EXAMINING ASSOCIATIONS BETWEEN EMOTIONAL FACIAL EXPRESSIONS, RELATIVE LEFT FRONTAL CORTICAL ACTIVITY, AND TASK PERSISTENCE

A Dissertation

by

THOMAS FRANKLIN PRICE V

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

August 2012

Major Subject: Psychology

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ABSTRACT

Examining Associations between Emotional Facial Expressions, Relative Left Frontal Cortical Activity, and Task Persistence. (August 2012)

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Past research associated relative left frontal cortical activity with approach motivation, or the inclination to move toward a stimulus, as well as positive affect. Work with anger, a negative emotion often high in approach, helped clarify the role of relative left frontal cortical activity. Less work, however, examined positive emotional states varying in approach motivation and relative left frontal cortical activity. In the present research, it was predicted that positive facial expressions varying in degrees of approach motivation would influence relative left frontal cortical activity measured with electroencephalography (EEG) alpha power and task persistence measured with time working on insolvable geometric puzzles. Furthermore, relative left frontal cortical activity should positively relate to task persistence.

In support of these predictions, determination compared to satisfaction facial expressions caused greater relative left frontal activity measured with EEG alpha power, a neural correlate of approach motivation. This effect remained when accounting for the contribution of muscle activity in the EEG signal, subjective task difficulty, and the extent to which participants made facial expressions. Determination compared to neutral facial expressions also caused greater self-reported interest following the puzzle task. Facial expressions did not directly influence task persistence. However, relative left frontal cortical activity was positively correlated with total time working on insolvable puzzles in the determination condition only. These results extend embodiment theories and motivational models of asymmetric frontal cortical activity.

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1. INTRODUCTION

Asymmetric frontal cortical activity is a widely used measure in emotion and motivational research (Allen, Coan, & Nazarian, 2004; E. Harmon-Jones, Gable, & Peterson, 2010). Previous research, however, has debated the role of asymmetric frontal cortical activity in emotive processes. Some evidence has suggested that relative left frontal cortical activity relates to approach motivation, or the inclination to move toward a stimulus (E. Harmon-Jones, Gable, & Peterson, 2010), whereas other research suggests that it relates to positive affect (Spielberg, Stewart, Levin, & Heller, 2008). Work attempting to disambiguate the role of relative left frontal cortical activity has used anger, a negative emotion that can be high in approach (Carver & E. Harmon-Jones, 2009). Other research, however, has suggested that determination and satisfaction might be positive emotive states differing in approach motivation (C. Harmon-Jones, Schmeichel, Mennitt, & E. Harmon-Jones, 2010), and there has been less work examining asymmetric frontal cortical activity and positive emotions differing in approach motivation. Thus, the present experiment tested if manipulated facial expressions of determination and satisfaction influence asymmetric frontal cortical activity and molar persistence behavior. Furthermore, the present experiment examined the relationship between relative left frontal cortical activity and task persistence.

This dissertation follows the style of Biological Psychology.

1.1 Asymmetric frontal cortical activity and approach motivation

Asymmetric activity within the frontal cortex has been linked to the motivational direction of emotions. This was originally observed in World War I soldiers who experienced changes in positive affect (approach motivation) or negative affect (withdrawal motivation) after damage to the right or left anterior cortex, respectively (Goldstein, 1939). Later research supported these findings using the Wada test, which involves injecting sodium amytal (barbiturate) into the carotid arteries within the neck. Injections into the left interior artery, suppressing left hemispheric brain activation, caused depressive symptoms. Injections into the right interior artery, suppressing right hemispheric brain activation, caused euphoria. (Terzian & Cecotto, 1959; Alema, Rosadini, & Rossi, 1961; Perria, Rosadini, & Rossi, 1961; Rossi & Rosadini, 1967). These results suggested that the right and left hemispheres of the brain exert inhibitory effects on one another; a disinhibited right hemisphere produces depressive symptoms, whereas a disinhibited left hemisphere produces euphoria.

Stroke lesion studies suggested that damage to the left and right hemispheres were associated with emotional changes. Lesions to the left hemisphere were associated with depressive symptoms (Black, 1975; Gasparrini, Satz, Heilman, & Coolidge, 1978; Gainotti, 1972; Robinson & Price, 1982), whereas lesions to the right hemisphere were associated with mania symptoms (Gainotti, 1972; Robinson & Price, 1982; Sackeim et al., 1982). Other research revealed asymmetries associated with appetitive and avoidant behaviors in animals ranging from apes and reptiles (Deckel, Lillaney, Ronan, &

Summers, 1998; Hopkins, Bennett, Bales, Lee, & Ward, 1993) to pigeons (Güntürkün et al., 2000), amphibians (Rogers, 2002), and spiders (Ades & Ramires, 2002).

More recent research supported these findings using EEG methodologies and measuring cortical activity with EEG alpha power. Research using behavioral and hemodynamic measures revealed alpha power is inversely associated with regional brain activity (Davidson, Chapman, Chapman, & Henriques, 1990; Cook, O'Hara, Uijtdehaage, Mandelkern, & Leuchter 1998). This research often examines frontal cortical activation in analogous areas on the left and right sides of the head. Difference scores are used in this research; their use is consistent with the abovementioned amytal and lesion studies that suggest a complementary relationship between the left and right frontal regions.

Later research observed that trait approach motivation was associated with greater left than right frontal cortical activity (Amodio, Master, Yee, & Taylor, 2008; E. Harmon-Jones & Allen, 1997; Sutton & Davidson, 1997). These studies suggested that relative left frontal cortical activity was associated with approach motivation as opposed to affective valence. Positive affect and approach, however, are often associated with one another (Carver & White, 1994), which clouded initial interpretations of the role of relative left frontal cortical activity. Similarly, the finding of promotion (vs. prevention) focus being associated with greater relative left (vs. right) frontal activation at baseline (Amodio, Shah, Sigelman, Brazy, & E. Harmon-Jones, 2004) could be interpreted from a motivational direction or affective valence view because promotion (vs. prevention) is more often associated with positive (vs. negative) affect. Some frontal asymmetry research, therefore, confounded motivational direction with affective valence. Researchers interpreted greater relative left than right frontal cortical activity reflecting greater approach motivation and positive affect, whereas greater relative right than left frontal cortical activity reflecting greater withdrawal motivation and negative affect (Ahern & Schwartz, 1985; Heller 1990; Heller & Nitschke, 1998; Spielberg, Stewart, Levin, Miller, & Heller, 2008). These claims fit well into dominant emotion theories that associated positive affect with approach motivation and negative affect with withdrawal motivation (Lang, 1995; Watson, 2000).

Not all emotion theories posit that negative affect is invariably associated with withdrawal motivation, however. Anger can be high in approach motivation in instances such as attack or offensive aggression (e.g., Berkowitz, 1993; Blanchard & Blanchard, 1984; Lagerspetz, 1969). Anger has also been associated with trait measures of approach motivation, such the behavioral activation sensitivity (BAS) scale from Carver and White's (1994) scale (E. Harmon-Jones, 2003; Smits & Kuppens, 2005). Furthermore, in an attempt to disambiguate the role of relative left frontal cortical activity, research suggested that approach-related anger relates to greater relative left frontal cortical activity. For example, trait anger measured with the Buss and Perry (1992) aggression questionnaire has been associated with greater left than right resting frontal cortical activity (E. Harmon-Jones & Allen, 1998). An experiment by E. Harmon-Jones and Sigelman (2001), furthermore, found that insulted participants demonstrated greater relative left frontal activity than participants who were not insulted. Past research also suggested that relative left frontal activity is greater when anger occurs in an approach-oriented setting (E. Harmon-Jones et al., 2003, 2006). In these settings, participants are led to believe that they can rectify the anger-evoking situation.

In order to find a stronger causal link between relative left frontal activity and anger, researchers have also used transcranial direct current stimulation (tDCS) methodologies. tDCS sends minute voltages past an individual's skull and can cortically excite and inhibit brain regions. This research has indicated that electrically increasing relative left frontal cortical activity leads to aggressive responses in individuals who are angry (Hortensius, Schutter, & E. Harmon-Jones, 2012). Findings from these experiments have indicated that greater relative left frontal activity is not always associated with positive emotions (E. Harmon-Jones, 2003).

1.2 Positive emotions differing in approach

Some researchers have viewed the abovementioned work with anger as insufficient to discount the valence model, stating that "anger is sometimes associated with positive valence, further complicating reliance on anger to adjudicate differences between the [valence and motivational] models" (Spielberg et al., 2008, p. 5). One way to deal with this issue is to examine positive emotional states varying in approach motivation. Research has suggested that determination is a positive emotional state higher in approach motivation than satisfaction (C. Harmon-Jones, Schmeichel, Mennitt, & E. Harmon-Jones, 2011, Study 1). In this study, participants were randomly assigned to a positive action-oriented or a positive non-action-oriented condition. In the positive action-oriented condition, participants were asked to think of an intended project (goal) and steps toward accomplishing it. In the positive non-action condition, participants were asked to think of a past event that made them feel good without any personal action (e.g., a time someone did something wonderful for you). Afterwards, participants were asked to name the emotion that they experienced most strongly during the exercise. Results indicated that, in the positive action-oriented mindset condition, the most common response was *determination*. Determination is also a word on one of the most commonly used measures of positive affect, the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988).

Less work, however, has tested whether positive emotions varying in approach motivation influence relative left frontal cortical activity. One experiment has tested this idea (E. Harmon-Jones, C. Harmon-Jones, Fearn, Sigelman, & Johnson, 2008, Experiment 2). In this experiment, participants were randomly assigned to a positive action-oriented (think of steps toward a goal), neutral (describe normal day), or positive non-action condition (think of past event that made you feel good without personal action). Positive emotions were assessed with self-reports to the items: *enthusiastic*, *interested*, *happy*, *proud*, and *feel good about myself*. Results indicated that self-reported positivity was greater in the action and non-action positive conditions as compared to the neutral condition. More importantly, participants in the positive action condition had greater relative left frontal cortical activity as compared to participants in the other two conditions.

Although this experiment supported the hypothesis that an action-oriented positive state caused greater relative left frontal activity than a non-action-oriented positive state, one could question whether the emotive state or another aspect of the cognitive manipulation caused the differences in relative left frontal activation. In emotive research, it is imperative to utilize multiple manipulations of emotive states. This insures that the emotive state, not another aspect of the manipulation, is causing predicted differences.

1.3 Facial expressions of determination vs. satisfaction

One way to deal with this issue is to use embodied emotional manipulations, such as manipulating the physical expression of high and low approach motivated positive states. The idea that bodily manipulations, such as facial expressions, share inherent connections with emotions is not new; it was proposed by William James (1890), and the innateness and universality of certain facial expressions was recognized by Charles Darwin (1872). Building upon these earlier theoretical arguments, the facial feedback hypothesis (Laird 1974) suggests that manipulated facial expressions of emotion cause self-reported changes in emotions. Support for this hypothesis has come from experiments that manipulate participants' facial expressions with instructions or nonobtrusive methods, such as having participants hold a pen between their teeth to facilitate smiling (Strack, Martin, & Stepper, 1988). Afterwards, participants are often presented with a stimulus and asked to give their self-reported emotional reactions. For example, facilitating as compared to inhibiting smiling has been found to increase self-reported positive reactions toward cartoons. Experiments have also demonstrated that inhibiting muscle movements interferes with emotional processes. For example, denervating facial muscles with botulinum toxin-A (BTX) slows the reading of emotional passages (Havas, Glenberg, Gutowski, Lucarelli, & Davidson, 2010). In addition, bodily manipulations designed to elicit varying levels of approach motivation have been found to influence cognitive processes (Price & E. Harmon-Jones, 2010), asymmetric frontal cortical activity (Harmon-Jones, Gable, & Price, 2011; Price & E. Harmon-Jones, 2011), and other physiological measures sensitive to emotive processes (Price, Dieckman, & E. Harmon-Jones, 2012). This program of research has suggested that bodily manipulations can influence varying levels of approach motivation at the neural level (Price, Peterson, & E. Harmon-Jones, 2012).

1.4 The present experiment

In the present experiment, determination and satisfaction were manipulated via facial expressions. Past research connecting positive emotions with approach motivation relied on self-reports (Watson, 2000), and valence might be especially accessible to self-reports. Motivational intentions might be more salient as facial expressions, however. When seeing another individual’s facial expression, for example, the most important question may be what that individual will do next as compared to how they are feeling. Previous research also revealed that facial expressions influence frontal cortical activity. Approach-oriented facial expressions (e.g., joy and anger), for example, have been associated with greater relative left than right frontal cortical activity (Coan, Allen, & E. Harmon-Jones, 2001). Withdrawal-oriented facial expressions (e.g., sadness and disgust), on the other hand, have been associated with less relative left than right frontal cortical activity (Coan et al., 2001). This past experiment, however, did not compare positive facial expressions varying in approach motivation.

A secondary research question in the present experiment is if these facial expressions influence more molar motivational behavior, such as task persistence. The present experiment examined participants' persistence on an insolvable puzzle task taken from Glass and Singer (1972). Some past work has suggested that bodily manipulations influence task persistence. For example, slumped/helpless postures relative to more upright and expansive postures have been found to decrease persistence on these insolvable puzzles (Riskind & Gotay, 1982). The present research examined if facial expressions associated with varying degrees of approach motivated positivity influence approach oriented behavior. A third and final question tested is whether relative left frontal cortical activity produced by the facial expressions correlated with persistence on the insolvable tasks.

Thus, three primary predictions were tested in the present experiment. Foremost, determination as compared to satisfaction and neutral facial expressions should cause greater relative left frontal activity. Second, these facial expressions might influence persistence on the puzzle task; determination should cause greater persistence as compared to satisfaction and neutral expressions. Finally, there should be a positive relationship between relative left frontal cortical activity and persistence on the insolvable puzzles, especially for participants in the determination facial expression condition.

2. METHOD

2.1 Participants

Forty-nine (31 women) right handed university students aged 18-24 years were recruited from introductory psychology classes and participated for course credit. Participants were randomly assigned to condition and experimenters were blind to condition. For the EEG analyses, one participant in the satisfaction condition was excluded due to noise in baseline EEG recordings. For the self-report data, one participant in the determination condition and another in the satisfaction condition lacked data and therefore were not included in these analyses. This experiment received institutional ethics approval and participants provided informed consent.

2.2 Materials and procedures

Participants sat in a stationary chair with a table of four stacks of puzzles labeled 1 to 4 [in order from first to last consistent with Glass and Singer (1972): insolvable, solvable, insolvable, solvable] and a computer monitor on a desk in front of them. Puzzles were face down, printed on three by five inch cards, and there were always 30 in each stack. Participants were informed that the experiment involved facial expressions, cognitive tasks, and brain activity. After providing informed consent, participants were fitted with an EEG electrode cap. After full EEG setup, participants were fitted with a stereo headset with an attached microphone (the stereo headset had cushions on each ear piece that placed the headset out of contact with temporal EEG electrodes). This allowed the experimenter to hear participant's auditory responses from an adjacent control room throughout the experiment.

After these preparations, the experimenter verbally explained that the participant would attempt to solve four different puzzles. Consistent with Glass and Singer (1972), participants were told that they could not retract any lines or lift their pen from the card while working on a puzzle. Participants were also told that they could take as many attempts as they wished at a specific puzzle (with an unspecified maximum of 30 attempts for each puzzle), but each individual attempt was limited to 30 seconds. At the end of each 30 second period, participants heard pre-recorded audio messages over the headset that informed them "Times-up, please discard your old sheet. Please say aloud which stack you are drawing a new card from, continue to make the target facial expression, and begin working." Participants were also told that once they moved on to the next stack of puzzles, they could not return to a previously attempted stack. Participants were directed to verbally say, "Solved." upon solving a puzzle, and "I'm finished." after their last desired attempt at the fourth puzzle. Finally, they were told to wait to begin working on puzzles until instructed to do so over the computer monitor in front of them. After answering any questions, the experimenter left the room and closed the door and entered the adjacent control room (participants could no longer see the experimenter, but the experimenter closely monitored the participant at all times via a video monitor). At this point, the experimenter randomly assigned participants to condition via a randomization sheet.

Text instructions were presented to participants on the computer monitor. These instructions restated the details of the tasks and reiterated that the decision to move on to a new stack of puzzles was the participants' choice. Participants were then asked to make and maintain a neutral facial expression for one minute while brain activity was recorded. This served as a baseline measure of asymmetric frontal cortical activity. Then, depending upon which condition the participant was assigned, they were directed to make and maintain a determination, satisfaction, or neutral facial expression for an additional minute of EEG recording. The instructions were: Please express the emotion as clearly as you can. Try to make an expression so that absolutely anyone would be able to recognize what emotion you are communicating. Please make a (determination, satisfaction, or neutral) expression now." These instructions were taken from C. Harmon-Jones, Schmeichel, Mennit, and E. Harmon-Jones (2010).

During this recording, the experimenter also recorded how well participants made the target facial expression on a scale ranging from 1 (not very well) to 7 (extremely well) consistent with other research examining the effect of manipulated facial expressions on frontal asymmetry (Coan et al., 2001). Via the video monitor, the experimenter compared participants' facial expressions to pictures of exemplary determination, satisfaction, and neutral facial expressions taken from C. Harmon-Jones et al. (2010). After the EEG recordings, text instructions reminded participants to maintain their assigned facial expressions throughout the tasks. Participants were then directed to take a puzzle from the first stack and begin working. After each 30 second interval working on a specific puzzle, the audio reminders described above were played over the headset. When participants said aloud “Solved.” pre-recorded audio clips informed them to “Move on to the next stack of puzzles”.

Following the puzzle tasks, participants completed the PANAS-X (Watson & Clark, 1994) on the computer monitor. This included a one-item measure asking them to rate the difficulty of making the target facial expression on a 1 (very easy) to 7 (very difficult) point scale (Coan et al., 2001). The experimenter then returned to the room and probed participants for suspicion by asking the following questions: (1) what do you think we are studying in this experiment; (2) what did you think about being asked to make and hold a certain facial expression; (3) what did you think about the puzzles you completed. Afterwards, participants were explained the full details of the experiment.

2.3 EEG assessment and processing

To obtain EEG data, a stretch-lycra cap (Electro-Cap, Eaton, OH) with 32 tin electrodes was placed on the participant’s head and filled with conductive gel (Electro-Geo) until impedance values were less than 5 kilo-ohms. Electrodes were also placed on the participant’s left earlobe to provide a reference electrode, and on the right earlobe to provide an off-line average of ears for re-referencing the EEG signals. Signals were amplified using Neuroscan Synamps (El Paso, TX), bandpass filtered (0.1 to 100Hz with a 60 Hz notch filter), and digitized at 500Hz.

All data were hand scored to remove artifacts, then a regression-based eye movement correction was applied to correct for vertical eyeblinks (Semlitsch, Anderer, Schuster, & Presslich, 1986). Next, all epochs, each 1.024 s in duration, were extracted through a Hamming window (50% taper of distal ends) and re-referenced using an average ear reference. Consecutive epochs were overlapped by 50% to minimize data loss due to windowing. A fast Fourier transform calculated power spectra. Power values within the alpha band (8–13 Hz) were averaged across epochs for each minute of data. In addition, power values in the EMG band (70-90 Hz) were extracted from the power spectra for the second minute of data (with emotional facial expressions) to examine the contribution of muscle activity (Coan et al., 2001).

Asymmetry indexes (log right minus log left) were computed for all sites, but predictions focused on midfrontal (F4/3; Harmon-Jones, Sigelman, Bohlig, & Harmon-Jones, 2003), frontal central (Fc4/3; Harmon-Jones & Gable, 2009; Peterson, Gravens, & Harmon-Jones, 2011), and lateral frontal (F8/7; Jensen-Campbell, Knack, Waldrip, & Campbell, 2007) sites based on past research examining frontal asymmetry, approach motivation, and manipulated facial expressions (Coan et al., 2001). Because alpha power is inversely related to cortical activity, higher scores indicated greater left than right activity (Allen, Coan, & Nazarian, 2004).

3. RESULTS

3.1 EEG asymmetry as a function of facial expressions

In order to examine the effects of facial expressions on frontal asymmetry, analyses were performed in-line with Coan et al. (2001). Analyses were also consistent with past research examining the effects of bodily manipulations on frontal asymmetry (Price & E. Harmon-Jones, 2011) and research suggesting that differences in relative left frontal cortical activity are often observed at some but not all frontal regions (Allen, Coan, & Nazarian, 2004). Because of the between-subjects design, frontal asymmetry scores during the resting, first neutral facial expression minute (for the same pair of homologous sites, e.g., F3/F4) were used as changing covariates in all analyses of covariance (ANCOVAs). Within each of these analyses, frontal asymmetry during the second minute associated with emotional facial expressions served as the dependent measure. Because predictions were directional, based on theory, and specified in advance theses covariate analyses were further evaluated using planned contrasts and a one-tailed criterion of significance (Rosenthal, Rosnow, & Rubin, 2000). The determination condition was contrast coded +2, whereas satisfaction and neutral conditions were each coded -1.

As predicted, a significant planned contrast emerged for midfrontal sites, $t(44) = 2.21$, $p = .01$, indicating that participants had greater relative left midfrontal activity in the determination ($M = -.03$, $SD = .02$) as compared to satisfaction ($M = -.13$, $SD = .03$) and neutral ($M = -.10$, $SD = .02$) conditions. Follow-up tests revealed that determination differed from the satisfaction condition, $p = .02$, and was marginally different from the neutral condition, $p = .058$; satisfaction did not differ from the neutral condition, $p = .55$. Contrasts, however, were not significant for frontal-central, $t(44) = .57$, $p = .28$, or lateral-frontal sites, $t(44) = .56$, $p = .28$. Additionally, all other asymmetry indices produced nonsignificant effects, *p*s > .24. There was no interactive effect of gender and facial expression condition on relative left midfrontal activity, $F(2, 41) = 1.41$, $p = .25$.

3.2 Muscle artifact

Consistent with Coan et al. (2001), the contribution of EMG frequencies (70-90 Hz) was also examined during the one minute participants adopted emotional facial expressions. Asymmetry scores (log F4 minus log F3) were constructed on this EMG band for midfrontal regions, as these regions were the only sites to produce differences in frontal asymmetry as a function of emotional facial expressions. These EMG asymmetries along with resting alpha midfrontal asymmetries were used as changing covariates in an analysis of covariance (ANCOVA). Results indicated that the planned contrast remained significant, $t(43) = 2.10$, $p = .02$.

3.3 Task difficulty

The contribution of perceived task difficulty was also examined on asymmetric midfrontal activity, because the perceived difficulty of making facial expressions might influence asymmetry results (Coan et al., 2001). The ANOVA for task difficulty ratings was non-significant, $p = .17$. Means and standard deviations were as follows: determination ($M = 3.12$, $SD = .23$), satisfaction ($M = 3.07$, $SD = .25$) and neutral conditions ($M = 2.55$, $SD = .22$). Difficulty ratings alongside resting alpha midfrontal asymmetries were used as changing covariates in an ANCOVA. The effect of facial expressions on relative left midfrontal activity remained significant, $t(43) = 2.20$, $p = .01$.

3.4 Task quality

Another issue is whether participants' ability to produce target facial expressions influenced the asymmetry effect (Coan et al., 2001). An ANOVA performed for quality ratings across conditions was significant, $F(2, 45) = 6.93$, $p = .002$. Follow-up tests indicated that participants were rated better at making neutral ($M = 6.55$, $SD = .31$) as compared to determination ($M = 4.93$, $SD = .33$; $p < .001$) and satisfaction ($M = 5.28$, $SD = .35$; $p = .01$) facial expressions; determination did not differ from the satisfaction condition, $p = .47$. Alongside resting alpha midfrontal asymmetries, these rating were included as changing covariates in an ANCOVA. The effect of facial expressions on relative left midfrontal activity remained significant, $t(43) = 2.20$, $p = .01$.

3.5 Persistence as a function of facial expressions

Total attempts and total time working on the insolvable puzzles were highly correlated with one another, $r = .84$, $p < .001$. Thus, each variable was standardized and added together to obtain the variable of *persistence* on the insolvable task. Means are presented in Table 1. Consistent with the frontal asymmetry analyses above, a planned contrast was performed for persistence coding the determination condition as +2, and the other conditions as -1s. This test was non-significant, $t(46) = .27$, $p = .39$.

Next, the association between relative left midfrontal activity and persistence was examined by testing correlations between these two variables within each condition.

Participants who made determination facial expressions persisted more on the insolvable puzzles when they had greater relative left midfrontal activity, $r(16) = .62$, $p = .01$. In contrast, there was no relationship between relative left midfrontal activity and persistence for participants who made satisfaction expressions, $r(15) = .06$, $p = .82$. Interestingly, relative left midfrontal activity was negatively associated with persistence in the neutral condition, $r(18) = -.49$, $p = .03$. Figure 1 shows the scatterplots of the correlations between relative left midfrontal activity and persistence on the insolvable puzzles for the three conditions.

In an overall test of the above correlations, a step-wise linear regression analysis (method: probability of F to enter < .05; probability of F to remove > .01) was employed to examine the relationship between relative left midfrontal activity during the emotional facial expression EEG recordings and persistence for the three conditions. Facial expression condition was entered as a dummy variable and the determination condition was always set to 0 because it was the critical condition against which the other conditions were compared. The following codes were used: dummy variable 1: neutral = 1, satisfaction = 0, determination = 0; dummy variable 2: neutral = 0, satisfaction = 1, determination = 0. The equation for the regression model is: persistence = $b_0$intercept + b_1 left midfrontal activity + $b_2$dummy$_1$ + $b_3$dummy$_2$ + b_4 left midfrontal activity × dummy$_1$ + b_5 left midfrontal activity × dummy$_2$ (West, Aiken, & Krull, 1996). Because the determination condition was always set to 0, the equation for this condition is reduced to persistence = $b_0$intercept + b_1 left midfrontal activity. The regression coefficient b_1 left midfrontal activity in the full equation gives the regression of persistence on relative left midfrontal activity in the determination condition.

In addition, the dummy variables and the dummy × left midfrontal activity variables examine the difference in mean persistence and the influence of relative left midfrontal activity on persistence for the neutral vs. determination conditions (dummy 1 and dummy 1 × left midfrontal activity), and satisfaction vs. determination conditions (dummy 2 and dummy 2 × left midfrontal activity). Relative left midfrontal activity scores were centered, and interactions were calculated as the product of relative left midfrontal activity and the dummy variables (West et al., 1996). Cohen's effect size (f) was calculated using the following formula: $f = R^2/(1\text{-}R^2)$.

The overall regression model was significant, $F(3, 45) = 5.46$, $p = .002$, $R^2 = .25$, $f = .35$. Relative left midfrontal activity was a significant predictor for persistence in the determination condition, $b = 6.55$, $p = .003$. In addition, significant dummy-coded interactions revealed that this relationship between relative left midfrontal activity and persistence in the determination condition differed from both the satisfaction, $b = -6.05$, $p = .04$, and neutral conditions, $b = -12.58$, $p = .0002$. No other effects were significant (ps > .52, see Table 2).

3.6 Self-report measures

One-way ANOVAs were conducted to examine the effect of condition on self-reported emotions, with the exception of the determination construct (see below), which was analyzed with a planned comparison as it was a predicted manipulation check. Means and standard deviations are presented in Table 1. Research has indicated that items within the PA and NA scales of the PANAS-X load on separate factors (E. Harmon-Jones, C. Harmon-Jones, Abramson, & Peterson, 2009), and therefore it is necessary to create subscales. In the case of PA, three subscales were created consistent with prior research (Egloff, Schmukle, Burns, Kohlmann, & Hock, 2003). Results indicated that condition did not influence joy (enthusiastic, excited, proud; $p = .18$) or activation (active, attentive, inspired, alert; $p = .89$). The planned contrast, coding determination as +2 and the other conditions as -1, on interest (interested, strong, determined) was significant, $t(44) = 2.12$, $p = .02$. Follow-up tests indicated that participants reported higher interest in the determination as compared to the neutral condition, $p = .02$. All other follow-up comparisons were non-significant, *p*s > .19.

For the NA scale, four subscales were created consistent with prior research (E. Harmon-Jones et al., 2009, Study 3). Results indicated that condition did not influence fear (afraid, scared, nervous, guilty, ashamed; $p = .92$), upset ($p = .49$), distress (distressed, jittery; $p = .99$) or irritated (irritable, hostile; $p = .98$). Following related research (Riskind & Gotay, 1982), the effect of condition on fatigue was also examined (sleepy, tired, sluggish, drowsy). This too proved to be non-significant, $p = .36$.

4. DISCUSSION

As predicted, facial expressions of positive emotions differing in approach motivational intensity caused different patterns of relative left frontal cortical activity. This effect remained significant when covarying subjective difficulty ratings for forming emotional facial expressions and how well participants made facial expressions. The effect also remained significant when covarying EMG activity. This suggests that the observed differences in EEG alpha power as a function of emotional facial expressions were not due to changes in asymmetric facial muscle movements.

These findings extend neuroscientific embodiment research (Price et al., 2012), and past work suggesting that withdrawal-oriented facial expressions (e.g., fear, disgust) are associated with less relative left frontal activity than approach oriented facial expressions (e.g., anger, joy; Coan et al., 2001). Specifically, the current findings suggest that facial expressions often associated with positive emotional states (e.g., determination and satisfaction) but varying levels of approach motivation influence relative left frontal cortical activity. High approach determination facial expressions caused greater relative left frontal cortical activity as compared to low approach satisfaction facial expressions, and marginally greater relative left frontal activity compared to neutral facial expressions.

In addition, the present results add further support to the motivational model of frontal asymmetry (Harmon-Jones et al., 2010), and appear inconsistent with other models that posit asymmetric frontal cortical activity relates to emotional valence

(Spielberg et al., 2008). These models differ in other ways, however. The valence model has recently relied on functional magnetic resonance imaging data (fMRI; e.g., Herrington et al., 2005). fMRI methodologies measure blood oxygenation (BOLD signal) in neural regions. EEG, on the other hand, measures electrical potentials of open field neurons. Thus, these methodologies might measure different neural processes. Furthermore, some past fMRI experiments have examined participants' neural responses to positive words, such as the words desire and excite (Herrington et al., 2005). These emotional states are often associated with heightened approach motivation (e.g., Harmon-Jones et al., 2011). These words, therefore, may evoke approach motivation. Confounding affective valence with motivational direction makes it difficult to determine if the results of Herrington et al. (2005) support the valence or motivational model of frontal asymmetry.

Other regression analyses suggested that relative left frontal activity was associated with task persistence in the high approach determination condition. In particular, relative left frontal activity arising from making a determination facial expression predicted persistence on the insolvable puzzles. This was not the case for the satisfaction condition. This suggests that relative left frontal cortical activity associated with high approach manipulated facial expressions might play a role in persistence-related behaviors.

The self-reported emotions measures in the present experiment suggested that facial expressions might have influenced some self-reported emotions following the puzzle task. In particular, participants reported greater interest in the determination as compared to the neutral facial expression condition. This was not the case for the determination compared to the satisfaction condition. This result suggests that the effect of facial expressions on self-reports might have been weakened by integral aspects of the experimental design.

4.1 Limitations

In the present experiment, facial expressions only influenced self-reported levels of interest between the determination and neutral conditions. However, it is important to note that self-reported emotions were measured after the persistence task. This likely weakened any self-reported changes due to facial expressions. Self-reported emotions were measured after the persistence task, because completing emotion questionnaires can alert participants to their emotional state. Awareness of emotional states, furthermore, can dampen emotion-related behavioral changes (Berkowitz, 2000). Thus, self-reports were measured at the end of the experiment in order to give the facial manipulation the greatest chance of impacting persistence on the task.

Facial expressions also did not directly influence task persistence, as predicted. Past research finding that bodily manipulations influenced task persistence (Riskind & Gotay, 1982) had participants adopt different body postures for longer periods of time (8 minutes) relative to the present experiment (1 minute with facial expressions) before working on the puzzle task. Asking participants to maintain manipulated postures for 30 minutes is possible (Price et al., 2012). However, discomfort is likely to result from adopting facial expressions for longer periods of time. These longer time frames are rarely used for facial expression manipulations (Coan et al., 2001). On the other hand, the short duration of the facial expression manipulation may have simultaneously weakened its effect on task persistence in the present experiment.

It was surprising that relative left frontal cortical activity was negatively correlated with task persistence in the neutral condition. Approach motivation measured by relative left frontal cortical activity should relate directly to approach behavior. One may wonder, therefore, why relative left frontal cortical activity was not at least somewhat positively correlated with task persistence in the neutral condition. It is possible that this is a spurious correlation. Another possibility is that the current measure of task persistence was not sensitive. Supporting this idea, facial expressions did not influence task persistence, but produced predicted differences on the sensitive measure of asymmetric frontal cortical activity. Nevertheless, when approach motivation is present in the form of a determination face combined with greater relative left frontal cortical activation, greater task persistence might be uncovered even in this insensitive measure. It is also important to note that although relative left frontal cortical activity is associated with approach motivation, it is not associated with approach motivation in a perfect one-to-one fashion. Other brain regions are involved in approach motivation (Harmon-Jones, 2011).

4.2 Future directions

The present results suggest that these facial expressions influence relative left frontal cortical activity, which is furthermore associated with task persistence. It would be interesting to examine how these facial expressions influence different measures sensitive to approach motivation, and possibly other molar motivational behaviors. For example, do these facial expressions influence dissonance reduction? The action-based model of dissonance proposes that heightened approach motivation should be associated with greater dissonance reduction. More importantly, the action-based model proposes that dissonance reduction occurs to facilitate effective action (E. Harmon-Jones, Amodio, & C. Harmon-Jones, 2009). However, it has yet to be demonstrated that dissonance reduction facilitates more molar motivational behaviors related to physical action. For example, past experiments have found that greater as compared to lesser approach motivation increases spreading alternatives (E. Harmon-Jones et al., 2008). Spreading of alternatives is a relatively cognitive measure, however, and not as molar as physically persisting on a task one is committed to accomplishing. Do high approach determination as compared to low approach satisfaction facial expressions influence dissonance reduction? More importantly, do high approach determination facial expressions facilitate effective action?

Belief disconfirmation (Festinger, Riecken, & Schachter, 1956) would be a novel dissonance paradigm in which to test this idea. When individuals who strongly hold a belief are presented with disconfirming evidence that they also accept, it creates dissonance. A common way to reduce this dissonance is belief intensification. For example, devout Christians agreeing with evidence that Jesus is not the son of God creates dissonance in these individuals. In order to reduce this dissonance, these individuals have been shown to intensify their belief in Jesus's divinity (Batson, 1975).

In this case, after individuals commit to their belief, approach motivation is high. More importantly, for those high in approach motivation, the action-based model would propose several outcomes. Belief intensification should occur in self-reports but, more importantly, highly motivated individuals should be more likely to engage in religious activities following disconfirming evidence (e.g., praying with greater frequency).

It might be interesting to examine if high approach determination as compared low approach satisfaction and neutral facial expressions influence these processes. For example, participants might be asked to adopt one of these facial expressions while declaring a belief. Then, participants might see disconfirming evidence. There are two primary predictions in accordance with the action based model of dissonance. First, high approach determination as compared to lower approach satisfaction and neutral facial expressions should cause greater belief intensification (dissonance reduction) following disconfirming evidence. Second, individuals in the high approach condition should be more motivated to physically engage in activities related to their belief. In addition, relative left frontal cortical activity arising from facial expressions may positively correlate with this activity, in the determination condition especially. In short, examining the influence of these facial expressions on more molar motivational behaviors, perhaps in dissonance paradigms, would be interesting in future research .

5. CONCLUSIONS

The present findings suggest that high approach as compared to low approach facial expressions are associated with greater relative left frontal cortical activity. Furthermore, relative left frontal activity is associated with approach-related behavioral persistence when individuals are making facial expressions of determination. Together, these findings further the motivational model of asymmetric frontal cortical activity while also extending theories of embodiment in motivational and emotional processes.

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APPENDIX A

FIGURE AND TABLES

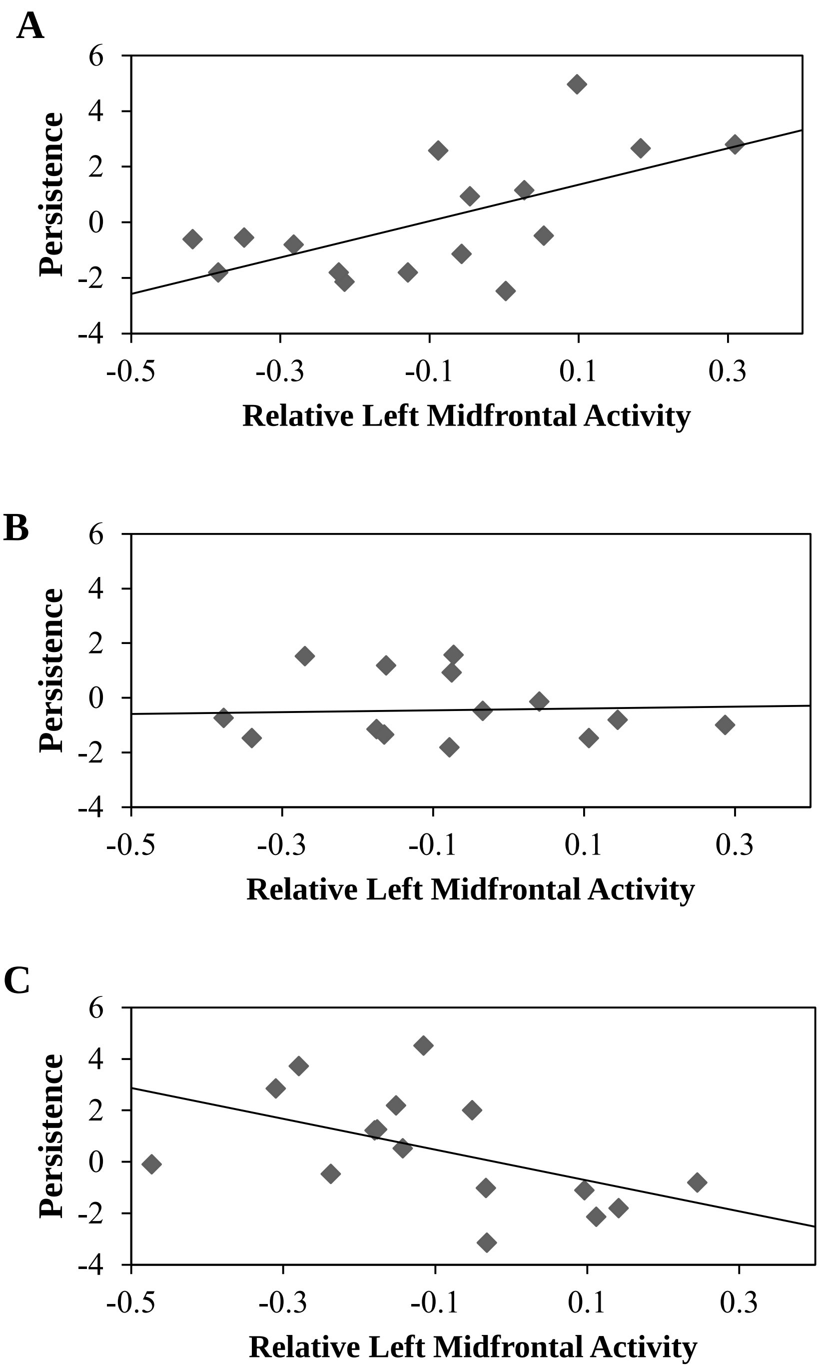

Figure 1. The Influence of Relative Left Midfrontal Activity on Persistence in Each Condition. Relative Left Midfrontal Activity Was Related to Persistence after Participants Made (A) Determination, but not (B) Satisfaction or (C) Neutral Facial Expressions.

Table 1. Means for persistence and self-reports

	Determination	Neutral	Satisfaction
	(*N* = 16)	(*N* = 18)	(*N* = 15)
Means for persistence[a]	.08 (.48)	.31 (.45)	-.46 (.49)
	Determination (*N* = 15)	Neutral (*N* = 18)	Satisfaction (*N* = 14)
Self-report measures[b]			
PA			
Joy	3.35 (.18)	3.12 (.16)	3.64 (.19)
Interest	3.68 (.14)	3.20 (.13)	3.40 (.15)
Activation	3.41 (.15)	3.34 (.14)	3.30 (.17)
NA			
Fear	1.84 (.15)	1.92 (.14)	1.87 (.16)
Upset	1.73 (.20)	2.05 (.18)	2.00 (.22)
Distress	2.00 (.20)	1.97 (.18)	2.00 (.21)
Irritated	1.96 (.21)	1.97 (.19)	1.89 (.23)
Fatigue	3.10 (.20)	3.38 (.18)	3.00 (.21)

[a]Higher numbers indicate greater persistence on insolvable puzzles (based on standardized scores of total time and total attempts).
[b]Higher numbers indicate higher scores on the composite self-report measures [on a 1 (very slightly or not at all) to 5 (extremely) scale].

Table 2. Results for stepwise linear regression analysis

Overall model: $F(3, 45) = 5.24$, $p = .003$, $R^2 = .25$, $f = .33$.	*b*	*p*-value
Included predictors		
Regression of persistence on left midfrontal acitivity in the determination condition.	6.55	.003
Difference between left midfrontal activity and persistence for determination vs. neutral condition.	-12.58	.0002
Difference between left midfrontal activity and persistence for determination vs. satisfaction condition.	-6.05	.04
Excluded predictors		
Difference in persistence for determination vs. satisfaction condition.	-.49	.41
Difference in persistence for determination vs. neutral condition.	.32	.58

b = unstandardized coefficient

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