawal motivation and perhaps relative right frontal activity, research has found that trait rumination is correlated with BIS and not BAS (Denson, Pedersen, & Miller, 2006), and trait rumination is more highly correlated with trait anger toward oneself than with trait anger toward other people (Martin & Dahlen, 2005). In this study on anger and rumination (Kelley, Hortensius, & Harmon-Jones, 2013), participants were randomly assigned to receive one of three tDCS treatments to increase relative right, relative left, or neither hemispheric frontal activity, as in Hortensius et al. (2012). Then, participants received insulting interpersonal feedback. However, unlike past research, they never expected any opportunity to retaliate. After receiving the feedback, participants completed questionnaires designed to measure rumination about the situation. Results revealed that participants who received tDCS to increase relative right frontal activity ruminated more than participants in the other conditions. Thus, when individuals are blocked from acting on their anger, those who have greater relative right frontal cortical activity show increased repetitive thoughts about their situation and a passive focus on their anger.

5.6 | Questions about the anger research

Some scientists have raised questions and concerns about the use of anger to address conceptual issues surrounding asymmetric frontal cortical activity. For example, Watson (2009) suggested that anger has both approach and avoidance properties. As reviewed above, research has revealed that anger is associated with both approach and avoidance (e.g., Harmon-Jones, 2003b). However, based on the evidence, we believe that it is more often associated with approach motivation, and when it is associated with avoidance, it is also associated with fear/anxiety and relative right frontal activity (e.g., Zinner et al., 2008).

Others have raised questions about the relationship of different types of anger with asymmetric frontal cortical activity (e.g., Miller, Crocker, Spielberg, Infantolino, & Heller, 2013) but typically done so with correlational studies (e.g., Stewart, Levin-Silton, Sass, Heller, & Miller, 2008). We believe that conceptual questions are often best examined in experiments in which the conceptual variables can be directly manipulated. Ideally, these manipulations would involve relatively strong manipulations of emotive processes; studies that simply have participants read emotion-related words are unlikely to manipulate emotional experiences or motivational intensity for the majority of individuals.

We believe this review presents conceptually and empirically strong work linking angers that vary in motivational direction and intensity with patterns of asymmetric frontal cortical activity. As such, we hope it addresses many questions that have been raised.

5.7 | Investigating guilt: Toward an understanding of temporal dynamics of emotion processes

Research on asymmetric frontal cortical activity and guilt yielded some novel insights by delving into the issue of whether asymmetric frontal cortical activity varies with changes in motivational intensity over relatively brief periods of time. In other words, if relative left frontal cortical activity is associated with approach motivation, it should change as approach motivational intensity changes. Guilt provides an interesting test case, because guilt has been posited to serve two distinct motivational functions that operate in temporal sequence (Amodio, Devine, & Harmon-Jones, 2007). That is, guilt has been proposed to first cause a reduction in approach motivation when the person becomes aware of having committed a social transgression. This reduced approach motivation is then followed by increased approach motivation when the person has a behavioral opportunity to repair the transgression.

In one test of these hypotheses, White Americans who scored low in self-reported racial prejudice were given rigged feedback that pointed out they had just provided physiological evidence of prejudice toward Blacks while viewing pictures of Blacks, Whites, and Asians. Immediately following the presentation of this feedback on the computer monitor, EEG was recorded for 2 min and self-reported emotions were assessed. Then, the participants' responses to stimuli associated with repairing the transgression (e.g., prejudice reduction) were measured. This reparation behavior was assessed by showing participants magazine article titles that were relevant (e.g., "10 ways to reduce prejudice in everyday life") or irrelevant to reparation (e.g., "Five steps to a healthier lifestyle"). In response to each title, participants indicated the extent to which they would want to read the article.

In support of hypotheses, self-reported guilt was associated with a decrease in relative left frontal cortical activity to the feedback; this suggested a decrease in approach motivation occurred initially. Later, when participants were given the opportunity to repair their transgression, self-reported guilt was correlated with more interest in prejudice-reducing behavior, which was also associated with greater relative left frontal activity. These results suggest that asymmetric frontal cortical activity varies with changes in approach motivation even when these changes occur over relatively brief periods of time. Future research along these lines is needed to further examine the dynamic changes of motivation using asymmetric frontal cortical activity.

6 | SUMMARY, FUTURE DIRECTIONS, AND CONCLUSION

In this article, we have reviewed research that has shown that greater relative left frontal cortical activity is associated with approach motivational processes, whereas greater relative right frontal cortical activity is associated with withdrawal motivational processes. However, much less research has tested the relationship of relative right frontal activity and withdrawal motivation. Future research is thus needed to address this relationship.

The research we reviewed is more consistent with predictions derived from the motivational direction model than the affective valence model. For many psychological traits and states, the two models converge in their predictions and explanations of the observed results, because most positive affects are associated with approach motivation and most negative affects are associated with withdrawal motivation. The two models diverge in their predictions for anger: The affective valence model predicts anger as a negative affect should be associated with greater relative right frontal activity, whereas the motivational direction model predicts anger as an approach motivation should be associated with greater relative left frontal activity. As reviewed, anger has been found to be associated with greater relative left frontal activity. The two models would also diverge in their predictions for low versus high approach-motivated positive affect. The affective valence model would predict that both types of positive affect would be associated with greater relative left frontal activity. However, the research that has been conducted so far has revealed that high approach-motivated positive affect is associated with greater relative left frontal activity than low approach-motivated positive affect (Harmon-Jones, Harmon-Jones et al., 2008; Price et al., 2013). These results are consistent with predictions derived from the motivational direction model. It should be noted, however, that there are only a few experiments comparing the effects of low versus high approach-motivated positive affect on asymmetric frontal cortical activity. More research of this kind is needed. Also needed is research examining negative affective states that vary in the intensity of withdrawal motivation.

The frontal cortex is involved in a number of psychological processes, and it is possible that asymmetric frontal cortical activity may still be associated with affective valence. Other methods such as fMRI may reveal more complex patterns of activation (e.g., Miller et al., 2013), but the EEG research, although less spatially sensitive, is consistent with lesion work, tDCS/rTMS research, and research using magnetoencephalography (Moran, Weierstall, & Elbert, 2014). Apparently, there are some large areas of the left and right frontal cortices sensitive to electrical measures and manipulations that relate to approach and withdrawal motivation. Moreover, these results are consistent with research conducted with nonhuman animals (e.g., Gygax, Reefmann, Wolf, & Langbein, 2013; Quaranta, Siniscalchi, & Vallortigara, 2007; Rogers, 2002).

In this article, we reviewed research that suggested that resting asymmetric frontal cortical activity's relationship with other trait variables may be moderated by situational variables. These variables may influence resting asymmetry and trait relationships because these variables influence approach or withdrawal motivation. For instance, certain times of day and seasons (Peterson & Harmon-Jones, 2009) may influence the intensity of approach/withdrawal motivation, and it is possible some individuals may be even more susceptible to these influences (e.g., individuals with seasonal affective disorder or tendencies toward it). Research is needed to further test these ideas. Another situational variable that may influence resting-trait relationships is body posture, which has been found to influence asymmetric frontal cortical activity via its influence on approach motivational intensity (see review by Price, Peterson, & Harmon-Jones, 2012). For example, recording resting EEG while participants are in a supine body posture may reduce approach motivation and also reduce relationships between relative left frontal cortical activity and other measures of trait approach motivation (e.g., BAS). Alternatively, recording resting EEG while participants are in a leaning-forward body posture may increase approach motivation and also increase relationships between relative left frontal cortical activity and other measures of trait approach motivation (assuming, of course, that the leaning forward does not become uncomfortable). Characteristics of the experimenters may also inadvertently influence resting-trait relationships, as Wacker and colleagues' (2013) research has suggested. Experimenters who evoke approach motivation in participants might inadvertently increase relationships between trait approach motivation and relative left frontal activity, whereas experimenters who evoke withdrawal motivation in participants might inadvertently increase relationships between trait withdrawal motivation and relative right frontal activity. All of these ideas need further empirical tests.

Although most of the research reviewed in this article was aimed at understanding the involvement of asymmetric frontal cortical activity in emotive processes, this research has also made other contributions to understanding emotion and motivation more generally. In particular, the research on anger has illustrated how negative affect is not always associated with withdrawal motivation as some previous theories had posited. Moreover, the research on positive affect has illustrated that some positive affects are associated with low approach motivation, whereas other positive affects are associated with high approach motivation.

We hope this review inspires new research on the psychophysiological functions of asymmetric frontal cortical activity. We also hope this review illustrates how psychological theory can assist in a more complete understanding of neural processes, and how psychophysiological research can assist in the development and refinement of psychological theories.

ACKNOWLEDGEMENTS

Portions of this work were funded by a grant from the Australian Research Council (DP150104514).

REFERENCES

Alema, G., Rosadini, G., & Rossi, G. F. (1961). Preliminary experiments on the effects of the intracarotid introduction of sodium amytal in parkinsonian syndromes. *Bollettino della Società italiana di biologia sperimentale*, *37*, 1036–1037.

Allen, J. J. B., Harmon-Jones, E., & Cavender, J. H. (2001). Manipulation of frontal EEG asymmetry through biofeedback alters self-reported emotional responses and facial EMG. *Psychophysiology*, *38*, 685–693. Doi: 10.1111/1469-8986.3840685

Allen, J. J. B., Iacono, W. G., Depue, R. A., & Arbisi, P. (1993). Regional electroencephalographic asymmetries in bipolar seasonal affective disorder before and after exposure to bright light. *Biological Psychiatry*, *33*, 642–646. Doi: 10.1016/0006-3223(93)90104-L

Amodio, D. M., Devine, P. G., & Harmon-Jones, E. (2007). A dynamic model of guilt: Implications for motivation and self-regulation in the context of prejudice. *Psychological Science*, *18*, 524–530. Doi: 10.1111/j.1467-9280.2007.01933.x

Amodio, D. M., Master, S. L. Yee, C. M., & Taylor, S. E. (2008). Neurocognitive components of behavioral inhibition and activation systems: Implications for theories of self-regulation. *Psychophysiology*, *45*, 11–19. Doi: 10.1111/j.1469-8986.2007.00609.x

Amodio, D. M., Shah, J. Y., Sigelman, J., Brazy, P. C., & Harmon-Jones, E. (2004). Implicit regulatory focus associated with resting frontal cortical asymmetry. *Journal of Experimental Social Psychology*, *40*, 225–232. Doi: 10.1016/S0022-1031(03)00100-8

Bauer, M. S., Crits-Christoph, P., Ball, W. A., Dewees, E., McAllister, T., Alahi, P., . . . Whybrow, P. C. (1991). Independent assessment of manic and depressive symptoms by self-rating: Scale characteristics and implications for the study of mania. *Archives of General Psychiatry*, *48*, 807–812. Doi: 10.1001/archpsyc.1991. 01810330031005

Beeney, J. E., Levy, K. N., Gatzke-Kopp, L. M., & Hallquist, M. N. (2014). EEG asymmetry in borderline personality disorder and depression following rejection. *Personality Disorders: Theory, Research, and Treatment*, *5*, 178–185. Doi: 10.1037/per0000032

Berkowitz, L., & Harmon-Jones, E. (2004). Toward an understanding of the determinants of anger. *Emotion*, *4*, 107–130. Doi: 10.1037/1528-3542.4.2.107

Black, E. W. (1975). Unilateral brain lesions and MMPI performance: A preliminary study. *Perceptual and Motor Skills*, *40*, 87–93. Doi: 10.2466/pms.1975.40.1.87

Blanchard R. J., & Blanchard D. C. (1984). Affect and aggression: An animal model applied to human behavior. In R. J. Blanchard & D. C. Blanchard (Eds.) *Advances in the study of aggression* (pp. 1–62). Orlando, FL: Academic Press. Doi: 10.1016/B978-0-12-037701-5.50006-4

Brehm, J. W. (1999). The intensity of emotion. *Personality and Social Psychology Review*, *3*, 2–22. Doi: 10.1207/s15327957pspr0301_1

Brehm, J. W., & Self, E. A. (1989). The intensity of motivation. *Annual Review of Psychology*, *40*, 109–131. Doi: 10.1146/annurev.ps.40.020189.000545

Buss, A. H., & Perry, M. (1992). The Aggression Questionnaire. *Journal of Personality and Social Psychology*, *63*, 452–459. Doi: 10.1037/0022-3514.63.3.452

Carver, C. S. (2004). Negative affects deriving from the behavioral approach system. *Emotion*, *4*, 3–22. Doi: 10.1037/1528-3542.4.1.3

Carver, C. S. (2009). Threat sensitivity, incentive sensitivity, and the experience of relief. *Journal of Personality*, *77*, 125–138. Doi: 10.1111/j.1467-6494.2008.00540.x

Carver, C. S., & Harmon-Jones, E. (2009). Anger is an approach-related affect: Evidence and implications. *Psychological Bulletin*, *135*, 183–204. Doi: 10.1037/a0013965

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. Doi: 10.1037/0022-3514.67.2.319

Coan, J. A., & Allen, J. J. (2003). Frontal EEG asymmetry and the behavioral activation and inhibition systems. *Psychophysiology*, *40*, 106–114. Doi: 10.1111/1469-8986.00011

Coan, J. A., & Allen, J. J. (2004). Frontal EEG asymmetry as a moderator and mediator of emotion. *Biological Psychology*, *67*, 7–50. Doi: 10.1016/j.biopsycho.2004.03.002

Coan, J. A., Allen, J. J. B., & Harmon-Jones, E. (2001). Voluntary facial expression and hemispheric asymmetry over the frontal cortex. *Psychophysiology*, *38*, 912–925. Doi: 10.1111/1469-8986.3860912

Cook, I. A., O'Hara, R., Uijtdehaage, S. H. J., Mandelkern, M., & Leuchter, A. F. (1998). Assessing the accuracy of topographic EEG mapping for determining local brain function. *Electroencephalography and Clinical Neurophysiology*, *107*, 408–414. Doi: 10.1016/S0013-4694(98)00092-3

Cyders, M. A., & Smith, G. T. (2007). Mood-based rash action and its components: Positive and negative urgency. *Personality and Individual Differences*, *43*, 839–850.

d'Alfonso, A. A. L., van Honk, J., Hermans, E., Postma, A., & de Haan, E. H. F. (2000). Laterality effects in selective attention to threat after repetitive transcranial magnetic stimulation at the prefrontal cortex in female subjects. *Neuroscience Letters*, *280*, 195–198. Doi: 10.1016/S0304-3940(00)00781-3

Darwin, C. (1872/1965). *The expressions of the emotions in man and animals*. New York, NY: Oxford University Press.

Davidson, R. J., Chapman, J. P., Chapman, L. J., & Henriques, J. B. (1990). Asymmetric brain electrical-activity discriminates between psychometrically-matched verbal and spatial cognitive tasks. *Psychophysiology*, *27*, 528–543. Doi: 10.1111/j.1469-8986.1990.tb01970.x

Davidson, R. J., & Fox, N. (1982). Asymmetric brain activity discriminates between positive and negative affective stimuli in 10 month old infants. *Science*, *218*, 1235–1237. Doi: 10.1126/science.7146906

Davidson, R. J., & Fox, N. A. (1989). Frontal brain asymmetry predicts infants' response to maternal separation. *Journal of Abnormal Psychology*, *98*, 127–131. Doi: 10.1037/0021-843X.98.2.127

Denson, T. F., Pedersen, W. C., & Miller, N. (2006). The displaced aggression questionnaire. *Journal of Personality and Social Psychology*, *90*, 1032–1051. Doi: 10.1037/0022-3514.90.6.1032

De Pascalis, V., Cozzuto, G., Caprara, G. V., & Alessandri, G. (2013). Relations among EEG-alpha asymmetry, BIS/BAS, and dispositional optimism. *Biological Psychology*, *94*, 198–209. Doi: 10.1016/j.biopsycho.2013.05.016

Ekman, P. (2003). *Emotions revealed*. New York, NY: Henry Holt.

Ekman, P., & Davidson, R. J. (1993). Voluntary smiling changes regional brain activity. *Psychological Science*, *4*, 342–345. Doi: 10.1111/j.1467-9280.1993.tb00576.x

Ekman, P., & Friesen, W. V. (1975). *Unmasking the face: A guide to recognizing emotions from facial clues*. Englewood Cliffs, NJ: Prentice-Hall.

Elgavish, E., Halpern, D., Dikman, Z., & Allen, J. J. B. (2003). Does frontal EEG asymmetry moderate or mediate responses to the International Affective Picture System (IAPS)? *Psychophysiology*, *40*, S38. Doi: 10.1111/1469-8986.40.s1.1

Gable, P. A., & Harmon-Jones, E. (2008). Relative left frontal activation to appetitive stimuli: Considering the role of individual differences. *Psychophysiology*, *45*, 275–278. Doi: 10.1111/j.1469-8986.2007.00627.x

Gable, P. A., & Harmon-Jones, E. (2010). Late positive potential to appetitive stimuli and local attentional bias. *Emotion*, *10*, 441–446. Doi: 10.1037/a0018425

Gable, P. A., Harmon-Jones, E. (2013). Does arousal per se account for the influence of appetitive stimuli on attentional scope and the late positive potential? *Psychophysiology*, *50*, 344–350. Doi: 10.1111/psyp.12023

Gable, P. A., Mechin, N., Hicks, J. A., & Adams, D. A. (2015). Supervisory control system and frontal asymmetry: Neurophysiological traits of emotion-based impulsivity. *Social Cognitive and Affective Neuroscience. 10*, 1310–1315. Doi: 10.1093/scan/nsv017

Gable, P. A., Mechin, N., & Neal, L. B. (2016). Booze cues and attentional narrowing: Neural correlates of virtual alcohol myopia. *Psychology of Addictive Behaviors*, *30*, 377–382.

Gable, P. A., & Poole, B. D. (2014). Influence of trait behavioral inhibition and behavioral approach motivation systems on the LPP and frontal asymmetry to anger pictures. *Social Cognitive and Affective Neuroscience*, *9*, 182–190. Doi: 10.1093/scan/nss130

Gable, P. A., Poole, B. D., & Cook, M. S., (2013). Asymmetrical hemisphere activation enhances global-local processing. *Brain and Cognition*, *83*, 337–341. Doi: 10.1016/j.bandc.2013.09.012

Gainotti, G. (1972). Emotional behavior and hemispheric side of the lesion. *Cortex*, *8*, 41–55. Doi: 10.1016/S0010-9452(72)80026-1

Gasparrini, W. G., Satz, P., Heilman, K., & Coolidge, F. L. (1978). Hemispheric asymmetries of affective processing as determined by the Minnesota Multiphasic Personality Inventory. *Journal of Neurology, Neurosurgery and Psychiatry*, *41*, 470–473. Doi: 10.1136/jnnp.41.5.470

Gendolla, G. H., Wright, R. A., & Richter, M. (2012). Effort intensity: Some insights from the cardiovascular system. In R. M. Ryan (Ed.), *The Oxford handbook of human motivation* (pp. 420–438). Oxford, UK: Oxford University Press.

Gianotti, L. R., Knoch, D., Faber, P. L., Lehmann, D., Pascual-Marqui, R. D., Diezi, C., . . . Fehr, E. (2009). Tonic activity level in the right prefrontal cortex predicts individuals' risk taking. *Psychological Science*, *20*, 33–38. Doi: 10.1111/j.1467-9280.2008.02260.x

Goldstein, K. (1939). *The organism: An holistic approach to biology, derived from pathological data in man*. New York, NY: American Book.

Graham, R., & Cabeza, R. (2001). Event-related potentials of recognizing happy and neutral faces. *NeuroReport*, *12*, 245–248. Doi: 10.1097/00001756-200102120-00013

Gray, J. A. (1987). *The psychology of fear and stress* (2nd ed.). Cambridge, UK: Cambridge University Press.

Gray, J. A., & McNaughton, N. (2000). *The neuropsychology of anxiety: An enquiry into the functions of the septo-hippocampal system* (2nd ed.). Oxford, UK: Oxford University Press.

Gross, J. J. & Levenson, R. W. (1993). Emotional suppression: Physiology, self-report, and expressive behavior. *Journal of Personality and Social Psychology*, *64*, 970–986. Doi: 10.1037/0022-3514.64.6.970

Gygax, L., Reefmann, N., Wolf, M., & Langbein, J. (2013). Prefrontal cortex activity, sympatho-vagal reaction and behaviour distinguish between situations of feed reward and frustration in dwarf goats. *Behavioural Brain Research*, *239*, 104–114. Doi: 10.1016/j.bbr.2012.10.052

Hagemann, D., Hewig, J., Seifert, J., Naumann, E., & Bartussek, D. (2005). The latent state-trait structure of resting EEG asymmetry: Replication and extension. *Psychophysiology*, *42*, 740–752. Doi: 10.1111/j.1469-8986.2005.00367.x

Hagemann, D., Naumann, E., Becker, G., Maier, S., & Bartussek, D. (1998). Frontal brain asymmetry and affective style: A conceptual replication. *Psychophysiology*, *35*, 372–388. Doi: 10.1111/1469-8986.3540372

Hagemann, D., Naumann, E., Thayer, J. F., & Bartussek, D. (2002). Does resting EEG asymmetry reflect a trait? An application of latent state-trait theory. *Journal of Personality and Social Psychology*, *82*, 619–641. Doi: 10.1037/0022-3514.82.4.619

Harmon-Jones, C., Schmeichel, B. J., Mennitt, E., & Harmon-Jones, E. (2011). The expression of determination: Similarities between anger and approach-related positive affect. *Journal of Personality and Social Psychology*, *100*, 172–181. Doi: 10.1037/a0020966

Harmon-Jones, C., Schmeichel, B. J., Inzlicht, M., & Harmon-Jones, E. (2011). Trait approach motivation relates to dissonance reduction. *Social Psychological and Personality Science*, *2*, 21–28. Doi: 10.1177/1948550610379425

Harmon-Jones, E. (1999). Toward an understanding of the motivation underlying dissonance processes: Is feeling personally responsible for the production of aversive consequences necessary to cause dissonance effects? In E. Harmon-Jones & J. Mills (Eds.), *Cognitive dissonance: Perspectives on a pivotal theory in social psychology* (pp. 71–99). Washington, DC: American Psychological Association.

Harmon-Jones, E. (2003a). Clarifying the emotive functions of asymmetrical frontal cortical activity. *Psychophysiology*, *40*, 838–848. Doi: 10.1111/1469-8986.00121

Harmon-Jones, E. (2003b). Anger and the behavioural approach system. *Personality and Individual Differences*, *35*, 995–1005. Doi: 10.1016/S0191-8869(02)00313-6

Harmon-Jones, E. (2004). On the relationship of anterior brain activity and anger: Examining the role of attitude toward anger. *Cognition and Emotion*, *18*, 337–361. Doi: 10.1080/02699930341000059

Harmon-Jones, E. (2006). Unilateral right-hand contractions cause contralateral alpha power suppression and approach motivational affective experience. *Psychophysiology*, *43*, 598–603. Doi: 10.1111/j.1469-8986.2006.00465.x

Harmon-Jones, E. (2007). Trait anger predicts relative left frontal cortical activation to anger-inducing stimuli. *International Journal of Psychophysiology*, *66*, 154–160. Doi: 10.1016/j.ijpsycho.2007.03.020

Harmon-Jones, E., Abramson, L. Y., Sigelman, J., Bohlig, A., Hogan, M. E., & Harmon-Jones, C. (2002). Proneness to hypomania/mania or depression and asymmetric frontal cortical responses to an anger-evoking event. *Journal of Personality and Social Psychology*, *82*, 610–618. Doi: 10.1037/0022-3514.82.4.610

Harmon-Jones, E., Abramson, L. Y., Nusslock, R., Sigelman, J. D., Urosevic, S., Turonie, L. D., . . . Fearn, M. (2008). Effect of bipolar disorder on left frontal cortical responses to goals differing in valence and task difficulty. *Biological Psychiatry*, *63*, 693–698. Doi: 10.1016/j.biopsych.2007.08.004

Harmon-Jones, E., & Allen, J. J. B. (1997). Behavioral activation sensitivity and resting frontal EEG asymmetry: Covariation of putative indicators related to risk for mood disorders. *Journal of Abnormal Psychology*, *106*, 159–163. Doi: 10.1037/0021-843X.106.1.159

Harmon-Jones, E., & Allen, J. J. B. (1998). Anger and prefrontal brain activity: EEG asymmetry consistent with approach motivation despite negative affective valence. *Journal of Personality and Social Psychology*, *74*, 1310–1316. Doi: 10.1037/0022-3514.74.5.1310

Harmon-Jones, E., Amodio, D. M., & Harmon-Jones, C. (2009). Action-based model of dissonance: A review, integration, and expansion of conceptions of cognitive conflict. In M. P. Zanna (Ed.), *Advances in experimental social psychology*, *41*, 119–166. San Diego, CA: Academic Press. Doi: 10.1016/S0065-2601(08)00403-6

Harmon-Jones, E., & Gable, P. A. (2009). Neural activity underlying the effect of approach-motivated positive affect on narrowed attention. *Psychological Science*, *20*, 406–409. Doi: 10.1111/j.1467-9280.2009.02302.x

Harmon-Jones, E., Gable, P. A., & Peterson, C. K. (2010). The role of asymmetric frontal cortical activity in emotion-related phenomena: A review and update. *Biological Psychology*, *84*, 451–462. Doi: 10.1016/j.biopsycho.2009.08.010

Harmon-Jones, E., Gable, P. A., & Price, T. F. (2011). Leaning embodies desire: Evidence that leaning forward increases relative left frontal cortical activation to appetitive stimuli. *Biological Psychology*, *87*, 311–313. Doi: 10.1016/j.biopsycho.2011.03.009

Harmon-Jones, E., Gerdjikov. T., & Harmon-Jones, C. (2008). The effect of induced compliance on relative left frontal cortical activity: A test of the action-based model of dissonance. *European Journal of Social Psychology*, *38*, 35–45. Doi: 10.1002/ejsp.399

Harmon-Jones, E., & Harmon-Jones, C. (2002). Testing the action-based model of cognitive dissonance: The effect of action-orientation on post-decisional attitudes. *Personality and Social Psychology Bulletin*, *28*, 711–723. Doi: 10.1177/0146167202289001

Harmon-Jones, E., Harmon-Jones, C., Abramson, L. Y., & Peterson, C. K. (2009). PANAS positive activation is associated with anger. *Emotion*, *9*, 183–196. Doi: 10.1037/a0014959

Harmon-Jones, E., Harmon-Jones, C., Amodio, D. M., & Gable, P. A. (2011). Attitudes toward emotions. *Journal of Personality and Social Psychology*, *101*, 1332–1350. Doi: 10.1037/a0024951

Harmon-Jones, E., Harmon-Jones, C., & Price, T. F. (2013). What is approach motivation? *Emotion Review*, *5*, 291–295. Doi: 10.1177/1754073913477509

Harmon-Jones, E., Harmon-Jones, C., Fearn, M., Sigelman, J. D., & Johnson, P. (2008). Left frontal cortical activation and spreading of alternative: tests of the action-based model of dissonance. *Journal of Personality and Social Psychology*, *94*, 1–15. Doi: 10.1037/0022-3514.94.1.1

Harmon-Jones, E., Harmon-Jones, C., & Levy, N. (2015). An action-based model of cognitive dissonance processes. *Current Directions in Psychological Science*, *24*, 184–189. Doi: 10.1177/0963721414566449

Harmon-Jones, E., Harmon-Jones, C., Serra, R., & Gable, P. A. (2011). The effect of commitment on relative left frontal cortical activity: Tests of the action-based model of dissonance. *Personality and Social Psychology Bulletin*, *37*, 395–408. Doi: 10.1177/0146167210397059

Harmon-Jones, E., Lueck, L., Fearn, M., & Harmon-Jones, C. (2006). The effect of personal relevance and approach-related action expectation on relative left frontal cortical activity. *Psychological Science*, *17*, 434–440. Doi: 10.1111/j.1467-9280.2006.01724.x

Harmon-Jones, E., & Peterson, C. K. (2008). Effect of trait and state approach motivation on aggressive inclinations. *Journal of Research in Personality*, *42*, 1381–1385. Doi: 10.1016/j.jrp.2008.05.001

Harmon-Jones, E., & Peterson, C. K. (2009). Supine body position reduces neural response to anger evocation. *Psychological Science*, *20*, 1209–1210. Doi: 10.1111/j.1467-9280.2009.02416.x

Harmon-Jones, E., Peterson, C. K., & Harris, C. R. (2009). Jealousy: Novel methods and neural correlates. *Emotion*, *9*, 113–117. Doi: 10.1037/a0014117

Harmon-Jones, E., Price, T. F., & Harmon-Jones, C. (2015). Supine body posture decreases rationalizations: Testing the action-based model of dissonance. *Journal of Experimental Social Psychology*, *56*, 228–234. Doi: 10.1016/j.jesp.2014.10.007

Harmon-Jones, E., & Sigelman, J. D. (2001). State anger and prefrontal brain activity: Evidence that insult-related relative left-prefrontal activation is associated with experienced anger and aggression. *Journal of Personality and Social Psychology*, *80*, 797–803. Doi: 10.1037/0022-3514.80.5.797

Harmon-Jones, E., Sigelman, J. D., Bohlig, A., & Harmon-Jones, C. (2003). Anger, coping, and frontal cortical activity: The effect of coping potential on anger-induced left frontal activity. *Cognition and Emotion*, *17*, 1–24. Doi: 10.1080/02699930302278

Harmon-Jones, E., Vaughn-Scott, K., Mohr, S., Sigelman, J., & Harmon-Jones, C. (2004). The effect of manipulated sympathy and anger on left and right frontal cortical activity. *Emotion*, *4*, 95–101. Doi: 10.1037/1528-3542.4.1.95

Hellige, J. B. (1993). *Hemispheric asymmetry: What's right and what's left*. Cambridge, MA: Harvard University 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. Doi: 10.1037/0021-843X.99.1.22

Hewig, J., Hagemann, D., Seifert, J., Naumann, E., & Bartussek, D. (2004). On the selective relation of frontal cortical activity and anger-out versus anger-control. *Journal of Personality and Social Psychology*, *87*, 926–939. Doi: 10.1037/0022-3514.87.6.926

Higgins, E. T. (1997). Beyond pleasure and pain. *American Psychologist*, *52*, 1280–1300. Doi: 10.1037/0003-066X.52.12.1280

Hortensius, R., Schutter, D. J. L. G., & Harmon-Jones, E. (2012). When anger leads to aggression: Induction of relative left frontal cortical activity with transcranial direct current stimulation increases the anger-aggression relationship. *Social Cognitive Affective Neuroscience*, *7*, 342–347. Doi: 10.1093/scan/nsr012

Hughes, D. M., Yates, M. J., Morton, E. E., & Smillie, L. D. (2015). Asymmetric frontal cortical activity predicts effort expenditure for reward. *Social Cognitive and Affective Neuroscience*, *10*, 1015–1019. Doi: 10.1093/scan/nsu149

Izard, C. E. (1991). *The psychology of emotions*. New York, NY: Plenum Press.

Izard, C. E. (2010). The many meanings/aspects of emotion: Definitions, functions, activation, and regulation. *Emotion Review*, *2*, 363–370. Doi: 10.1177/1754073910374661

Jacobs, G. D., & Snyder, D. (1996). Frontal brain asymmetry predicts affective style in men. *Behavioral Neuroscience*, *110*, 3–6. Doi: 10.1037/0735-7044.110.1.3

Jensen-Campbell, L. A., Knack, J. M., Waldrip, A. M., & Campbell, S. D. (2007). Do Big Five personality traits associated with self-control influence the regulation of anger and aggression? *Journal of Research in Personality*, *41*, 403–424. Doi: 10.1016/j.jrp.2006.05.001

Johnson, S. L., Ruggero, C. J., & Carver, C. S. (2005). Cognitive, behavioral, and affective responses to reward: Links with hypomanic symptoms. *Journal of Social and Clinical Psychology*, *24*, 894–906. Doi: 10.1521/jscp.2005.24.6.894

Johnson, S. L., Sandrow, D., Meyer, B., Winters, R., Miller, I., Solomon, D., & Keitner, G. (2000). Increases in manic symptoms after life events involving goal attainment. *Journal of Abnormal Psychology*, *109*, 721–727. Doi: 10.1037/0021-843X.109.4.721

Kamiya, J. (1979). Autoregulation of the EEG alpha rhythm: A program for the study of consciousness. In S. A. E. Peper & M. Quinn (Eds.), *Mind/body integration: Essential readings in biofeedback* (pp. 289–297). New York, NY: Plenum Press.

Kano, K., Nakamura, M., Matsuoka, T., Iida, H., & Nakajima, T. (1992). The topographical features of EEGs in patients with affective disorders. *Electroencephalography and Clinical Neurophysiology*, *83*, 124–129. Doi: 10.1016/0013-4694(92)90025-D

Kelley, N. J., Eastwick, P. W., Harmon-Jones, E., & Schmeichel, B. J. (2015). Jealousy increased by induced relative left frontal cortical activity. *Emotion*, *15*, 550–555. Doi: 10.1037/emo0000068

Kelley, N. J., Hortensius, R., & Harmon-Jones, E. (2013). When anger leads to rumination: Induction of relative right frontal cortical activity with transcranial direct current stimulation increases anger-related rumination. *Psychological Science*, *24*, 475–481. Doi: 10.1177/0956797612457384

Keune, P. M., Schönenberg, M., Wyckoff, S., Mayer, K., Riemann, S., Hautzinger, M., & Strehl, U. (2011). Frontal alpha-asymmetry in adults with attention deficit hyperactivity disorder: Replication and specification. *Biological Psychology*, *87*, 306–310. Doi: 10.1016/j.biopsycho.2011.02.023

Keune, P. M., van der Heiden, L., Várkuti, B., Konicar, L., Veit, R., & Birbaumer, N. (2012). Prefrontal brain asymmetry and aggression in imprisoned violent offenders. *Neuroscience Letters*, *515*, 191–195. Doi: 10.1016/j.neulet.2012.03.058

Keune, P. M., Wiedemann, E., Schneidt, A., & Schönenberg, M. (2015). Frontal brain asymmetry in adult attention-deficit/hyperactivity disorder (ADHD): Extending the motivational dysfunction hypothesis. *Clinical Neurophysiology*, *126*(4), 711–720. Doi: 10.1016/j.clinph.2014.07.008

King, J. A., Rosal, M. C., Ma, Y., Reed, G., Kelly, T., Stanek III, E. J., & Ockene, I. S. (2000). Sequence and seasonal effects of salivary cortisol. *Behavioral Medicine*, *26*, 67–73.

Kotchoubey, B., Kubler, A., Strehl, U., Flor, H., & Birbaumer, N. (2002). Can humans perceive their brain states? *Consciousness and Cognition*, *11*, 98–113. Doi: 10.1006/ccog.2001.0535

Lagerspetz, K. M. J. (1969). Aggression and aggressiveness in laboratory mice. In S. Garattini & Sigg, E.B. (Eds.), *Aggressive behavior* (pp. 77–85). New York, NY: Wiley.

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

Lewis, M., Alessandri, S. M., & Sullivan, M. W. (1990). Violation of expectancy, loss of control, and anger expressions in young infants. *Developmental Psychology*, *26*, 745–751. Doi: 10.1037/0012-1649.26.5.745

Lewis, M., Sullivan, M. W., Ramsey, D. S., & Alessandri, S. M. (1992). Individual differences in anger and sad expressions during extinction: Antecedents and consequences. *Infant Behavior and Development*, *15*, 443–452. Doi: 10.1016/0163-6383(92)80012-J

Magnusson, A. (2000). An overview of epidemiological studies on seasonal affective disorder. *Acta Psychiatrica Scandinavica*, *101*, 176–184.

Martin, R. C., & Dahlen, E. R. (2005). Cognitive emotion regulation in the prediction of depression, anxiety, stress, and anger. *Personality and Individual Differences*, *39*, 1249–1260. Doi: 10.1016/j.paid.2005.06.004

Meyer, B., Johnson, S. L., & Carver, C. S. (1999). Exploring behavioral activation and inhibition sensitivities among college students at risk for bipolar spectrum symptomatology. *Journal of Psychopathology and Behavioral Assessment*, *21*, 275–292. Doi: 10.1023/A:1022119414440

Meyer, B., Johnson, S. L., & Winters, R. (2001). Responsiveness to threat and incentive in bipolar disorder: Relations of the BIS/BAS scales with symptoms. *Journal of Psychopathology and Behavioral Assessment*, *23*, 133–143. Doi: 10.1023/A:1010929402770

Miller, G. A., Crocker, L. D., Spielberg, J. M., Infantolino, Z. P., & Heller, W. (2013). Issues in localization of brain function: The case of lateralized frontal cortex in cognition, emotion, and psychopathology. *Frontiers in Integrative Neuroscience*, *7*, 2. Doi: 10.3389/fnint.2013.00002

Miller, P. A., & Eisenberg, N. (1988). The relation of empathy to aggressive and externalizing/antisocial behavior. *Psychological Bulletin*, *103*, 324–344. Doi: 10.1037/0033-2909.103.3.324

Mitchell, J. T. (2010). Behavioral approach in ADHD: Testing a motivational dysfunction hypothesis. *Journal of Attention Disorders*, *13*, 609–617. Doi: 10.1177/1087054709332409

Mize, K. D., & Jones, N. A. (2012). Infant physiological and behavioral responses to loss of maternal attention to a social-rival. *International Journal of Psychophysiology*, *83*(1), 16–23. Doi: 10.1016/j.ijpsycho.2011.09.018

Molden, D. C., Lee, A. Y., & Higgins, E. T. (2008). Motivations for promotion and prevention. In J. Y. Shah & W. L. Gardner (Eds.), *Handbook of motivation science* (pp. 169–187). New York, NY: The Guilford Press.

Moran, J. K., Weierstall, R., & Elbert, T. (2014). Differences in brain circuitry for appetitive and reactive aggression as revealed by realistic auditory scripts. *Frontiers in Behavioral Neuroscience*, *8*, 425. Doi: 10.3389/fnbeh.2014.00425

Murphy, F. C., Nimmo-Smith, I., & Lawrence, A. D. (2003). Functional neuroanatomy of emotion: A meta-analysis. *Cognitive, Affective, & Behavioral Neuroscience*, *3*, 207–233. Doi: 10.3758/CABN.3.3.207

Muraven, M., & Baumeister, R. F. (2000). Self-regulation and depletion of limited resources: Does self-control resemble a muscle? *Psychological Bulletin*, *126*, 247–259. Doi: 10.1037/0033-2909.126.2.247

Nash, K., Inzlicht, M., & McGregor, I. (2012). Approach-related left prefrontal EEG asymmetry predicts muted error-related negativity. *Biological Psychology*, *91*, 96–102. Doi: 10.1016/j.biopsycho.2012.05.005

Neal, L. B., & Gable, P. A. (2016). Neurophysiological markers of multiple facets of impulsivity. *Biological Psychology*, *115*, 64–68.

Nitsche, M. A., & Paulus, W. (2000). Excitability changes induced in the human motor cortex by weak transcranial direct current stimulation. *Journal of Physiology*, *527*, 633–639. Doi: 10.1111/j.1469-7793.2000.t01-1-00633.x

Nolen-Hoeksema, S. (2000). The role of rumination in depressive disorders and mixed anxiety/depressive symptoms. *Journal of Abnormal Psychology*, *109*, 504–511. Doi: 10.1037/0021-843X.109.3.504

Nusslock, R., Abramson, L. Y., Harmon-Jones, E., Alloy, L. B., & Hogan, M. E. (2007). A goal-striving life event and the onset of hypomanic and depressive episodes and symptoms: Perspective from the behavioral approach system (BAS) dysregulation theory. *Journal of Abnormal Psychology*, *116*, 105–115. Doi: 10.1037/0021-843X.116.1.105

Perria, P., Rosadini, G., & Rossi, G. F. (1961). Determination of side of cerebral dominance with Amobarbital. *Archives of Neurology*, *4*, 175–181. Doi: 10.1001/archneur.1961.0040080055006

Peterson, C. K., Gable, P., & Harmon-Jones, E. (2008). Asymmetric frontal ERPs, emotion, and behavioral approach/inhibition sensitivity. *Social Neuroscience*, *3*, 113–124. Doi: 10.1080/17470910701612736

Peterson, C. K., Gravens, L., & Harmon-Jones, E. (2011). Asymmetric frontal cortical activity and negative affective responses to ostracism. *Social Cognitive Affective Neuroscience*, *6*, 277–285. Doi: 10.1093/scan/nsq027

Peterson, C. K., & Harmon-Jones, E. (2009). Circadian and seasonal variability of resting frontal EEG asymmetry. *Biological Psychology*, *80*, 315–320. Doi: 10.1016/j.biopsycho.2008.11.002

Peterson, C. K., Shackman, A. J., & Harmon-Jones, E. (2008). The role of asymmetric frontal cortical activity in aggression. *Psychophysiology*, *45*, 86–92. Doi: 10.1111/j.1469-8986.2007.00597.x

Pizzagalli, D., Shackman, A. J., & Davidson, R. J. (2003). The functional neuroimaging of human emotion: Asymmetric contributions of cortical and subcortical circuitry. In K. Hugdahl & R. J.

Davidson (Eds.), *The asymmetric brain* (pp. 511–532). Cambridge, MA: MIT Press.

Plant, E. A., & Devine, P. G. (1998). Internal and external motivation to respond without prejudice. *Journal of Personality and Social Psychology*, *75*, 811–832. Doi: 10.1037/0022-3514.75.3.811

Plant, E. A., & Devine, P. G. (2001). Responses to other-imposed pro-Black pressure: Acceptance or backlash. *Journal of Experimental Social Psychology*, *37*, 486–501. Doi: 10.1006/jesp.2001.1478

Plant, E. A., & Devine, P. G. (2003). The antecedents and implications of interracial anxiety. *Personality and Social Psychology Bulletin*, *29*, 790 – 801. Doi: 10.1177/0146167203029006011

Plutchik, R. (1980). *Emotion: A psychoevolutionary synthesis*. New York, NY: HarperCollins College Division.

Price, T. F., Dieckman, L., & Harmon-Jones, E. (2012). Embodying approach motivation: Body posture influences startle eyeblink and event-related potential responses to appetitive stimuli. *Biological Psychology*, *90*, 211–217. Doi: 10.1016/j.biopsycho.2012.04.001

Price, T. F., & Harmon-Jones, E. (2011). Approach motivational body postures lean toward left frontal brain activity. *Psychophysiology*, *48*, 718–722. Doi: 10.1111/j.1469-8986.2010.01127.x

Price, T. F., Hortensius, R., & Harmon-Jones, E. (2013). Neural and behavioral associations of manipulated determination facial expressions. *Biological Psychology*, *94*, 221–227. Doi: 10.1016/j.biopsycho.2013.06.001

Price, T. F., Peterson, C. K., & Harmon-Jones, E. (2012). The emotive neuroscience of embodiment. *Motivation and Emotion*, *36*, 27–37. Doi: 10.1007/s11031-011-9258-1

Putman, P., Hermans, E., & van Honk, J. (2004). Emotional Stroop performance for masked angry faces: It's BAS, not BIS. *Emotion*, *4*, 305–311. Doi: 10.1037/1528-3542.4.3.305

Quaedflieg, C. W. E. M., Smulders, F. T. Y., Meyer, T., Peeters, F. P. M. L., Merckelbach, H. L. G. J., & Smeets, T. (2016). The validity of individual frontal alpha asymmetry EEG neurofeedback. *Social Cognitive and Affective Neuroscience*, *11*, 33–43. Doi: 10.1093/scan/nsv090

Quaranta, A., Siniscalchi, M., & Vallortigara, G. (2007). Asymmetric tail-wagging responses by dogs to different emotive stimuli. *Current Biology*, *17*, R199–R201. Doi: 10.1016/j.cub.2007.02.008

Reid, S. A., Duke, L. M., & Allen, J. J. B. (1998). Resting frontal electroencephalographic asymmetry in depression: Inconsistencies suggest the need to identify mediating factors. *Psychophysiology*, *35*, 389–404. Doi: 10.1111/1469-8986.3540389

Rinn, W. E. (1984). The neuropsychology of facial expression: A review of the neurological and psychological mechanisms for producing facial expressions. *Psychological Bulletin*, *95*, 52–77. Doi: 10.1037/0033-2909.95.1.52

Riskind, J. H., & Gotay, C. C. (1982). Physical posture: Could it have regulatory or feedback effects on motivation and emotion? *Motivation and Emotion*, *6*, 273–298. Doi: 10.1007/BF00992249

Robinson, R. G., & Price, T. R. (1982). Post-stroke depressive disorders: A follow-up study of 103 patients. *Stroke*, *13*, 635–641. Doi: 10.1161/01.STR.13.5.635

Rogers, L. J. (2002). Lateralised brain function in anurans: Comparison to lateralisation in other vertebrates. *Laterality: Asymmetries of Body, Brain and Cognition*, *7*, 219–239. Doi: 10.1080/13576500244000012

Rossi, G. F., & Rosadini, G. R. (1967). Experimental analyses of cerebral dominance in man. In D. H. Millikan & F. L. Darley (Eds.), *Brain mechanisms underlying speech and language*. New York, NY: Grune & Stratton.

Rutherford, H. J., & Lindell, A. K. (2011). Thriving and surviving: Approach and avoidance motivation and lateralization. *Emotion Review*, *3*, 333–343. Doi: 10.1177/1754073911402392

Sackeim, H., Greenberg, M. S., Weimen, A. L., Gur, R. C., Hungerbuhler, J. P., & Geschwind, N. (1982). Hemispheric asymmetry in the expression of positive and negative emotions: Neurologic evidence. *Archives of Neurology*, *39*, 210–218. Doi: 10.1001/archneur.1982.00510160016003

Santesso, D. L., Segalowitz, S. J., Ashbaugh, A. R., Antony, M. M., McCabe, R. E., & Schmidt, L. A. (2008). Frontal EEG asymmetry and sensation seeking in young adults. *Biological Psychology*, *78*, 164–172. Doi: 10.1016/j.biopsycho.2008.02.003

Schaffer, C. E., Davidson, R. J., & Saron, C. (1983). Frontal and parietal electroencephalogram asymmetry in depressed and nondepressed subjects. *Biological Psychiatry*, *18*, 753–762.

Schiff, B. B., & Lamon, M. (1989). Inducing emotion by unilateral contraction of facial muscles: A new look at hemispheric specialization and the experience of emotion. *Neuropsychologia*, *27*, 923–935. Doi: 10.1016/0028-3932(89)90068-7

Schiff, B. B., & Lamon, M. (1994). Inducing emotion by unilateral contraction of hand muscles. *Cortex*, *30*, 247–254. Doi: 10.1016/S0010-9452(13)80196-7

Schmeichel, B. J., Crowell, A., & Harmon-Jones, E. (2016). Exercising self-control increases relative left frontal cortical activation. *Social Cognitive and Affective Neuroscience*, *11*, 282–288. Doi: 10.1093/scan/nsv112

Schmeichel, B. J., Harmon-Jones, C., & Harmon-Jones, E. (2010). Exercising self-control increases approach motivation. *Journal of Personality and Social Psychology*, *99*, 162–173. Doi: 10.1037/a0019797

Schöne, B., Schomberg, J., Gruber, T., & Quirin, M. (2016). Event-related frontal alpha asymmetries: Electrophysiological correlates of approach motivation. *Experimental Brain Research*, *234*(2), 559–567. Doi: 10.1007/s00221-015-4483-6

Schutter, D. J. L. G. (2009). Transcranial magnetic stimulation. In E. Harmon-Jones & J. S. Beer (Eds.), *Methods in social neuroscience*, pp. 233– 258. New York, NY: Guilford.

Schutter, D. J. L. G., & Harmon-Jones, E. (2013). The corpus callosum: A commissural road to anger and aggression. *Neuroscience & Biobehavioral Reviews*, *37*, 2481–2488. Doi: 10.1016/j.neubiorev.2013.07.013

Schutter, D. J. L. G., van Honk, J., d'Alfonso, A. A. L., Postma, A., & de Haan, E. H. F. (2001). Effects of slow rTMS at the right dorsolateral prefrontal cortex on EEG asymmetry and mood. *NeuroReport*, *12*, 445–447. Doi: 10.1097/00001756-200103050-00005

Shankman, S. A., & Klein, D. N. (2003). The relation between depression and anxiety: An evaluation of the tripartite, approach-withdrawal and valence-arousal models. *Clinical Psychology Review*, *23*, 605–637. Doi: 10.1016/S0272-7358(03)00038-2

Siniatchkin, M., Kropp, P., & Gerber, W-D. (2000). Neurofeedback—The significance of reinforcement and the search for an appropriate strategy for the success of self-regulation. *Applied Psychophysiology and Biofeedback*, *25*, 167–175. Doi: 10.1023/A:1009502808906

Smits, D. J. M., & Kuppens, P. (2005). The relations between anger, coping with anger, and aggression, and the BIS/BAS system. *Personality and Individual Differences*, *39*, 783–793. Doi: 10.1016/j.paid.2005.02.023

Spielberger, C. D. (1988). *State–Trait Anger Expression Inventory*. Orlando, FL: Psychological Assessment Resources.

Spielberger, C. D., Reheiser, E. C., & Sydeman, S. J. (1995). Measuring the experience, expression, and control of anger. In H. Kassinove (Ed.), *Anger disorders: Definition, diagnosis, and treatment* (pp. 49–67). Philadelphia, PA: Taylor & Francis.

Stewart, J. L., Levin-Silton, R., Sass, S. M., Heller, W., & Miller, G. A. (2008). Anger style, psychopathology, and regional brain activity. *Emotion*, *8*, 701–713.

Stucke, T. S., & Baumeister, R. F. (2006). Ego depletion and aggressive behavior: Is the inhibition of aggression a limited resource? *European Journal of Social Psychology*, *36*, 1–13. Doi: 10.1002/ejsp.285

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. Doi: 10.1111/j.1467-9280.1997.tb00413.x

Terzian, H., & Cecotto, C. (1959). Determination and study of hemisphere dominance by means of intracarotid sodium amytal injection in man: II. Electroencephalographic effects. *Bolletino della Societa Ztaliana Sperimentale*, *35*, 1626–1630.

Thibodeau, R., Jorgensen, R. S., & Kim, S. (2006). Depression, anxiety, and resting frontal EEG asymmetry: A meta-analytic review. *Journal of Abnormal Psychology*, *115*(4), 715–729. Doi: 10.1037/0021-843X.115.4.715.

Tomarken, A. J., Davidson, R. J., & Henriques, J. B. (1990). Resting frontal brain asymmetry predicts affective responses to films. *Journal of Personality and Social Psychology*, *59*, 791–801. Doi: 10.1037/0022-3514.59.4.791

Tomarken, A. J., Davidson, R. J., Wheeler, R. E., & Doss, R. (1992). Individual differences in anterior brain asymmetry and fundamental dimensions of emotion. *Journal of Personality and Social Psychology*, *62*, 676–687. Doi: 10.1037/0022-3514.62.4.676

van de Laar, M. C., Licht, R., Franken, I. H. A., & Hendriks, V. M. (2004). Event-related potentials indicate motivational relevance of cocaine cues in abstinent cocaine addicts. *Psychopharmacology*, *177*, 121–129. Doi: 10.1007/s00213-004-1928-1

van Honk, J., & Schutter, D. J. L. G. (2006). From affective valence to motivational direction: The frontal asymmetry of emotion revisited. *Psychological Science*, *17*, 963–965. Doi: 10.1111/j.1467-9280.2006.01813.x

Verona, E., Sadeh, N., & Curtin, J. J. (2009). Stress-induced asymmetric frontal brain activity and aggression risk. *Journal of Abnormal Psychology*, *118*, 131–145. Doi: 10.1037/a0014376

Wacker, J., Chavanon, M. L., & Stemmler, G. (2010). Resting EEG signatures of agentic extraversion: New results and meta-analytic integration. *Journal of Research in Personality*, *44*, 167–179. Doi: 10.1016/j.jrp.2009.12.004

Wacker, J., Heldmann, M., & Stemmler, G. (2003). Separating emotion and motivational direction in fear and anger: Effects on frontal asymmetry. *Emotion*, *3*, 167–193. Doi: 10.1037/1528-3542.3.2.167

Wacker, J., Mueller, E. M., Pizzagalli, D. A., Hennig, J., & Stemmler, G. (2013). Dopamine-D2-receptor blockade reverses the association between trait approach motivation and frontal asymmetry in an approach-motivation context. *Psychological Science*, *24*, 489–497. Doi: 10.1177/0956797612458935

Watson, D. (2009). Locating anger in the hierarchical structure of affect: comment on Carver and Harmon-Jones (2009). *Psychological Bulletin*, *135*, 205–208.

Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology*, *54*, 1063–1070. Doi: 10.1037/0022-3514.54.6.1063

Watson, D., Wiese, D., Vaidya, J., & Tellegen, A. (1999). The two general activation systems of affect: Structural findings, evolutionary considerations, and psychobiological evidence. *Journal of Personality and Social Psychology*, *76*, 820–838. Doi: 10.1037/0022-3514.76.5.820

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. Doi: 10.1111/j.1469-8986.1993.tb03207.x

Whiteside, S. P., Lynam, D. R., Miller, J. D., & Reynolds, S. K. (2005). Validation of the UPPS impulsive behaviour scale: A four-factor model of impulsivity. *European Journal of Personality*, *19*, 559–574.

Wu, C. C., Samanez-Larkin, G. R., Katovich, K., & Knutson, B. (2014). Affective traits link to reliable neural markers of incentive anticipation. *NeuroImage*, *84*, 279–289. Doi: 10.1016/j.neuroimage.2013.08.055

Wright, R. A., Tunstall, A. M., Williams, B. J., Goodwin, J. S., & Harmon-Jones, E. (1995). Social evaluation and cardiovascular response: An active coping approach. *Journal of Personality and Social Psychology*, *69*, 530–543. Doi: 10.1037/0022-3514.69.3.530

Young, P. T. (1943). *Emotion in man and animal: Its nature and relation to attitude and motive*. New York, NY: John Wiley and Sons.

Zinner, L. R., Brodish, A. B., Devine, P. G., & Harmon-Jones, E. (2008). Anger and asymmetric frontal cortical activity: Evidence for an anger-withdrawal relationship. *Cognition & Emotion*, *22*, 1081–1093. Doi: 10.1080/02699930701622961

How to cite this article: Harmon-Jones E, Gable PA. On the role of asymmetric frontal cortical activity in approach and withdrawal motivation: An updated review of the evidence. *Psychophysiology*. 2017;00: 1–23. https://doi.org/10.1111/psyp.12879