

# The role of asymmetrical frontal cortical activity in aggression

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## Abstract

Aggression correlates with relatively greater left than right frontal electroencephalographic activity (inverse of EEG alpha power). The present experiment extends this research by manipulating frontal asymmetry and examining its effect on aggression. Participants were assigned to increase left frontal activation or increase right frontal activation by contracting their contralateral hand. They then received insulting feedback and played a game in which they could aggress toward the person who insulted them. Right-hand contractions caused greater left than right central and frontal activation and aggression as compared to left-hand contractions. Within the right-hand contraction condition, greater relative left frontal activity was associated with greater aggression.

**Descriptors:** Frontal asymmetry, Aggression, Approach motivation

Over 70 published studies have examined the relationship between frontal brain asymmetry and emotion or emotion-related constructs (for a review, see Coan & Allen, 2004). It has become widely accepted that the left prefrontal cortex (PFC) is associated with positive emotions, whereas the right PFC is associated with negative emotions (e.g., Davidson, 1984, 1998; Davidson, Ekman, Saron, Senulis, & Friesen, 1990; Heller, 1990; Silberman & Weingartner, 1986). This notion of specificity between positive and negative affect has been referred to as the *affective-valence* hypothesis of frontal EEG asymmetry.

However, more recent research has suggested that affective valence may not explain the relationship of emotive states/traits with asymmetrical frontal activity, and that motivational direction may provide a more accurate explanation of this relationship (Harmon-Jones, 2003). For example, research has shown that greater left frontal activation is related to approach motivation (Coan & Allen, 2003; Harmon-Jones, 2004a; Harmon-Jones & Allen, 1997; Harmon-Jones, Lueck, Fearn, & Harmon-Jones, 2006; Harmon-Jones, Sigelman, Bohlig, & Harmon-Jones, 2003; Schiff, Guirguis, Kenwood, and Herman, 1998), whereas greater right frontal activity is related to withdrawal motivation (for a review, see Davidson, 1992). Indeed, over a dozen published

studies have found anger, an approach-oriented negative emotion, relates to relatively greater left frontal cortical activity rather than relatively greater right frontal cortical activity (d'Alfonso, van Honk, Hermans, Postma, & de Haan, 2000; Harmon-Jones, 2004a, 2004b, in press; Harmon-Jones & Allen, 1998; Harmon-Jones & Sigelman, 2001; Harmon-Jones et al., 2002, 2003, 2006; Hewig, Hagemann, Seifert, Naumann, & Bartussek, 2004; Rybak, Crayton, Young, Herba, & Konopka, 2006; van Honk & Schutter, 2006; Wacker, Heldmann, & Stemmler, 2003). These findings, which are inconsistent with the affective-valence hypothesis, support the *motivational direction* model of frontal asymmetry. It proposes that approach motivation relates to relatively greater left than right frontal activity, whereas withdrawal motivation relates to relatively greater right than left frontal activity (Harmon-Jones, 2004a). Research has also found that relatively greater left frontal activation relates to aggression (Harmon-Jones & Sigelman, 2001).

A crucial limitation of prior work examining interrelations between the constructs of aggression and frontal asymmetry is that it is correlational (Harmon-Jones & Sigelman, 2001; Rybak et al., 2006). Thus, the degree to which frontal asymmetry makes a causal contribution to aggression is unknown. In support of a causal relationship, however, research has shown rTMS-induced left frontal activation causes increased attention to and memory for angry faces (d'Alfonso et al., 2000; van Honk & Schutter, 2006). Although this research suggests a possible causal relationship between relative left frontal activity and aggression, more direct aggression evidence is needed to conclude that relative left frontal activation leads to aggressive behavior.

To manipulate relative left frontal activation, we used unilateral hand contractions, as research suggests that unilateral contractions of muscles of the face or body bias perceptions, judgments, and behaviors in directions consistent with the

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affective-valence and motivational-direction models of asymmetrical frontal cortical activity. That is, contractions of the left hand and of the left side of the lower third of the face induce sadness and bias perceptions and judgments negatively. In contrast, contractions of the right hand and of the right side of the face induce positive affect and assertiveness and bias perceptions and judgments positively (Schiff & Lamon, 1989, 1994). These effects have been explained as a result of activation of the contralateral hemisphere (Schiff et al., 1998). Innervation of facial muscles in the lower third of the face (Morecraft, Stilwell-Morecraft, & Rossing, 2004; Rinn, 1984) and of muscles in the hand is contralateral (Hellige, 1993). Thus, it had been assumed that the emotional and motivational outcomes produced by the contractions resulted from the spread of activation to, or recruitment of, contralateral frontal areas (Schiff & Lamon, 1989, 1994). More recent research conceptually replicated these results, finding that unilateral contractions of the right hand, as compared to the left hand, caused increased self-reported approach affect to a mildly positive approach-oriented stimulus (Harmon-Jones, 2006). This research also extended the past work by showing that the unilateral hand contractions caused contralateral activations in the central and frontal cortical regions (Harmon-Jones, 2006).

However, the outcomes obtained in this research are consistent with both the affective valence and motivational direction models. Lacking is an experiment that eliminates the confound between affective valence and motivational direction. Examining the effects of unilateral contractions on angry aggressive behavior would provide such a test. Thus, we designed an experiment in which unilateral hand contractions were manipulated and their effects on asymmetrical frontal cortical activity and behavioral aggression following an anger induction were observed. Such an experimental manipulation would allow us to more closely test the causal role of asymmetrical frontal activity in aggression. We expected that right-hand contractions, as compared to left-hand contractions, would increase relative left frontal cortical activation and consequently prime the approach motivational system, as in past research (Harmon-Jones, 2006). The priming of the approach motivational system should, in turn, lead to more behavioral aggression in response to an anger-inducing event.

Unilateral body contractions may cause activation of mid-frontal regions via cortico-cortical connections between the motor cortex (MC) and dorsolateral prefrontal cortex (PFC). This activation of the left dorsolateral PFC, in turn, might ready or prime individuals for approach-motivating stimuli and cause individuals who contract the right hand to respond with more approach motivational responses to the stimulus. The coactivation of the left motor cortex and left dorsolateral PFC during right-hand contractions may assist in explaining why approach motivational processes are lateralized to the left dorsolateral PFC. That is, perhaps basic approach motivational movements are accomplished more often and/or efficiently via the right hand or right side of the body, as suggested by some prior animal research (Vallortigara & Rogers, 2005). In humans, the relatively close cortico-cortical connections between the left MC and left dorsolateral PFC may assist in the efficient execution of approach motivational processes and behaviors. Indeed, research has demonstrated that unilateral facial contractions affect approach and withdrawal responses, so that right-sided facial contractions facilitated finger flexion (approach) responses, but impeded finger extension (withdrawal) responses (Schiff & Bassel, 1996). In contrast, left-sided facial contractions facilitated finger extension, but impeded finger flexion (Schiff & Bassel, 1996). More

recently, Schutter, de Weijer, Meuwese, Morgan, and van Honk (in press) used rTMS to assess neural excitability of the left and right primary motor cortex. They then compared such excitability to individual differences in approach and withdrawal motivation, as measured by the BIS/BAS scale (Carver & White, 1994). Greater relative left than right motor cortex excitability was associated with enhanced approach compared to withdrawal motivation (Schutter et al.).

Thus, a secondary aim of the present research was to further examine the idea that the unilateral hand contractions caused contralateral central region activations that spread to frontal regions. That is, in the past research, unilateral hand contractions led to effects over the central and frontal regions, although the central effects were stronger than the frontal effects, as would be expected (Harmon-Jones, 2006). However, because past research has shown correlations of relative left frontal but not central activity and aggression, we suspected that the aggression effects would be due to activations of the frontal regions. To explicitly examine the spreading of activity from central to frontal regions, EEG coherence analyses were conducted. Coherence measures the degree to which EEG signals (within a given frequency band) measured at two distinct scalp locations are linearly related to one another. High coherence implies that amplitudes at a given frequency are correlated across EEG samples. Moreover, there tends to be a constant phase angle (or time lag) between the two signals. Research has suggested that high EEG coherence occurs between regions connected by known white matter tracts (Thatcher, Krause, & Hrybyk, 1986).

## Method

### *Participants and Design*

Forty-three right-handed female introductory psychology students at Texas A&M University participated in exchange for course credit. The design was a two-condition between-subjects design. Five participants were removed prior to analyses because they expressed suspicion about the existence of the other ostensible player (see below), leaving 38 participants. A review of unobtrusive video recorded during the hand contractions indicated that 2 participants did not follow instructions and thus were also removed from analyses, for a total of 36 participants (right hand:  $n = 17$ ; left hand:  $n = 19$ ).

Following earlier suggestions (e.g., Basso, Schefft, & Hoffmann, 1994; Davidson et al., 1990; Levenson, 2003; Shackman et al., 2006; Stemmler, 2003), we excluded from analyses those participants who failed to show an asymmetric effect of the unilateral contraction manipulation on contralateral motor strip. More specifically, data from 12 participants who failed to show greater relative left (right) activation in contralateral central electrodes during unilateral right (left) contractions were discarded,<sup>1</sup> leaving 24 participants (right hand:  $n = 11$ ; left hand:  $n = 13$ ) for hypothesis testing.

### *Procedure*

Participants were brought to the laboratory under the assumption that there was another participant in a room next door. Experimenters were careful to drop subtle hints during the course

<sup>1</sup>Within these 12 participants, the hand contractions did not affect noise level or noise length ( $ps > .79$ ) or frontal asymmetry ( $ps > .55$ ). It is possible that these individuals failed to contract the hand muscles during the task. Future research should employ EMG measures to ensure that participants comply with the muscle contraction instructions.

of the experiment to make this cover story believable. Participants were told they would be doing two experiments, and that the first one examined how personality variables and muscular activity affect essay content and impressions of others, whereas the other involved playing a reaction time game against the other participant.

After giving consent, participants were told they had been randomly assigned to write an essay and that the other participant would evaluate it. Instructions contained five essay topic choices of potential importance of participants (e.g., reducing the drinking age, the legality of smoking in public places). Participants were asked to select the side of the issue that they believed most strongly and write a persuasive essay arguing their position. Participants had 10 min to write, after which the experimenter took it to the other "participant" to evaluate.

Once the essay was "delivered," the experimenter did the EEG attachment. Then 4 min of resting EEG were recorded (2 min with eyes open, 2 min with eyes closed). To allow the experimenter to remain blind to condition, participants were given an envelope containing the instructions for the hand contractions. Participants were instructed to squeeze the ball as hard as they could with their right or left hand while their opposite hand remained flat with the palm facing down. A photograph of an individual's hand performing the contraction was included. Both conditions were told there would be four 45-s trials with a 15-s period to relax between each trial, and that they should remain still during the entire task. This procedure is identical to that used in previous research (Harmon-Jones, 2006; Schiff et al., 1998). EEG was recorded.

After the hand contractions, the experimenter returned to the room with an envelope containing the essay feedback. Participants were nonchalantly asked if they would like to see the feedback, and were left alone in the room to read it. The feedback rated participants on six characteristics using a 9-point scale (e.g., for intelligence, 1 = *unintelligent*, 9 = *intelligent*). All participants were given the following ratings: intelligence, 3; interest, 3; friendliness, 2; logic, 3; respectability, 4; and rationality, 3. Additional comments said, "I can't believe an educated person would think like this. I hope this person learns something while at A&M." All feedback was handwritten by a female. This exact insult manipulation has been used in other research (Harmon-Jones & Sigelman, 2001; Harmon-Jones, Vaughn-Scott, Mohr, Sigelman, & Harmon-Jones, 2004).<sup>2</sup> When the participants indicated they were done, participants were told via the intercom that the game would begin as soon as the other participant was ready. The game began approximately 15 s later with instructions presented over the computer.

The game was modeled after one used in previous research on aggression (Taylor, 1966), in which participants were able to shock another participant if her reaction time on a task was fastest. We used noise blasts instead of electric shocks, as in other research (Bartholow & Anderson, 2002). The game consisted of four blocks of five trials. During each trial, participants were to press the right shift key if a plus sign appeared on the right side of the screen and the left shift key if a plus sign appeared on the left

side of the screen. If they responded fastest, they would be able to deliver up to 10 s of 60–100 dB white noise to their opponent; however, if they were slowest, they would receive a noise blast from their opponent. Each trial consisted of noise selection (5 s), fixation (2 s), stimulus (2 s), feedback (3 s), and delivery/receiving of noise blast (up to 10 s/5 or 7 s). The game was designed so that participants lost 10 of the 20 trials regardless of how they performed. The noise blasts received by the participants were presented through stereo headphones and were either 85 dB or 102 dB and lasted either 5 or 7 s. Participants won 10 trials as long as they responded to the stimulus within 1.5 s, which all participants did. Three practice trials preceded the four blocks and were not included in analyses. After the game, participants were probed carefully for suspicion and debriefed (see Harmon-Jones, Amodio, & Zinner, 2007).

#### **Data Collection and Reduction**

To record EEG, 27 tin electrodes mounted in a stretch-lycra electrode cap (Electro-Cap, Eaton, OH) were placed on the participant's head. The ground electrode was mounted in the cap on the midline between the frontal pole and the frontal site. The reference electrode was placed on the left ear, and data were also acquired from an electrode on the right ear, so that an off-line, averaged ears' reference could be computed. Vertical and horizontal eye movements (EOG) were also recorded to facilitate artifact correction of the EEG. All electrode impedances were under 5000  $\Omega$ , and homologous sites were within 1000  $\Omega$  of each other.

EEG and EOG were amplified (an analog 60-Hz notch filter was enabled) with Neuroscan Synamps (El Paso, TX), bandpass filtered (0.1–100 Hz), and digitized at 500 Hz. The signals were visually scored, and portions of the data that contained artifacts were removed. Then, a regression-based eye movement correction was applied (Semlitsch, Anderer, Schuster, & Presslich, 1986), after which the data were again visually inspected to insure proper correction. All epochs 1.024 s in duration were extracted through a Hamming window. A fast Fourier transform was used to calculate the power spectra, which were averaged across epochs of each resting minute and the periods of hand contraction. Total power within the alpha band (8–13 Hz) was obtained. Asymmetry indexes were created for all homologous sites by taking natural log right minus natural log left. Because alpha power is inversely related to cortical activity, higher scores indicate greater left than right activity (Davidson, Jackson, & Larson, 2000).

To examine whether activations observed at central (MC; C3/4) sites indeed "spread" to frontal sites, coherence analyses were performed. Coherence, the magnitude of squared coherency, was computed using Neuroscan software version 4.3 (El Paso, TX). Analyses were conducted on data from the second 45-s period of hand contraction, because exploratory analyses indicated that the second 45-s period was affected most strongly by hand contractions. Coherence values were computed for the alpha band (no normalization; mean excluded). Coherence estimates were square-root transformed, to more closely resemble the absolute value of Pearson correlation coefficients, and natural log transformed to normalize the distribution.

#### **Data Analytic Strategy**

Because all a priori comparisons were directional and were derived from theory, which was based on much past research, they were evaluated using a one-tailed criterion of significance

<sup>2</sup>In our past research (Harmon-Jones & Sigelman, 2001; Harmon-Jones et al., 2004), self-reported anger, fear, distress, sadness, and happiness have been measured following insulting versus neutral feedback and only anger has differed between conditions. These past results suggest that the insult manipulation evokes only anger and not a mixed emotional state.

(Hayes, 1988; Rosenthal, Rosnow, & Rubin, 2000). Effect sizes are reported using the correlation effect size  $r$  (Rosenthal et al.).

## Results

### Asymmetry Effects

To examine the affect of the hand contractions on asymmetrical EEG activity, individual  $t$  tests were conducted for each asymmetry index (see Table 1).<sup>3</sup> As predicted, a significant effect of hand contraction on midfrontal (F3/4) and lateral frontal (F7/8) activation during the contractions was found. Participants who made right-hand contractions evidenced greater relative left activation than those who made left-hand contractions. This effect was also found in other regions.

### Effect on Aggression

As predicted, hand contraction significantly affected behavioral aggression during the reaction time game, with participants who made right-hand contractions choosing louder ( $M = 2.2$ ,  $SD = 0.1$ ) and longer ( $M = 1.1$ ,  $SD = 0.5$ ) noise blasts than those who made left-hand contractions ( $M = 1.5$ ,  $SD = 0.8$  and  $M = 0.8$ ,  $SD = 0.5$ ),  $t(22) = 1.8$ ,  $p < .05$ , and  $t(22) = 1.7$ ,  $p < .05$ .

### Relations between Asymmetry and Aggression

Following Harmon-Jones (2006), we examined correlations between asymmetry and aggression within each condition. Within the right-hand condition, frontal asymmetry variables related positively to noise length ( $.21 < rs < .60$ ), with relatively greater left frontal-central activity relating significantly to longer delivery of noise (Fc3/4:  $r = .60$ ,  $p < .05$ ). See Figure 1. Central (C3/4;  $r = .68$ ,  $p < .05$ ) and central-parietal (Cp3/4;  $r = .62$ ,  $p < .05$ ) asymmetry also related positively with noise length, so that greater relative left central activation was associated with longer delivery of noise. For noise level, no significant relationships emerged.

In contrast, within the left-hand condition, frontal asymmetry related negatively or slightly positively to noise length ( $-.62 < rs < .08$ ), with relatively greater right midfrontal activity relating to significantly longer delivery of noise (F3/4;  $r = -.62$ ,  $p < .05$ ). Central and central-parietal asymmetry did not relate significantly to noise length ( $rs = -.22$  and  $-.02$ ). For noise level, relative right midfrontal asymmetry related negatively to louder noise delivery ( $r = -.58$ ,  $p < .05$ ). Other frontal and central asymmetry variables were not significantly related to noise level, and they related in similar directions and magnitudes as noise duration. The relationship between relative right midfrontal activation and greater aggression is interesting, especially given that these participants were less aggressive and had greater activation over the right frontal regions when compared to participants who made right-hand contractions.

<sup>3</sup>Individual hemispheric comparisons were also conducted in addition to examining asymmetry scores, but no significant results over the frontal regions were found. Similar results have occurred in other studies (Harmon-Jones et al., 2002), suggesting that the asymmetry index is a more sensitive index. This is consistent with research demonstrating a dynamic relationship between left and right frontal regions, so that lesions or rTMS stimulation of one hemisphere leads to greater activation of the opposite hemisphere (e.g., Robinson & Benson, 1981; Robinson, Kudos, Starr, Rao, & Price, 1984; van Honk & Schutter, 2006).

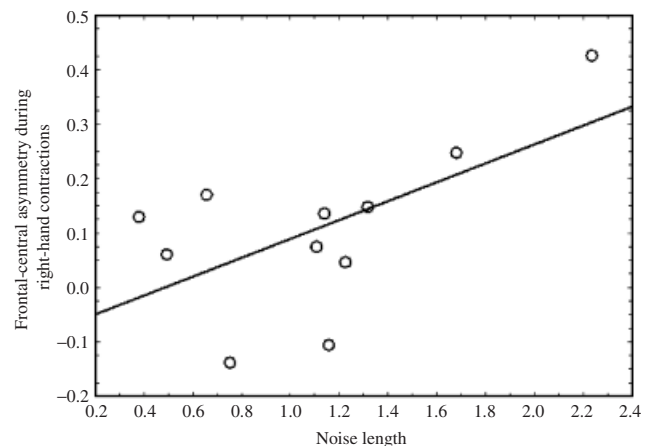
**Table 1.** Mean ( $SD$ ) Asymmetry Scores as a Function of Hand Contraction and Region

Region	Hand contraction		$t(22)$	$r$
	Right	Left		
Frontal-polar (Fp1/2)	0.21 (0.13)	0.18 (0.16)	0.43	.09
Midfrontal (F3/4)	0.11 (0.12)	0.02 (0.12)	1.85*	.35
Lateral-frontal (F7/8)	0.13 (0.19)	-0.03 (0.17)	2.13*	.40
Central (C3/4)	0.30 (0.28)	-0.12 (0.29)	3.57**	.62
Frontal-central (Fc3/4)	0.11 (0.15)	-0.03 (0.20)	1.90*	.36
Frontal-temporal (Ft7/8)	0.06 (0.17)	-0.13 (0.17)	2.58**	.48
Central-parietal (Cp3/4)	0.23 (0.31)	-0.14 (0.31)	2.93**	.53
Anterior temporal (T3/4)	0.16 (0.24)	-0.12 (0.34)	2.28*	.43
Posterior temporal (T5/6)	-0.05 (0.35)	-0.07 (0.53)	0.16	.03
Parietal (P3/4)	0.04 (0.25)	-0.14 (0.29)	1.57	.31
Occipital (O1/2)	0.07 (0.28)	0.02 (0.16)	0.56	.11

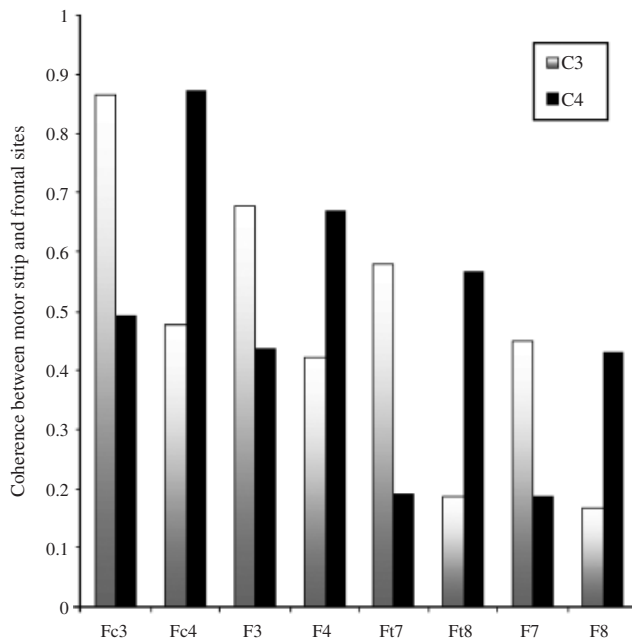
Note. Asymmetry scores were created such that higher scores indicate greater relative left hemisphere activation \* $p < .05$ , \*\* $p < .01$ .

### Coherence Analyses

Two hypotheses were tested using EEG coherence analyses. First, we tested whether coherence between central and frontal regions was primarily unilateral. To do this, we conducted a 2 (right vs. left central)  $\times$  2 (right vs. left frontal) repeated measures ANOVA at all frontal regions that were significantly affected by the hand contractions (i.e., frontal-central, midfrontal, frontal-temporal, lateral frontal). Significant interactions occurred for all of these regions: frontal-central:  $F(1,23) = 84.2$ ,  $r = .89$ ,  $p < .001$ ; midfrontal:  $F(1,23) = 100.9$ ,  $r = .90$ ,  $p < .001$ ; frontal-temporal:  $F(1,23) = 165.0$ ,  $r = .94$ ,  $p < .001$ ; lateral frontal:  $F(1,23) = 118.5$ ,  $r = .92$ ,  $p < .001$ . No other effects emerged,  $ps > .09$ . Simple effects were then examined separately for each of the central sites (C3, C4). For the left MC, greater coherence with the unilateral compared to the contralateral frontal electrode occurred for all of the regions: frontal-central:  $t(46) = 7.6$ ,  $r = .48$ ,  $p < .001$ ; midfrontal:  $t(46) = 5.0$ ,  $r = .34$ ,  $p < .001$ ; frontal-temporal:  $t(46) = 10.5$ ,  $r = .61$ ,  $p < .001$ ; lateral frontal:  $t(46) = 7.2$ ,  $r = .46$ ,  $p < .001$ . A similar bias toward greater unilateral coherence was also found for the right MC: frontal-central:  $t(46) = 7.8$ ,  $r = .50$ ,  $p < .001$ ; midfrontal:  $t(46) = 5.1$ ,  $r = .35$ ,  $p < .001$ ; frontal-temporal:  $t(46) = 8.6$ ,  $r = .53$ ,  $p < .001$ ; lateral frontal:  $t(46) = 6.2$ ,  $r = .41$ ,  $p < .001$ . See Figure 2.



**Figure 1.** Relation between noise length and frontal-central asymmetry during right-hand contractions. Higher asymmetry scores indicate greater relative left than right activation.

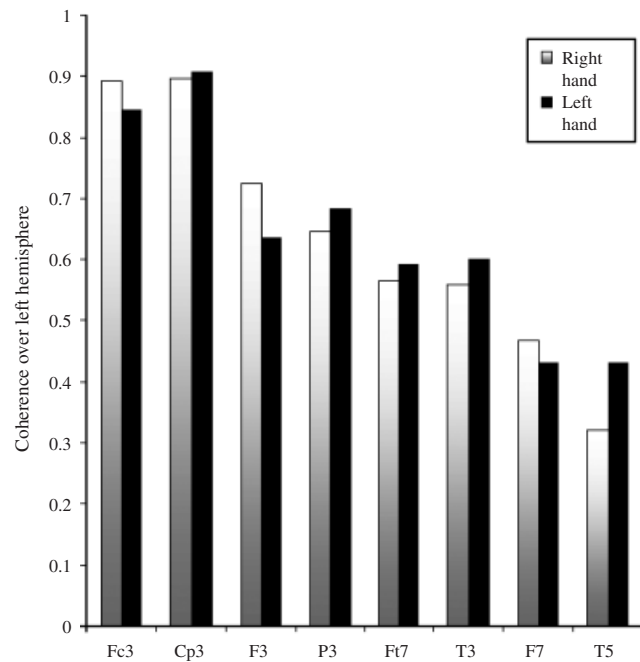


**Figure 2.** EEG coherence between central (C3/4) and frontal sites across all conditions.

Second, we tested whether central-frontal coherence was anatomically specific and whether it differed across hand contraction conditions. To do this, we examined central-frontal coherence for each hemisphere by testing it against a posterior control site of the same distance.<sup>4</sup> For the left hemisphere, a significant interaction emerged comparing frontal-central and central-parietal sites,  $F(1,22) = 5.2$ ,  $r = .54$ ,  $p < .05$ . A marginally significant interaction occurred between midfrontal and parietal sites,  $F(1,22) = 3.3$ ,  $r = .36$ ,  $p < .09$  (all other  $ps > .39$ ). To understand these interactions, we compared left frontal sites to left posterior sites within each hand condition. Within the right-hand condition, only lateral frontal and posterior temporal sites differed significantly,  $t(20) = 2.5$ ,  $r = .26$ ,  $p < .05$  (all other  $ps > .14$ ). This effect suggests that the right-hand contractions caused greater coherence between the MC and lateral frontal site compared to the posterior temporal site. Within the left-hand condition, greater coherence occurred between the MC and central-parietal site than between the MC and frontal-central site,  $t(24) = 2.3$ ,  $r = .22$ ,  $p < .05$  (all other  $ps > .29$ ).

Then we compared left central-frontal site coherence across hand conditions; central-frontal coherence was marginally greater during right- than left-hand contractions: frontal-central:  $t(22) = 1.5$ ,  $r = .14$ ,  $p < .08$ ; mid-frontal:  $t(22) = 1.4$ ,  $r = .13$ ,  $p < .09$ ; other  $ps > .20$ . Finally, we compared central-posterior site coherence across hand conditions; central-posterior temporal coherence was greater during left- than right-hand contractions,  $t(22) = 2.1$ ,  $r = .20$ ,  $p < .05$  (other  $ps > .20$ ). Taken together, these results suggest that the hand contractions affected coherence over the left hemisphere, so that right-hand contractions caused greater central-frontal site coherence, whereas left-hand contractions caused greater central-posterior site coherence.

<sup>4</sup>The electrodes on the cap have a roughly fixed interelectrode distance, approximately 3 cm. Electrodes were rank ordered based on their relative distance (in centimeters) from the MC, varying from 3 to 13 cm.



**Figure 3.** EEG coherence over the left hemisphere.

No significant interactions were found over the right hemisphere ( $ps > .13$ ). The lack of hand by anterior/posterior interactions over the right hemisphere suggests the hand contractions did not affect right hemisphere coherence the same as they affected left hemisphere coherence. See Figure 3.

## Discussion

As predicted, unilateral right-hand contractions caused greater relative left activity in the frontal cortical regions, as compared to unilateral left-hand contractions. As compared to participants who made left-hand contractions, participants who made right-hand contractions also showed greater behavioral aggression. These effects are consistent with past research showing that unilateral hand contractions affect central and frontal asymmetry (Harmon-Jones, 2006) and motivational responses (Harmon-Jones, 2006; Schiff et al., 1998), as well as past research linking greater relative left frontal cortical activity to aggression (Harmon-Jones & Sigelman, 2001; Rybak et al., 2006) and approach motivation (Coan & Allen, 2003; Harmon-Jones, 2004a; Harmon-Jones & Allen, 1997; Harmon-Jones et al., 2003, 2006; Schiff et al., 1998).

The present research provides an important extension of past work by showing that greater relative left frontal cortical activity is causally involved in behavioral aggression. That is, the present results suggest that changes to relative left frontal activation brought about by the hand contraction manipulation caused greater behavioral aggression in response to an anger-inducing event. Past research on asymmetrical frontal cortical activity and aggression is limited because only correlations between aggression and relative left frontal cortical activity were examined (Harmon-Jones & Sigelman, 2001; Rybak et al., 2006). We suggest that the greater relative left frontal activation caused by right-hand contractions activated approach motivational action tendencies, which, in turn, caused increased behavioral

aggression in response to an interpersonal insult. Such a conclusion is consistent with prior research that found increased self-reported approach positive affect to a mildly positive approach-oriented communication after right-hand contractions (Harmon-Jones, 2006).

Research on mu rhythm, an EEG oscillation with dominant frequencies in the 8–13-Hz band suggests that contraction of unilateral muscles is associated with activation of the contralateral motor cortex (Andrew & Pfurtscheller, 1997; Pineda, 2005). Thus, it is possible that the hand contractions may have affected mu rhythm rather than, or in addition to, alpha power. Differentiating between the two has been found to be difficult, because both mu rhythm and alpha occur between 8 and 13 Hz. Because the present research was predicated on the literature suggesting that asymmetrical frontal alpha power relates to approach/withdrawal motivation, and because the mu-rhythm research had not suggested asymmetrical involvement of mu with motivational outcomes, the present results are interpreted in light of the past research on frontal alpha asymmetry and motivation. Future studies should attempt to further integrate the literatures on mu, alpha asymmetries, and motivation.

Together with past research on asymmetrical frontal cortical activity, anger, and aggression (for a review, see Harmon-Jones, 2003), the present research demonstrates that the prefrontal cortex (PFC) does not only inhibit aggressive behavior, as suggested by some previous research (e.g., Anderson, Bechara, Damasio, Tranel, & Damasio, 1999; Blair & Cipolotti, 2000; Raine, Buchsbaum, & LaCasse, 1997; Raine et al., 1998). Instead, greater activation of the left PFC relative to the right PFC is involved in *causing* behavioral aggression. This research suggests a more complex view of the psychological and behavioral functions of

the PFC and is consistent with other evidence showing that the PFC may be involved in the activation of aggressive behavior (Halász, Tóth, Kalló, Liposits, & Haller, 2006; Lotze, Veit, Anders, & Birbaumer, 2007).

In addition, the present coherence analyses demonstrated that coherence exists between the MC and the frontal regions of the same hemisphere. Such relationships may indicate spreading of MC activations to the PFC. This is consistent with recent research suggesting that connections exist between motor cortex excitability and emotion (Hajcak et al., 2007; Lee, Josephs, Dolan, & Critchley, 2006) and motivation (Schutter et al., in press). The present coherence results, although weak, also showed that coherence between the left MC and left frontal/posterior sites varied by hand contraction condition. That is, right-hand contractions caused greater coherence between the left MC and left PFC as compared to the left posterior cortical region, whereas left-hand contractions caused greater coherence between the left MC and left posterior cortical region. These results suggest that right-hand contractions engage the left PFC, whereas left-hand contractions engage the left posterior region. However, our data cannot assess a causal path between MC and PFC, and it is possible that the direction of causality is reversed or bidirectional.

Whereas much previous research has found correlational relationships between aggression and frontal asymmetry, the present research was able to demonstrate a causal role of frontal asymmetry in aggressive behavior. Moreover, the present research suggests close cortico-cortical connections exist between the MC and PFC regions, and as such, assists in explaining why motivational processes are instantiated in frontal cortical regions.

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