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The relationship of approach/avoidance motivation and asymmetric frontal cortical activity: A review of studies manipulating frontal asymmetry

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ABSTRACT

The balance between activity in the left and right frontal cortex, commonly referred to as asymmetric frontal cortical activity, has served as a proxy for an organism's motivational direction (i.e., approach vs. avoidance). Many studies have examined the influence of the manipulation of motivational direction on asymmetrical frontal cortical activity and found results consistent with the idea that greater relative left (right) frontal cortical activity is associated with approach (avoidance) motivation. We critically review literature employing physical (versus psychological) manipulations of frontal asymmetry using a variety of methodologies including neurofeedback training, muscular contractions, and non-invasive brain stimulation. These reviewed methods allow us to make stronger causal inferences regarding the role of asymmetric frontal cortical activity in approach and avoidance motivation.

1. Introduction

Approach and avoidance motivation are vital for survival. Approach motivation refers to the urge to go toward a stimulus (see Harmon-Jones et al., 2013).[1] This contrasts with avoidance motivation, which refers to the "energization of behavior by or the direction of behavior away from negative stimuli" (Elliot, 2006, p. 112). Thus, the "intended" direction of physical movement is a key feature distinguishing these two motivational orientations. Evidence of this distinction is apparent even in simple organisms. Dark-adapted earthworms contract their bodies in the presence of intense light to avoid aversive stimuli, and elongate their bodies in the presence of darkness to approach the safety signified by the darkness (Schneirla, 1959). For these earthworms and many more species, acting appropriately in the face of appetitive stimuli (e.g., seeking opportunities to mate or eat) and threatening stimuli (e.g., evading predators) could mean the difference between life and death, suggesting that motivational orientation is crucial to driving the behavior of most, in not all, organisms.

Whereas the functional significance of approach-avoidance behavior in simple organisms is tied to rudimentary survival concerns over physical safety, in more complex social species the functional significance of approach-avoidance motivation may revolve around the pursuit of reward and avoidance of punishment in social animals, according to some theorists (van Honk and Schutter, 2005, 2006). From this viewpoint, the approach-avoidance motivation continuum evolved from subcortical fight-flight mechanisms whereby approach behavior would entail attacking or thwarting an enemy in addition to the pursuit of foods and mates.

Whereas the presence of approach-avoidance behavior may be present across all organisms, its expression differs across species. One way in which motivational orientation is expressed in many vertebrate species is through cerebral lateralization. Indeed, approach-avoidance laterality effects are observed many species including in frogs (Rogers, 2002), toads (Lippolis et al., 2002), fish (Cantalupo et al., 1995), rats (Denenberg et al., 1978), and pigeons (Güntürkün et al., 2000). Indeed, cerebral lateralization appears to have functional significant across wide swaths of vertebrate species (Vallortigara et al., 1999).

In species with more of a cortex, the balance between activity in the left and right frontal cortex, commonly referred to as asymmetric frontal

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[1] Although many scientists define approach motivation as the urge to go toward desirable stimuli, Harmon-Jones et al. (2013) argued against including "desirable stimuli" in the definition based on much scientific evidence showing approach motivation in the absence of desirable stimuli.

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cortical activity, has served as a proxy for an organism's motivational orientation and the expression of approach-avoidance laterality effects. These laterality effects are presumed to have evolved to increase an organism's neural capacity and processing efficiency. These laterality patterns may prevent the simultaneous initiation of two antagonistic responses through inhibitory connections between the hemispheres (for review, see Schutter and Harmon-Jones, 2013; Vallortigara and Rogers, 2005). That is, cerebral lateralization would prevent an organism from simultaneously initiating an approach and avoidance response. Left-over-right and right-over-left frontal cortical activity patterns are related to contrasting motivation tendencies. Left-over-right dominance, or relative left frontal cortical activity, is associated with approach motivation, and right-over-left dominance, or relative right frontal activity, is associated with avoidance motivation. These patterns have been observed in a variety of organisms. For example, dogs demonstrate more exaggerated tail wagging toward the right in the presence of appetitive stimuli (e.g., their owners), whereas the presence of aversive stimuli (e.g., a dominant unfamiliar dog) elicits exaggerated tail wagging toward the left side. These behaviors are thought to recruit the left and right prefrontal cortex respectively (Quaranta et al., 2007). Similarly, dogs more quickly orient toward aversive stimuli (e.g., snakes) in the left hemifield and slower to resume approach-motivated behavior after seeing aversive stimuli in the left hemifield (e.g., Siniscalchi et al., 2010). Similar effects occur in marsupials (Lippolis et al., 2005).

Even stronger evidence comes from work on non-human primates. Anxiolytic drugs reduce anxious temperament and reduce relative right frontal asymmetry in rhesus monkeys (Kalin and Shelton, 1989; Davidson et al., 1992, 1993). Kalin et al. (1998) demonstrated that rhesus monkeys with greater relative right frontal activity also have greater cortisol concentrations. In contrast, monkeys with greater relative left frontal cortical activity showed reduced cortisol concentrations. These associations occurred at both one and three years of age. Moreover, greater relative right frontal activity was associated with greater defensive responses (e.g., freezing). This work on non-human primates highlights the role of greater relative right frontal activity in activating avoidance motivation and greater relative left frontal activity in reducing the activation of avoidance motivation.

Using electroencephalographic (EEG) recordings, researchers have linked relative left frontal cortical activity with trait approach motivation (Coan and Allen, 2003; Harmon-Jones and Allen, 1997; Sutton and Davidson, 1997) and with individual differences in approach-motivated emotions (Harmon-Jones and Allen, 1998; Tomarken et al., 1992). Similarly, relative right frontal cortical activity is associated with avoidance motivation (Coan et al., 2001; Dawson et al., 1992). In addition to individual difference variables, the temporary experience of approach-motivated emotion has been correlated with relative left frontal cortical activity (Harmon-Jones, 2007, 2002, 2006; Harmon-Jones and Sigelman, 2001). Likewise, state variation in avoidance-motivated emotion influences has been correlated with relative right frontal cortical activity. For example, Davidson et al. (1990) recorded EEG activity while participants watched either a disgust-inducing film clip or a happiness-inducing clip. Results revealed that relative to the happiness clip, the disgust clip caused greater relative right frontal cortical activity. Taken together, converging evidence suggests that greater relative left frontal cortical activity is associated with approach motivation, whereas greater relative right frontal cortical activity is associated with avoidance motivation.

2. Physical vs. psychological manipulations of asymmetric frontal cortical activity

Physical manipulations of asymmetric frontal cortical activity are those that manipulate some aspect of the physical body tied to asymmetric frontal cortical activity. Some of these manipulations are more peripheral (i.e., manipulations of the hands and face) whereas others are more direct (e.g., neuromodulation). These techniques are contrasted with psychological manipulations that induce asymmetric patterns via some emotional or cognitive manipulation. Because physical manipulations generally circumvent affect and cognition, they can allow researchers to make more precise statements about the relationship motivational orientation and asymmetrical frontal cortical activity than psychological manipulations. Thus, the purpose of this paper is to review the literature employing physical manipulations of frontal asymmetry. The techniques reviewed include: a) neurofeedback training, b) muscular contractions, c) transcranial direct current stimulation (tDCS), and d) transcranial magnetic stimulation (TMS).

3. Neurofeedback training and asymmetric frontal cortical activity

Early studies manipulating asymmetric frontal cortical activity used neurofeedback. EEG neurofeedback training typically pairs a visual or auditory cue with the online movement in frontal EEG asymmetry either leftward or rightward. Participants view or hear a cue indicating reward when frontal asymmetry shifts in the desired direction; in other words, operant conditioning is used to alter asymmetric frontal cortical activity. Neurofeedback training has successfully altered EEG asymmetry in non-clinical and clinical contexts. Rosenfeld et al. (1995) used a tonal neurofeedback paradigm with operant conditioning where participants were rewarded when their frontal alpha asymmetry shifted in the desired direction (toward relative left frontal activity). Hardman et al. (1997) used neurofeedback training and the presence versus absence of affective instructions to guide neurofeedback training. To alter frontal asymmetry via neurofeedback, participants viewed a computer screen with a centrally located rocket ship, which rose to indicate an increase in relative left frontal activity and fell to indicate an increase in relative right frontal activity. Regardless of the instructions given, participants shifted asymmetric frontal cortical activity in the desired direction.

In clinical contexts, neurofeedback training has been utilized in conjunction with therapy for both depression and anxiety. For example, Baehr et al. (1997) found that neurofeedback training to reduce relative right frontal activity reduced depressive symptoms in individuals previously diagnosed with unipolar depression. More recently, these effects have been replicated in a randomized clinical trial of depressed individuals (Choi et al., 2010). Similar results were obtained in a neurofeedback study that aimed to reduce relative right frontal activity in clinically anxious individuals (Kerson et al., 2009).

The evidence just reviewed suggests that changes in resting frontal asymmetry covary with changes in mood state in patients undergoing neurofeedback treatment for some affective disorders. However, this evidence is limited, as these clinical case studies often involved participants receiving treatments in addition to neurofeedback and no control groups. Moreover, most of the studies described above trained participants in only the direction hypothesized to be therapeutic (i.e., increasing relative left frontal activity) but never in the opposite direction; this leaves open the possibility that nonspecific aspects of the neurofeedback training protocol, and not its specific effects on cortical activation, were therapeutic.

Allen et al. (2001) sought to determine whether manipulation of frontal asymmetry was causally related to emotional responding. Specifically, they sought to determine whether EEG changes could be obtained in both directions: increasing right-versus-left alpha power, and decreasing right-versus-left alpha power. To determine whether alteration of frontal EEG asymmetry could change subsequent emotional responses, participants viewed emotionally evocative film clips after the conclusion of training and reported their affective responses to the films. In addition to measuring self-reported affective responses to films, the researchers recorded facial electromyographic (EMG) responses over the corrugator supercilii and zygomatic major muscle regions; these muscle regions are activated during frowning and smiling respectively (Larsen et al., 2003). Following past research (e.g., Rosenfeld et al., 1995), Allen and colleagues utilized a 5-day tonal

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