# FRONTAL ASYMMETRY AND MOTIVATIONAL SYSTEMS: DOES RIGHT FRONTAL ASYMMETRY UNDERLIE AVOIDANCE OR MOTIVATIONAL CONTROL?

by

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ABSTRACT

Decades of theory and research have proposed a model of frontal asymmetrical cortical activity linking approach motivation and avoidance motivation to the left and right prefrontal cortices, respectively. However, more recent work has questioned the link between right frontal asymmetry and avoidance motivation, asserting instead that motivational control may be more closely related to right frontal asymmetry. The current study aimed to experimentally manipulate pure avoidance motivation and approach-avoidance conflicts in order to examine which evokes greater relative right frontal activation. Study 1 used a negative affective picture viewing paradigm with reward and non-reward trials. No differences were found with frontal asymmetry, but behavioral results suggested that approach-avoidance conflicts were successfully manipulated. Right frontal asymmetry related to behavioral outcomes of higher motivational control. Study 2 used a risk-taking task with reward and neutral trials to contrast loss aversion with reward seeking. No significant differences were found with frontal asymmetry, but behavioral outcomes of control again were related to right frontal asymmetry. Implications of the results for models of motivational processes and frontal asymmetry are discussed.

DEDICATION

To my parents for getting me here. To my husband Battle for seeing me through.

LIST OF ABBREVIATIONS AND SYMBOLS

| | |
|---|---|
| ANOVA | Analysis of Variance |
| BART | Balloon Analogue Risk Task |
| BAS | Behavioral Approach System |
| BOLD | Blood Oxygen-Level Dependent |
| CCT | Columbia Card Task |
| EEG | Electroencephalography |
| ERQ | Emotion Regulation Questionnaire |
| FFFS | Fight-Flight-Freeze System |
| FFT | Fast Fourier Transformation |
| fMRI | Functional Magnetic Resonance Imaging |
| IAPS | International Affective Picture Set |
| PFC | Prefrontal Cortex |
| rBIS | Revised Behavioral Inhibition System |
| RST | Reinforcement Sensitivity Theory |
| SAM | Self-Assessment Manikin |
| tDCS | Transcranial Direct Current Stimulation |
| TMS | Transcranial Magnetic Stimulation |

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# INTRODUCTION

Beginning with lesion studies, scientists have examined lateralization of function in the human brain. Early observations revealed that damage to the left prefrontal cortex was associated with deficits in positive emotionality, while damage to the right prefrontal cortex was associated with deficits in inhibition (Gainotti, 1972; Goldstein, 1939). These observations laid the groundwork for theories of frontal asymmetry. Later development of electroencephalography (EEG) methods allowed for studying the intact and functioning healthy human brain rather than relying on drawing inferences from patients with specific brain damage (Davidson et al., 1979). These EEG studies supported the findings from lesion studies; greater relative left frontal activation was observed in response to pleasant stimuli while greater relative right frontal activation was observed in response to unpleasant stimuli (Davidson & Fox, 1982; Tomarken, Davidson, & Henriques, 1990).

Later advances asserted that motivational direction rather than affective valence underlies frontal asymmetry. That is, approach motivation and avoidance motivation rather than positive affect and negative affect are linked to the left and right prefrontal cortex, respectively (Harmon-Jones & Allen, 1997; 1998; Sutton & Davidson, 1997; for a review see Harmon-Jones, Gable, & Peterson, 2010). Much of this theory was supported by studying anger, a negatively-valenced approach-motivated emotion that evokes greater relative left frontal asymmetry (Carver & Harmon-Jones, 2009; Harmon-Jones, 2003). This motivational direction view of frontal asymmetry has become the standard accepted theory regarding emotive processes in the frontal cortex, but has recently come under question. New evidence has suggested that motivational control rather than avoidance motivation may be more related to right frontal asymmetry. Frontal asymmetry as assessed by EEG remains a popular measure for assessing motivational and emotive processes (Allen, Keune, Schonenberg, & Nusslock, 2018) but questions still remain about which specific processes underlie right vs. left frontal asymmetry. The aim of this dissertation is to disentangle the relative contributions of avoidance motivation and motivational control on right frontal asymmetry.

## Revised Reinforcement Sensitivity Theory

The motivational direction model finds theoretical basis in Gray's Revised Reinforcement Sensitivity Theory (RST; Gray & McNaughton, 2000). According to RST, human behavior is directed through 3 primary motivational systems: the behavioral approach system (BAS), the fight-flight-freeze system (FFFS), and the revised behavioral inhibition system (rBIS). Together, these three systems coordinate functional human behavior. The BAS is responsible for responding to signals of reward and is generally tied to positive affect and approach-motivated goal pursuit. Consistent with the motivational directional model, trait levels of BAS relate to greater relative left frontal activation both at rest and during reward-related task performance (Gable, Mechin, & Neal, 2015; Harmon-Jones & Allen, 1997; Peterson, Gable, & Harmon-Jones, 2008; Sutton & Davidson, 1997). The FFFS encompasses response to threat and punishment via avoidance and defensive behaviors. Traditional theories of frontal asymmetry would suggest that the FFFS is related to right frontal activation due to withdrawal or avoidance motivation.

Lastly, the rBIS as outlined in revised RST primarily serves to respond to conflicts between the BAS and FFFS. When faced with conflicting urges of approach and avoidance, the rBIS is activated to inhibit ongoing behavior and conduct risk analysis of how best to proceed.

The rBIS is activated in instances of conflict, but this conflict can take many forms: BAS-FFFS, BAS-BAS, and FFFS-FFFS. The rBIS primarily serves to exercise motivational control in the face of conflicting motivational urges. The term "motivational control" used throughout this document refers to rBIS processes of motivational conflict detection and resolution, inhibition, and impulse control. At times, the rBIS may need to downregulate approach motivation to avoid risky outcomes (Neal & Gable, 2019). Other times the rBIS may need to tamp down avoidance motivation in order to continue goal pursuit in the face of threat.

The BAS, FFFS, and rBIS are systems thought to orchestrate motivated behavior in all humans. All individuals experience motivational urges from the BAS and FFFS and use rBIS processes to mediate these conflicting urges. However, many theorists have also suggested that humans have trait levels of sensitivity of these three systems (Carver & Scheier, 2008; Carver & White, 1994; Depue & Collins, 1999; Elliot, 2008). That is, people higher in their sensitivity to reward, sustained goal pursuit, and seeking of new experiences are thought to be higher in trait levels of behavioral approach (BAS). In contrast, those with heightened responses to punishment, fear-inducing stimuli, and negative affective stimuli are considered to be higher in trait levels of behavioral avoidance (FFFS). Lastly, the third personality system reflects the rBIS and is defined by ability to exercise inhibition and impulse control as well as to effectively deal with conflicting motivations (Gray & McNaughton, 2000). This system is thought to be inversely related to trait impulsivity and directly related to trait anxiety (Crost, Pauls, & Wacker, 2008; Gable et al., 2015; Jackson, 2009). These personality systems have been linked to neural responses in the frontal cortex, both at a trait and state level. However, debate remains about the best theoretical model of frontal asymmetry that describes these personality systems and state activation of these systems.

## Frontal Asymmetry and Motivational Control

Early studies established the link between right frontal activity and avoidance by examining frontal asymmetry in response to negative affective stimuli. For example, fear or disgust inducing stimuli often activate right frontal asymmetry (Canli et al., 1998; Tomarken, Davidson, & Henriques, 1990; Wheeler, Davidson, & Tomarken, 1993). Other studies have examined infants and found greater right frontal activity associated with negative affective experiences such as maternal separation or encountering a stranger (Buss et al., 2003; Davidson & Fox, 1989; Fox, Bell, & Jones, 1992). However, there is the possibility that these and other findings were due to rBIS and not avoidance motivation. In studies where participants are asked to attend to negative stimuli, study instructions to view (e.g. approach) these images may cause coactivation and conflict between BAS and FFFS. In infant studies, the subjects cannot self-report motivation and it is likely that anxiety (an rBIS process) is also present with negative affect. It is important to determine whether these tasks are specifically evoking avoidance or are perhaps evoking rBIS. Additionally, it is important to develop tasks that clearly contrast avoidance and motivational control in order to properly dissociate the two.

Although the past two decades have resulted in ample evidence supporting the link between left frontal asymmetry and approach motivation, the link between right frontal asymmetry and avoidance motivation has been less consistent. Many studies have failed to find a link between both state and trait avoidance and right frontal activity (Amodio, Master, Yee, & Taylor, 2008;  Berkman & Lieberman, 2010; Coan & Allen, 2003; Coan, Allen, & Harmon-Jones, 2001; De Pascalis, Cozzuto, Caprara, & Allessandri, 2013; Henriques & Davidson, 2000; Hewig, Hagemann, Seifert, Naumann, & Bartussek, 2004 & 2006; Jackson, et al, 2003; Keune, Bostanov, Kotchoubey, & Hautzinger, 2012; Kline et al., 2000; Pizzagalli, Sherwood, Henriques,

& Davidson, 2005; Quirin, Gruber, Kuhl, & Dusing, 2013; Wacker, Chavanon, Leue, & Stemmler, 2008; Wacker, Chavanon, & Stemmler, 2010). At the same time, another line of research has linked rBIS (e.g. motivational control and inhibition) to greater right frontal activation (for a review, see Gable, Neal, & Threadgill, 2018).

Converging evidence from lesion studies, EEG, source localization, fMRI, and neuronal stimulation studies suggests that right frontal activity underscores motivational control. Patients with damage to the right inferior frontal gyrus have trouble with inhibition in stop-signal tasks and engage in riskier decision making (Aron, Fletcher, Bullmore, Sahakian, & Robbins, 2003; Clark, Manes, Antoun, Sahakian, & Robbins, 2003). Greater right frontal activity, and in particular activity of the right inferior frontal gyrus, has been implicated in better inhibitory control across a wide range of tasks in fMRI studies (Aron, Robbins, & Poldrack, 2014; Garavan, Ross, & Stein, 1999; Konishi et al., 1998; Whelan et al., 2012). Greater risk taking has also been associated with less relative right frontal EEG activity at baseline, and localized to diminished activation of the right lateral PFC (Gianotti et al., 2009).

Manipulation of asymmetrical activity in the PFC through transcranial direct current stimulation (tDCS) and transcranial magnetic stimulation (TMS) have also supported the role of the right frontal cortex in motivational control. While most EEG studies manipulate approach, avoidance, or inhibition and then study frontal asymmetry as the dependent variable, these manipulation studies instead manipulate neuronal excitability and then study the behavioral consequences of changes in frontal asymmetry. Manipulation of tDCS and TMS to enhance neuron excitability in the right frontal cortex leads to better response inhibition in a variety of paradigms (Chambers et al., 2006; 2007; Ditye et al., 2012; Jacobson et al., 2011; Stramaccia et al., 2015). Additionally, stimulating the right frontal cortex reduces risky decision making

(Fecteau et al., 2007) while inhibiting the right frontal cortex increases risky decision making (Knoch et al., 2006; Hecht, Walsh, & Lavidor, 2013). Other tDCS work found that enhancing right frontal neuron excitability leads to better control on motivationally-incongruent responses to both approach and avoidance motivated stimuli (Kelley & Schmeichel, 2016). Specifically, participants were better at both approaching negative stimuli and avoiding positive stimuli after right frontal tDCS, supporting the model linking right frontal activity to motivational control. While not conclusive, these studies suggest a more causal role of right frontal activity in rBIS processes of inhibition and impulse control.

Many studies have related personality traits associated with impulsivity and motivational control to frontal asymmetry, with those reflecting less motivational control relating to higher left frontal asymmetry and those assessing greater motivational control relating to higher right frontal asymmetry (Gable, Mechin, Hicks, & Adams, 2015; Neal & Gable, 2016, 2017; Santesso et al., 2008). More recent attempts have been made to explore state changes in frontal asymmetry with motivational control. Specifically, Neal and Gable (2019) had participants complete a Balloon Analogue Risk Task (BART) and compared shifts in frontal asymmetry during the course of the trials. Results showed shifts in asymmetry towards left frontal activity during risky decision making, and shifts towards right frontal activity on trials where inhibition was successfully engaged.

Research on frontal asymmetry does not just study dispositional and situational approach and avoidance in healthy humans, but also extends to psychopathology. Specifically, those diagnosed with anxiety disorders exhibit greater relative right frontal activation at rest and during anxiety-provoking situations (Petruzzello & Landers, 1994; Smit, Posthuma, Boomsma, & De Gues, 2007; Thibodeau, Jorgenson, & Kim, 2006). Under previous models, results with anxiety studies were thought to reflect negative affectivity or desire to withdraw due to worry. Instead, these findings might be driven by other aspects of anxiety disorders, such as trouble dealing with conflicting motivations or cognitions. Taking a basic science perspective on the underlying biological personality systems influencing frontal asymmetry may point to which symptoms of mental disorders are driving neuropsychological differences between patients and control subjects. This can then direct research by clinicians on the biological bases of these disorders, which can in turn influence research on and treatment of psychological disorders.

## EEG Assessment of Frontal Asymmetry

Past work using EEG measurement to assess asymmetric function of the frontal cortex has primarily examined relative differences in alpha power. Activity in the human EEG from 8 to 13 Hz makes up the traditional alpha band. Alpha power has been shown to reflect the inverse of cortical activation (Cook, O'Hara, Uijtdehaage, Mandelkern, & Leuchter, 1998; Davidson, Chapman, Chapman, & Henriques, 1990). That is, greater cortical activation is accompanied by less alpha power in the EEG. Consistent with this assertion, simultaneous EEG and fMRI studies have shown that increases in the alpha rhythm is coupled with decreased BOLD signal in cortical areas, particularly in the frontal cortex (Goldman, Stern, Engel Jr., & Cohen, 2002; Laufs et al., 2003). Most research on frontal asymmetry utilizes difference scores to examine relative activation of the left vs. right hemispheres. Because individual differences in skull thickness can vary greatly and affect overall levels of alpha power observed, asymmetry difference scores are recommended for studying frontal asymmetry with emotive processes (Coan & Allen, 2004). Use of the asymmetry score produces a reliable and consistent metric of relative activation of the left and right hemispheres (Coan & Allen, 2004).

While psychological states have been shown to relate to differences in frontal asymmetry, it is worth mentioning that physical and biological variables can also influence frontal asymmetry. For example, some EEG work has found that frontal asymmetry may fluctuate as a function of time of day and year, and has suggested that this may be due to cortisol levels (Peterson & Harmon-Jones, 2009). Other research has manipulated frontal asymmetry through the use of hand contractions. Because the motor cortex is contralaterally represented in the human brain, hand contractions of the right hand are accompanied by activation of the left motor cortex and vice versa. Contractions of the hand reliably produce asymmetric activation of the opposite hemisphere (Hellige, 1993), and thus use of muscles on one side of the body over the other may influence frontal asymmetry and accompanying psychological processes (Gable, Poole, & Cook, 2013; Harmon-Jones, 2006). Consistent with this idea, the body-specificity hypothesis (Cassanto, 2009) suggests that handedness affects the ways in which we interact with our physical environments due to similar mechanisms. Cassanto (2009) suggests that right handed individuals tend to associate right with positivity and left with negativity. As a result, actions done with the right side of the body (e.g. hand contractions) may be more easily associated with positivity and vice versa. EEG research establishing links between approach motivation and left frontal activity has exclusively studied right-handed participants. Thus, this link between left frontal activation and approach might be due to preference for the right hand. An opposite pattern may be observed in left-hand dominant individuals. The current research will also use right handed participants, as is convention, but the dominance of the right hand and preference for the right side by right handed individuals may explain some of the findings that associate the left frontal hemisphere with positive and approach-motivating stimuli. The current research should not be generalized to left handed individuals, and future research is needed to understand the asymmetric functioning of the cortex in emotive processes for left handed individuals.

The field of affective neuroscience has made large progress very quickly. However, it is important to remember that this research area is still relatively young compared to most sciences. Techniques and analysis approaches in psychophysiology advance very rapidly (Kappenman & Keil, 2016) allowing researchers to continually update their theories as methods are improved. In this rapidly evolving landscape, continued refinement of past accepted theories and nuanced understanding of which psychological processes result in certain brain activation is necessary. In this spirit, the current project aimed to take steps towards resolving a recognized gap in the literature in understanding the differences between rBIS and FFFS and their accompanying neural activation (Amodio et al., 2008; Kelley & Schmeichel, 2016; Wacker et al., 2008).

## The Current Studies

Based on an extensive review of past research (Gable, Neal, & Threadgill, 2018), I hypothesized that conflict between motivational urges that engages motivational control rather than avoidance motivation underscores right frontal activation. The aim of the current project was to disentangle the relative contributions of rBIS and FFFS on right frontal asymmetry.

Most studies that examine motivational control with frontal asymmetry focus on the ability (or inability) to inhibit approach motivation. Tasks that measure response inhibition, risk taking, and impulsive behavior all examine contexts in which an individual must suppress a response associated with approach motivation. However, there are likely instances where motivational control must be engaged to inhibit an avoidance-motivated response or to increase an approach motivated response. A secondary aim of the current project was to examine instances in which an individual must inhibit avoidance motivation and upregulate approach motivation.

The current project will examine the neural correlates of motivational control versus approach and avoidance motivation in two psychophysiological studies. Both studies compared a state of approach-avoidance conflict in which the participant engaged motivational control to a state of pure avoidance. In Study 1, negative affective images were used in a reward paradigm to create a conflict between approach of monetary reward and avoidance of negatively valenced stimuli. In Study 2, a risk-taking task incentivized risky behavior, creating a conflict between loss aversion and pursuit of monetary reward.

# STUDY 1 METHOD

Study 1 manipulated a state of approach-avoidance conflict through the use of negative affective (e.g. disgust evoking) images combined with a monetary reward. The study employed a within-subjects design with two conditions that manipulate pure avoidance and motivational conflict.

**Participants**

Previous studies examining frontal asymmetry during task completion have achieved a medium effect size ($\eta_p^2 = .11$) with 44 participants in a within-subject paradigm (Neal & Gable, 2019). In order to balance feasibility with power, a target sample size of 50 was set for this within-subjects study. Data collection was set to stop at the end of the fall semester, provided at least 40 subjects had participated. Participants were recruited through the University of Alabama subject pool. A total of 68 participants were recruited for participation in the study. Eight participants did not complete the study due to the following reasons: five decided to stop participation upon seeing the disgust-inducing images, one was interrupted by a fire alarm, and two were not completed due to issues with EEG equipment. EEG data from an additional 4 subjects was not analyzed because it contained too many artifacts to be processed. Therefore, data from 56 participants was included in final analyses. The final sample consisted of 43 females and 13 males with an average age of 18.55 (*SD* = 1.17).

**Procedure** Participants were brought into the lab and gave informed consent. They were told that they would see images that may be disturbing to them, and reminded that their participation is voluntary and that they may withdraw participation at any time. Participants completed measures of demographics and personality. Then, a stretch-lycra EEG cap with 64 sensors was applied. Next, 8 minutes of resting baseline EEG was recorded with alternating minutes of eyes open and eyes closed. Participants then completed a picture viewing task (described below). Following the picture viewing task, participants completed various ratings of images from the study and manipulation check questions. Finally, psychophysiological equipment was removed and participants were thoroughly debriefed.

## Measures

### *The Disgust Scale*

The Disgust Scale (Haidt, McCauley & Rozin, 1994) was included to assess trait reactivity to disgusting stimuli. This scale contains 32 items assessing 7 domains of disgust which form a general dimension of disgust sensitivity. The composite disgust score was calculated. This Disgust Scale was used in exploratory analyses.

### *Emotional Regulation Questionnaire*

Participants completed the Emotion Regulation Questionnaire (ERQ) to assess participants' tendency to regulate their emotions using emotional suppression or cognitive reappraisal. The ERQ is a 10-item scale designed using a 7 point Likert scale (Gross & John, 2003). It contains two facets: Cognitive Reappraisal and Expressive Suppression. Because this task asked participants to view negative affective stimuli for a long duration, it may be that certain emotion regulation strategies play a role in how long participants view the photographs and their neural activity during picture viewing. The ERQ was used in exploratory analyses.

### *BIS/BAS Scales*

Participants completed the 20-item BIS/BAS Scale (Carver & White, 1994) assessing behavioral approach and inhibition sensitivity. The BAS subscale was analyzed as a single factor comprising approach behavior and sensitivity to reward. BIS comprises sensitivity to punishment (e.g. avoidance).These scales are frequently examined with frontal asymmetry both at rest and during tasks.

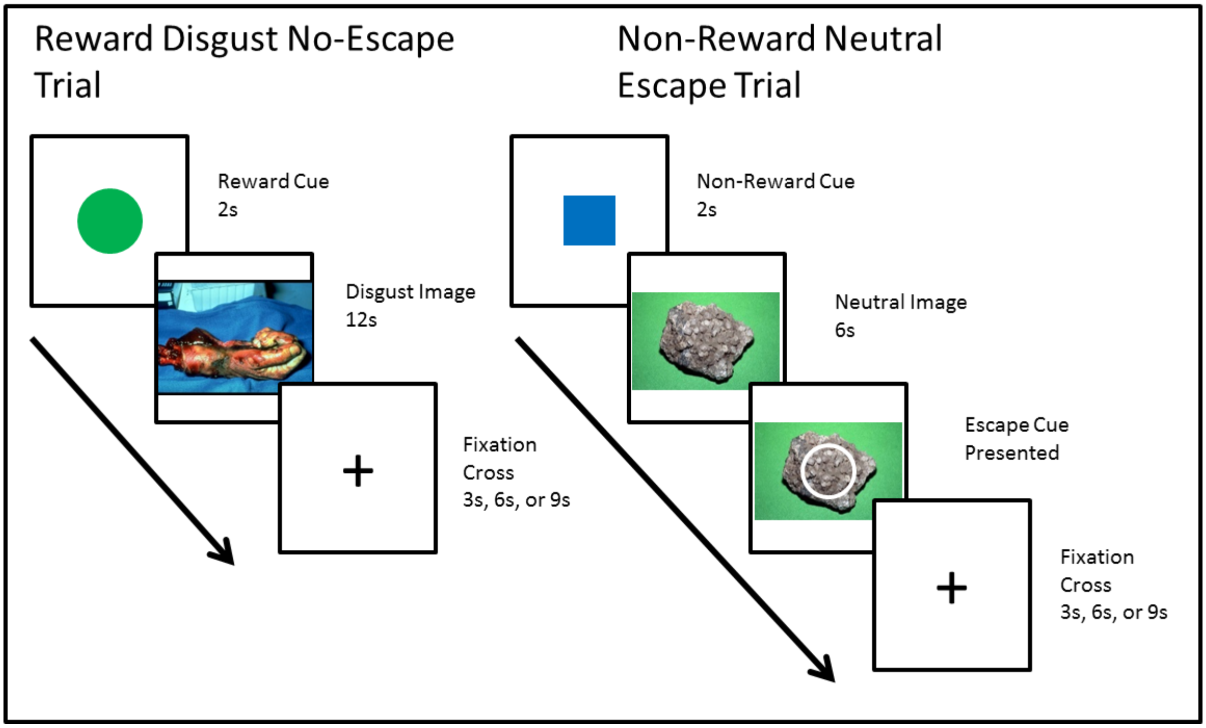
***UPPS-P Behavioral Impulsivity Scale***

The UPPS-P Impulsive Behavior Scale (Whiteside, Lynam, Miller, & Reynolds, 2005; Cyders & Smith, 2007) was used to measure trait impulsivity. The UPPS-P consists of 59 items assessing multiple facets of impulsivity including negative urgency (NUM), lack of premeditation, lack of perseverance, sensation seeking, and positive urgency (PUM). These subscales have been found to relate to frontal asymmetry in past research (Neal & Gable, 2016; 2017) and function as an index of the inverse of motivational control. The UPPS-P subscales were used in exploratory analyses.

***Picture Viewing Task***

Participants completed a task with two within-subjects conditions: non-reward trials and reward trials. Participants viewed pictures of injuries and matched neutrals (see Figure 1 for sample trial). Photos were taken from the International Affective Picture Set (IAPS; Lang, Bradley, & Cuthbert, 1997). On non-reward trials, participants were instructed to view the photos and fully feel the emotion that it evokes, but told that there was no possibility of reward on these trials. On the reward trials, participants were told that they could receive a reward for viewing the images for longer amounts of time. These reward trials were intended to create a conflict between avoidance (viewing a disgust-inducing stimulus) and approach (monetary reward).

Figure 1. *Example Trials from Picture Viewing Task.*




Prior to the beginning of each trial, participants were shown a trial cue that indicated whether it would be a non-reward or reward trial. Trial cues were a green circle or a blue square. For both trials types, an escape option was presented halfway through picture presentation on 80% of the trials. The escape option was signaled using a white circle cue that was superimposed over the image for 100 ms. On all but 20% of trials, after 6 seconds of photo presentation, participants were given an option to press the space bar on the keyboard and escape from the photo. The no escape trials were included to avoid habituation of the escape response. If pressed, the image was erased from the screen and replaced with a fixation cross until the next trial began. If the space bar was not pressed, the image remained on the screen for another 6 seconds, and then was replaced by a fixation cross. Inter-trial interval varied between 3s, 6s, and 9s to avoid predictability of picture presentation. Participants were presented with 32 disgust and 32 neutral images in randomized order for a total of 64 trials. There were equal numbers of each trial type: 16 disgust reward, 16 disgust non-reward, 16 neutral reward, and 16 neutral non-reward.

### *Manipulation Checks*

Following completion of the picture viewing task, participants answered a number of manipulation check questions. First, they reported how much they looked at the pictures while they were on the screen on a scale from 1 (not at all) to 5 (always). They also reported how motivated they were to get a reward and how disgusted they felt during the task on a scale from 1 (not at all) to 5 (extremely). Then, each picture used in the study was rated on dimensions of arousal and valence using the self-assessment manikin (SAM; Bradley & Lang, 1994). Additionally, participants reported their motivation towards the picture on a scale of 1 (move towards) to 9 (move away).

### *EEG Assessment*

EEG data was recorded and processed according to standard procedures. Data were recorded from 64 Ag/AgCl active electrodes in an actiCap (BrainProducts, Munich, Germany) based on the International 10/20 system using the actiCHamp system. Electrode impedances were kept below 20kΩ. EEG data was recorded at a sampling rate of 500Hz. Offline analyses were performed using BrainVision Analyzer software (BrainProducts). Data was rereferenced to a common average reference and band-pass filtered at 0.1-100Hz with a notch filter at 60Hz. Blink correction was applied using a regression-based algorithm. Following blink removal, artifacts related to muscle movement were removed using an automated algorithm to reject artifacts exceeding ±200 μV, and data was hand scored to remove additional artifacts. Data during picture presentation was segmented into 1000ms epochs, with segments overlapping by 50%. A Fast Fourier Transformation (FFT) with a Hamming window of 50% was applied. Power spectra from the traditional alpha band (8-13Hz) was extracted. Asymmetry difference scores were calculated for homologous pairs of frontal sites (F2-F1, F4-F3, F6-F5, F8-F7) by subtracting the natural log of alpha power for the left site from the natural log of alpha power from the right site. Because alpha power reflects the inverse of cortical activity (Laufs et al., 2003), higher values indicate greater relative left frontal activation, per convention.

**Hypotheses and Proposed Analyses**

The primary dependent variables in the study were frontal asymmetry difference scores (calculation described above in the EEG assessment section). A 2 (Condition: non-reward vs. reward) X 2 (Picture type: affective vs. neutral) repeated measures ANOVA with frontal asymmetry score as the dependent variable was used. A significant interaction was hypothesized, with the lowest asymmetry scores (e.g. greatest right frontal asymmetry) predicted for disgust pictures in the reward condition.

Amount of photos escaped from and average latency of escape decisions were calculated for each picture and trial type. These measures were compared for disgust and neutral pictures in the reward and non-reward conditions using a repeated-measures ANOVA. Participants were predicted to escape from more photos and do so more quickly in the non-reward condition than in the reward condition and for disgust compared to neutral images.

Pictures ratings were averaged across picture type. Comparisons between picture types were conducted using dependent-samples *t*-tests. Manipulation checks of picture ratings should reveal greater self-reported arousal, negative valence, and avoidance motivation for the affective compared to neutral photos.

## STUDY 1 RESULTS

### Descriptive Statistics

Descriptive statistics for all frontal asymmetry variables used in the analyses are included in Table 1. Descriptive statistics for all personality variables are included in Table 2.

Table 1. Descriptive Statistics for Frontal Asymmetry Variables in Study 1.

| Variables | Mean | Standard Deviation |
|---|---|---|
| 1. Disgust Reward F21 | .052 | .488 |
| 2. Disgust No Reward F21 | .053 | .500 |
| 3. Neutral Reward F21 | .045 | .497 |
| 4. Neutral No Reward F21 | .059 | .454 |
| 5. Disgust Reward F43 | .049 | .512 |
| 6. Disgust No Reward F43 | .042 | .537 |
| 7. Neutral Reward F43 | .040 | .485 |
| 8. Neutral No Reward F43 | .035 | .475 |
| 9. Disgust Reward F65 | .052 | .655 |
| 10. Disgust No Reward F65 | .070 | .610 |
| 11. Neutral Reward F65 | .085 | .572 |
| 12. Neutral No Reward F65 | .099 | .558 |
| 13. Disgust Reward F87 | -.058 | .642 |
| 14. Disgust No Reward F87 | -.055 | .699 |
| 15. Neutral Reward F87 | -.056 | .740 |
| 16. Neutral No Reward F87 | -.025 | .660 |

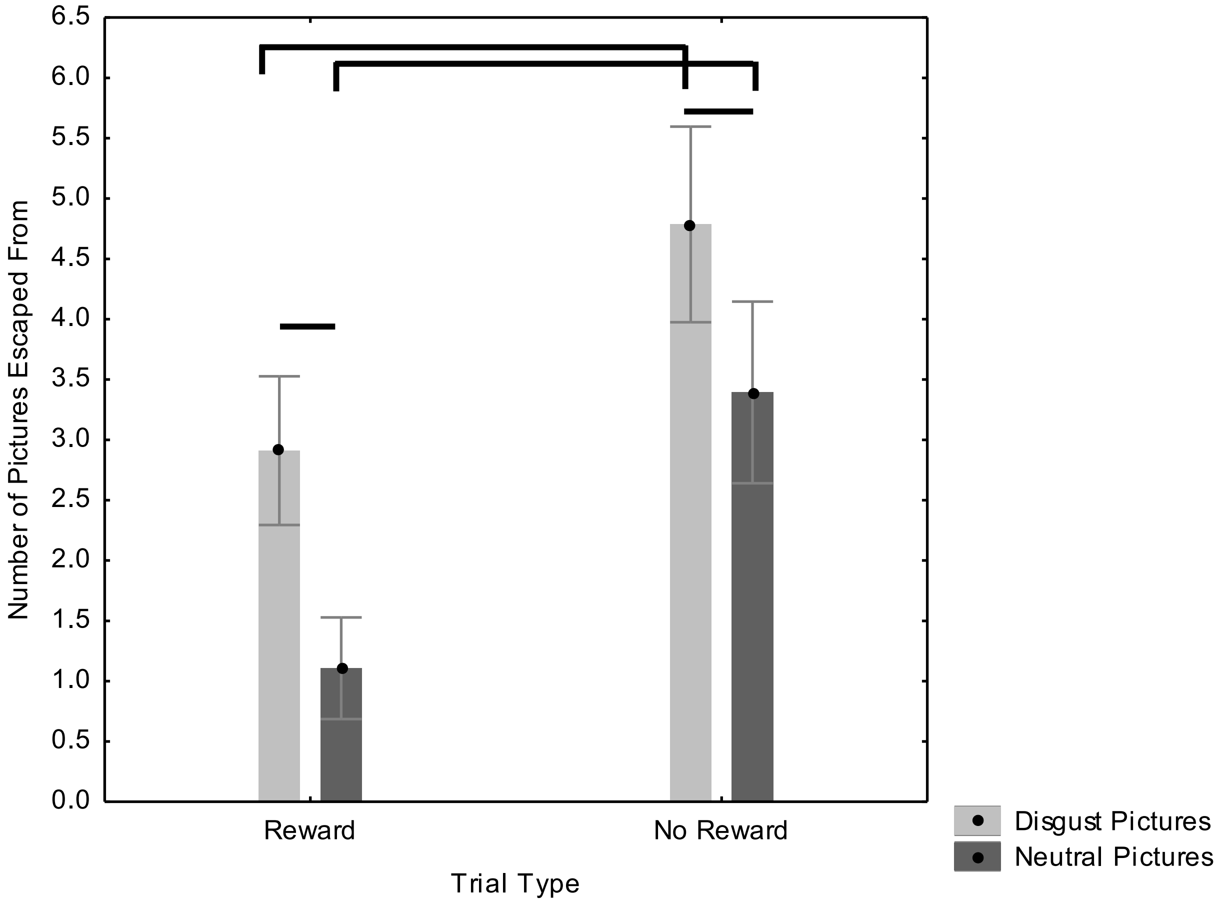
Table 2. Descriptive Statistics for Personality Variables in Study 1.

| Variables | Mean | Standard Deviation |
|---|---|---|
| 1. BAS | 3.20 | .29 |
| 2. BIS | 3.16 | .50 |
| 3. PUM | 2.13 | .33 |
| 4. NUM | 2.39 | .49 |
| 5. Lack of Premeditation | 2.06 | .34 |
| 6. Lack of Perseverance | 1.93 | .44 |
| 7. Sensation Seeking | 2.82 | .43 |
| 8. Emotional Suppression | 4.89 | .90 |
| 9. Cognitive Reappraisal | 4.30 | .75 |
| 10. Disgust Scale | 3.19 | .55 |

**Behavioral Analyses**

A 2 (Reward: non-reward vs. reward) X 2 (Picture type: affective vs. neutral) repeated measures ANOVA with average number of photos escaped as the dependent variable revealed a significant main effect of reward, $F(1, 55) = 11.15$, $p = .002$ (see Figure 2). Additionally, there was a significant main effect of picture type, $F(1, 55) = 15.84$, $p < .001$. There was no significant interaction of reward and picture type, $F(1, 55) = 2.36$, $p = .267$. Participants escaped from more pictures in the disgust no reward ($M = 4.79$, $SD = 6.07$) than any other condition, followed by no reward neutral ($M = 3.45$, $SD = 5.67$), disgust reward ($M = 2.91$, $SD = 4.61$), and reward neutral ($M = 1.11$, $SD = 3.15$). Fisher's post hoc tests revealed that all picture type and reward types were significantly different from one another except for reward disgust and no reward neutral.

Figure 2. Number of Images Escaped from by Trial and Picture Type.




Bars indicate significant differences in post hoc tests.

Next, a 2 (Reward: non-reward vs. reward) X 2 (Picture type: affective vs. neutral) repeated measures ANOVA with average latency of photos escaped as the dependent variable was conducted. Due to some participants not escaping from any photos in certain conditions, latency data was only available for all 4 categories for 12 participants. There was no significant interaction of reward and picture type on latency of escape decision, $F(1, 11) = .006$, $p = .942$. Additionally, there were no significant main effects of reward or picure type, $F$'s < 1.624, $p$'s > .229. Given the low power of these analyses with only 12 participants, no further analyses were done with latency of escape decisions.

Picture ratings revealed that the photos had the intended emotional effects. Disgust pictures (*M* = 5.42, *SD* = 2.18) were rated as more arousing than neutral images (*M* = 7.72, *SD* = 1.66), $t(53) = -6.26$, $p < .001$. Disgust pictures (*M* = 7.43, *SD* = 1.33) were rated as more withdrawal motivating than neutral images (*M* = 3.65, *SD* = 1.54), $t(53) = 11.60$, $p < .001$. Disgust pictures (*M* = 7.72, *SD* = 1.23) were rated as more negative than neutral images (*M* = 3.12, *SD* = 1.50), $t(53) = 18.02$, $p < .001$.

**Frontal Asymmetry Analyses**

A total of four 2 (Reward: non-reward vs. reward) X 2 (Picture type: affective vs. neutral) repeated measures ANOVAs with frontal asymmetry scores as the dependent variables (one ANOVA for each homologous pair of frontal sites) revealed no significant interactions (see Table 3).

Table 3. Repeated Measures ANOVA Results for Interaction Between Reward and Picture Type.

| | *df* | Type III SS | *F* | *p* |
|---|---|---|---|---|
| Sites F8 & F7 | 1, 54 | .016 | .454 | .503 |
| Sites F6 & F5 | 1, 54 | .004 | .370 | .546 |
| Sites F4 & F3 | 1, 53 | 0.000 | .023 | .880 |
| Sites F2 & F1 | 1, 54 | 0.000 | .000 | .991 |

**Correlations Among Variables**

Correlations were examined between the physiological, self-report, personality and behavioral variables included in the study. Frontal asymmetry variables were examined using sites F87 due to these sites being most commonly used in past research examining frontal asymmetry with motivational control (Neal & Gable, 2019; Reznik & Allen, 2018). First, frontal asymmetry was correlated with the personality measures collected at the beginning of the study. No significant relationships emerged between frontal asymmetry and personality constructs (see Table 4).

Table 4. Correlations between Frontal Asymmetry (F87) and Personality Variables in Study 1.

| Variables | Reward Disgust | Reward Neutral | No Reward Disgust | No Reward Neutral |
|---|---|---|---|---|
| 1.BIS | -.17 | -.19 | -.20 | -.14 |
| 2. BAS | .08 | .02 | .00 | .11 |
| 3. Negative Urgency | .22 | .14 | .21 | .25 |
| 4. Lack of Premeditation | .17 | .22 | .11 | .24 |
| 5. Lack of Perseverance | .10 | .10 | .05 | .10 |
| 6. Sensation Seeking | .03 | .08 | -.01 | .08 |
| 7. Positive Urgency | .00 | -.07 | .00 | .01 |
| 8. Emotional Suppression | .14 | .19 | .17 | .11 |
| 9. Cognitive Reappraisal | .17 | .23 | .16 | .20 |
| 10. The Disgust Scale | -.01 | -.07 | .01 | .00 |

* = $p < .05$, ** = $p < .01$

Next, frontal asymmetry was examined with the various self-report manipulation check questions. Likert-scale self-reported picture viewing, motivation, and disgust levels were included as well as averaged picture ratings for disgust pictures. No significant relationships were found between frontal asymmetry and manipulation check questions (see Table 5).

Table 5. Correlations between Frontal Asymmetry (F87) and Manipulation Check Questions and Picture Ratings in Study 1.

| Variables | Reward Disgust | Reward Neutral | No Reward Disgust | No Reward Neutral |
|---|---|---|---|---|
| 1. How motivated were you to get reward? | -.16 | -.14 | -.16 | -.16 |
| 2. How Disgusted were you? | -.05 | .01 | -.04 | -.07 |
| 3. Disgust Picture Arousal Ratings | -.16 | -.20 | -.22 | -.13 |
| 4. Disgust Picture Motivation Ratings | -.03 | .04 | .04 | -.03 |
| 5. Disgust Picture Valence Ratings | .06 | .12 | .11 | .08 |

* = $p < .05$, ** = $p < .01$

Finally, frontal asymmetry was correlated with behavioral outcome variables of number of escapes from each picture type. There was a significant relationship between frontal asymmetry to reward disgust pictures and escapes from reward disgust pictures ($r$ = .24, $p$ = .03). Additionally, there was a significant positive relationship for reward neutral pictures and reward neutral escapes, $r$ = .33, $p$ =.01. There were no significant relationships between frontal asymmetry score and escape options for no reward disgust trials ($r$ = .08, $p$ = .58) or no reward neutral trials ($r$ = .06, $p$ = .67).For reward disgust trials but not for no reward disgust trials, greater relative right frontal activation related to fewer escapes from these images.

Behavioral outcome variables of number of escaped photos were then correlated with the manipulation check variables (see Table 6). Greater self-reported length of time looking at the pictures related to less escaped pictured in the reward disgust ($r = -.47$, $p < .001$) and no reward disgust ($r = -.42$, $p < .001$) conditions. The more motivated towards the reward an individual reported they felt, the less pictures they escaped from in the reward disgust condition ($r = -.33$, $p = .01$). Greater overall self-reported disgust throughout the task related to more escaped photos in the reward disgust ($r = .30$, $p < .03$), no reward disgust ($r = .40$, $p = .002$), and no reward neutral ($r = .32$, $p = .01$) conditions. Greater average arousal reported during disgust pictures related to greater escaped pictures in the reward disgust ($r = -.40$, $p = .002$), no reward disgust ($r = -.47$, $p < .001$), and no reward neutral ($r = -.36$, $p = .008$) conditions. Last, average self-reported valence of disgust pictures related to escaped pictures in the reward disgust ($r = .27$, $p = .04$) and no reward disgust ($r = .29$, $p = .03$) conditions.

Table 6. Correlations between Escaped Pictures and Manipulation Check Questions and Picture Ratings in Study 1.

| Variables | Reward Disgust Escapes | Reward Neutral Escapes | No Reward Disgust Escapes | No Reward Neutral Escapes |
|---|---|---|---|---|
| 1.How long did you look at the picture? | -.47** | -.17 | -.42** | -.25 |
| 2. How motivated were you to get the reward? | -.33* | -.25 | -.02 | .05 |
| 3. How Disgusted were you? | .30* | .11 | .40** | .32* |
| 4. Disgust Picture Arousal Ratings | -.40** | -.15 | -.47** | -.36** |
| 5. Disgust Picture Motivation Ratings | .21 | .15 | .18 | .08 |
| 6. Disgust Picture Valence Ratings | .27* | .11 | .29* | .21 |

* = $p < .05$, ** = $p < .01$

Last, correlations between behavioral outcome variables of escaped pictures and personality constructs were examined (see Table 7). Behavioral Inhibition Sensitivity (BIS) correlated with number of pictures escaped from in the no reward disgust condition. Additionally, negative urgency correlated with number of pictures escaped from in the no reward disgust and no reward neutral conditions.

Table 7. Correlations between Escaped Pictures and Personality Variables in Study 1.

| Variables | Reward Disgust Escapes | Reward Neutral Escapes | No Reward Disgust Escapes | No Reward Neutral Escapes |
|---|---|---|---|---|
| 1.BIS | .08 | .03 | .28* | .20 |
| 2. BAS | -.23 | -.13 | -.13 | -.07 |
| 3. Negative Urgency | .24 | .11 | .39** | .44** |
| 4. Lack of Premeditation | .07 | .14 | .20 | .20 |
| 5. Lack of Perseverance | .21 | .15 | .25 | .23 |
| 6. Sensation Seeking | -.20 | -.19 | -.10 | -.09 |
| 7. Positive Urgency | -.07 | -.07 | .10 | .17 |
| 8. Emotional Suppression | -.18 | -.08 | -.24 | -.22 |
| 9. Cognitive Reappraisal | -.18 | -.03 | -.14 | -.08 |
| 10. The Disgust Scale | .12 | -.07 | .18 | .09 |

# STUDY 1 DISCUSSION

Behavioral results revealed that participants were more likely to escape from disgust photos and from non-reward trials, as hypothesized. Additionally, the amount of photos they escaped from in the approach-avoidance conflict condition of interest (reward disgust trials) were predicted by the length of time participants felt they looked at the photo, how motivated they felt to get the reward, their overall feelings of disgust during the task, and disgust picture ratings of arousal and negative valence. These manipulation checks suggest that participants did indeed feel a conflict between motivation to get the reward and heightened aversion to the disgust photos. Individual differences in these approach and avoidance motivations appeared to affect behavioral outcomes.

Escape latency was originally hypothesized to be faster for disgust photos than neutral photos and for non-reward compared to reward trials. Because too few participants escaped from all four trial types, this particular analysis was not well powered enough to draw conclusions from. In the future, to examine escape latency effectively more trials and shorter picture presentations should be used. The picture presentation length was chosen to give sufficient time for EEG recording, but questions about the speed with which participants made escape decisions depending on condition would be better answered in a paradigm with shorter picture presentations.

The main planned analysis of frontal asymmetry by reward and affective picture type did not reveal significant results at any of the pairs of frontal sites. It is possible that the presentation of all 4 trial types in a randomized fashion left carry-over effects between conditions, leading to null results. Although within-subjects randomized designs are generally preferred to increase power for psychophysiological studies, a blocked design where participants completed each condition of reward and affective picture type in counterbalanced blocks may have been better for separating brain activity associated with each picture type.

In addition to the carry-over effects between trial types, the frontal asymmetry differences may have been stronger with the use of a more intense comparison condition than neutral photos. Positive images high in approach motivation have been found to evoke heightened left frontal activation, which may have created a larger contrast from the disgust trials. However, using positive photos may erase the behavioral effects of differences between the number of escaped photos in the no reward and reward trials. Due to their pleasant valence and high approach motivation, participants may not be motivated to escape from any positive photos regardless of reward or no reward condition. The photos in the current study were affectively neutral enough to lead participants to escape from viewing them when not motivated by reward, but a positive comparison condition would instead contain motivation to view the photos in and of themselves and independent of condition. Although psychologically the decision making to escape would likely differ when using positive rather than neutral images, the anticipated effects on brain activity may have been easier to distinguish.

Although there were no differences between trial types on frontal asymmetry, the reward disgust condition had a unique relationship between frontal asymmetry and number of escaped photos. The greater right frontal asymmetry participants exhibited to reward disgust (e.g. approach-avoidance conflict trials), the less they tended to escape from these trials. This relationship between frontal asymmetry and behavioral outcome was not present for no reward disgust trials that evoked pure avoidance. Based on the theory that right frontal asymmetry is indicative of motivational control, this finding can be interpreted to suggest that participants who engaged better motivational control managed to continue looking at aversive images in the face of potential reward and exercised better control during a conflict between approach and avoidance.

Personality correlates suggested that impulsive personality and sensitivity to punishment played a role in task performance. Negative urgency predicted escaped photos in the no reward disgust condition. Negative urgency assesses the tendency to engage in impulsive behavior when in a negative affective state. Those higher in rash behavior in negative affective states (such as the manipulated state in this study) were more likely to escape from photos when there was no reward on the line. Interestingly, negative urgency did not predict escape from reward pictures, suggesting that the situational constraints created in this paradigm led even those who would normally be prone to escaping from the photos to continue engaging with them when reward was possible.

STUDY 2 METHOD

Study 2 manipulated approach-avoidance conflicts by creating a situation in which loss aversion (avoidance) conflicted with monetary reward (approach). Participants completed a modified hot Columbia Card Task (CCT; Figner, Mackinlay, Wilkening, & Weber, 2009). The hot version of the CCT is a risk-taking task in which participants can either win or lose money on each trial by flipping over cards containing rewards or losses. Typically, optimal strategy in a risk taking game is to be relatively cautious; at some point the odds of loss outweigh the potential gains. However, the intent of the current study was to manipulate a state in which participants had to engage in risky choices (e.g. flip more cards) in order to perform optimally in the task and obtain a reward. This was accomplished using cued conflict and neutral trials. Participants had to regulate feelings of loss aversion in order to continue flipping cards to gain points in the conflict trials, but this pressure to gain more rewards was not present in neutral trials.

**Participants**

As in Study 1, a target sample size of 50 participants was set to balance feasibility and power. Data collection was set to stop at the end of the fall semester, provided at least 40 subjects completed the study. Participants were recruited through the University of Alabama subject pool. A total of 54 participants were recruited for participation in the study. Three participants did not complete the study due to the following reasons: one participant was left-handed, one participant became sick before EEG equipment could be applied, and issues with EEG equipment prevented data collection from one participant. EEG data from an additional 3 subjects was not analyzed because it contained too many artifacts to be processed. Therefore, data from 48 participants was included in final analyses. The final sample consisted of 34 females and 14 males with an average age of 18.65 (*SD* = 0.82).

## Procedure

Participants were brought into the lab and informed consent was obtained. Participants completed measures of demographics and personality questionnaires. Then, a stretch-lycra EEG cap with 64 sensors was applied. This study utilized the same BrainVision AntiCHamp system and settings as Study 1. Following administration of EEG equipment, four minutes of resting baseline EEG was recorded with alternating minutes of eyes open and eyes closed. Participants then completed the modified CCT. Following the task, participants answered manipulation check questions. Finally, psychophysiological equipment was removed and participants were thoroughly debriefed.

## Measures

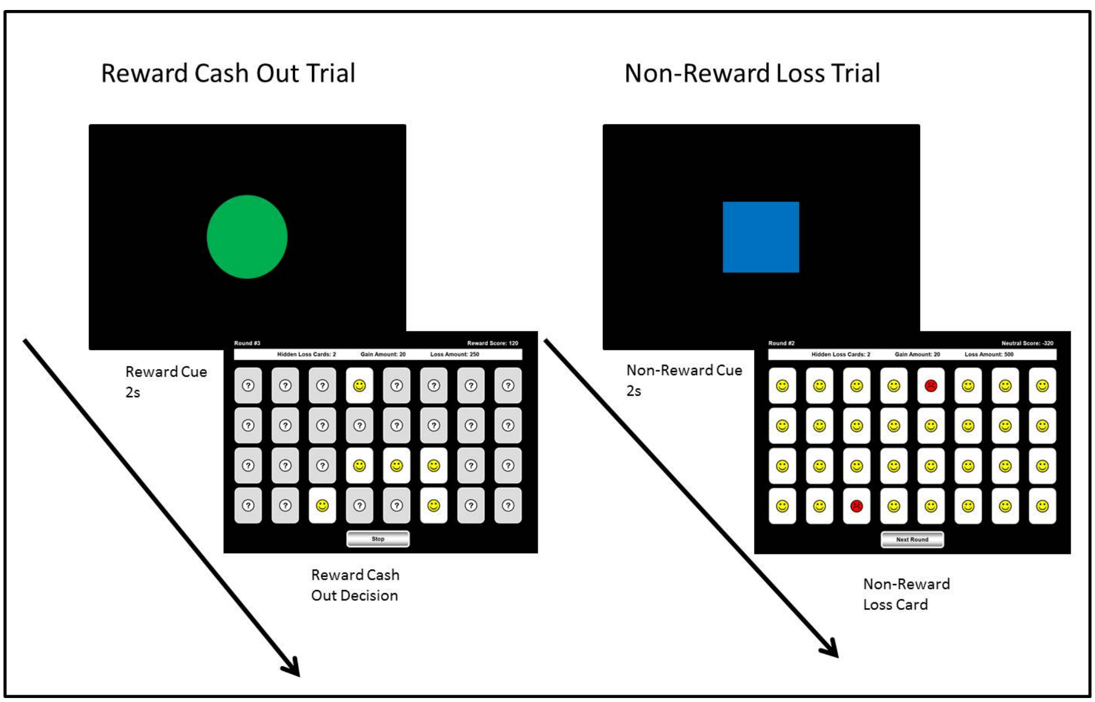
### *Demographics Measures and Personality Questionnaires*

The same demographics variables from Study 1 were collected. Personality questionnaires of BIS/BAS and UPPS-P were also included to use in exploratory analyses.

### *Columbia Card Task (CCT)*

The Columbia Card Task (CCT) shows participants 32 cards face down on the screen in 4 rows of 8 cards each (see Figure 3). The participant was instructed to turn over as many cards as they would like, and that they could continue turning cards over until they encounter a loss card. Each card they turn over rewarded 20 points. If they chose to end the trial before encountering a loss card, they gained the amount of points they had acquired up to that point into their total score. Upon encountering a loss card, the trial terminated and the loss value was subtracted from their bank of previous earnings. The dependent variable was the average number of cards turned over on each trial and the final score attained in the game. In the original task, the feedback is rigged such that the loss cards will always be chosen on the last possible card with a few filler trials trials to maintain the impression that the participant is playing a real game. However, pilot studies revealed that students in the target sample were able to discern that the task was rigged and ceiling effects were found for number of cards turned over. For the current study, the task did not use rigged feedback. Instead, the loss card was chosen randomly from a set pool of numbers for each trial. These number pools were identical for reward and non-reward trials. Participants completed 22 reward trials and 22 non-rewards trials for a total of 44 trials.

Figure 3. Example Trials from the Columbia Card Task (CCT). *Gain cards flipped over by the participant result in a smile face. Loss cards are represented by a red frown face and end the trial. Task parameters are located in the top white box. The participant's banked points are shown in the top right under "Reward Score" or "Neutral Score".*



Conflict and neutral trials were administered in a within-subjects design. The same conflict and neutral cues were used as Study 1: green circle and blue square. For conflict trials, participants were told that the points they gained would count towards a prize they could receive at the end of the study. For neutral trials, participants were told they should still try to get as many points as possible, but it wouldn't count towards the reward. On each trial screen the participant could see their current balance of points for both reward and neutral trials. The CCT allows the researcher to vary a number of parameters, which were held constant for the current study: number of hidden loss cards (2), amount of reward (20 points per gain card), and loss amount upon encountering a loss card (250 points). The balance of reward gained to potential loss was such to promote loss aversion.

***Manipulation Checks***

Participants were asked to report their feelings about the task including anxious they felt about the possibility of turning over a loss card, how negative they felt when they did turn over a loss card, and have motivated to win a reward they felt during the task on a scale of 1 (not at all) to 5 (extremely). They also reported state emotion ratings on a variety of positive and negative emotion words.

***EEG Assessment***

EEG recording was completed under identical parameters to Study 1. Processing steps were also similar, with one exception. Rather than average alpha activity during picture presentation, alpha activity during completion of the CCT was analyzed for reward trials and neutral trials. Event code markers were placed every 500ms during the time that participants were completing each trial. Asymmetry scores were calculated for both trial types in the same process described above in Study 1.

## Hypotheses and Analyses

The primary dependent variable in the study was frontal asymmetry difference scores (calculation described above in the EEG assessment section). Differences in frontal asymmetry between the two conditions were assessed utilizing a repeated-measures ANOVA with trial type (conflict vs. neutral) as the independent variable. I predicted greater right frontal asymmetry in the conflict condition compared to the neutral condition.

Average number of cards turned over in the CCT for each participant was also calculated. A repeated-measures ANOVA by trial type was expected to reveal a higher number of cards turned over for participants in the conflict condition versus the neutral condition. Additionally, number of points earned in the task was calculated, and participants were expected to earn more points in the conflict trials than the neutral trials.

STUDY 2 RESULTS

**Descriptive Statistics**

Descriptive statistics for all frontal asymmetry variables used in the analyses are included in Table 8. Descriptive statistics for all behavioral and manipulation check variables are included in Table 9. Descriptive statistics for all personality variables are included in Table 10.

Table 8. Descriptive Statistics for Frontal Asymmetry Variables in Study 2.

| Variables | Mean | Standard Deviation |
|---|---|---|
| 1. Conflict F21 | .18 | .55 |
| 2. Neutral F21 | .22 | .56 |
| 3. Conflict F43 | .00 | .63 |
| 4. Neutral F43 | .02 | .64 |
| 5. Conflict F65 | .04 | .72 |
| 6. Neutral F65 | .11 | .72 |
| 7. Conflict F87 | -.20 | 1.05 |
| 8. Neutral F87 | -.15 | .90 |

Table 9. Descriptive Statistics for Behavioral and Manipulation Check Variables in Study 2.

| Variables | Mean | Standard Deviation |
|---|---|---|
| 1. Conflict Score | 2562.50 | 881.00 |
| 2. Neutral Score | 1882.71 | 1683.12 |
| 3. Conflict Cards Flipped | 16.51 | 1.33 |
| 4. Neutral Cards Flipped | 16.79 | 1.11 |
| 5. Self-Reported Loss Anxiety | 2.75 | 1.12 |
| 6. Self-Reported Motivation | 3.15 | 1.07 |
| 7. Self-Reported Negative Affect Towards Loss | 2.94 | 1.21 |

Table 10. Descriptive Statistics for Personality Variables in Study 2.

| Variables | Mean | Standard Deviation |
|---|---|---|
| 1. BAS | 3.14 | .27 |
| 2. BIS | 2.98 | .47 |
| 3. PUM | 2.23 | .34 |
| 4. NUM | 2.42 | .41 |
| 5. Lack of Premeditation | 2.09 | .36 |
| 6. Lack of Perseverance | 1.95 | .46 |
| 7. Sensation Seeking | 2.89 | .43 |

**Behavioral Analyses**

Final Conflict and Neutral scores and number of cards flipped in each trial type were compared using repeated-measures ANOVAs. As predicted, participants achieved a higher score in the conflict ($M$ = 2562.50, $SD$ = 881.00) than in the neutral ($M$ = 1882.71, $SD$ = 1683.12) trials, $F(1, 47) = 11.12$, $p < .002$. Counter to prediction, participants flipped over more cards in the neutral ($M$ = 16.79, $SD$ = 1.11) than in the conflict ($M$ = 16.51, $SD$ = 1.33) trials, $F(1, 47)$ = 5.35, $p = .025$.

**Frontal Asymmetry Analyses**

Frontal asymmetry was compared between conflict and neutral trials for each set of homologous pairs of frontal sites. At each set of homologous pairs, there was greater right frontal asymmetry for the conflict than the neutral trials, but none of these differences were significant (see Table 11).

Table 11. Repeated Measures ANOVA Results for Frontal Asymmetry in Study 2.

| | *df* | Type III SS | *F* | *p* |
|---|---|---|---|---|
| Sites F8 & F7 | 1, 47 | .053 | 1.264 | .267 |
| Sites F6 & F5 | 1, 47 | .119 | 2.681 | .108 |
| Sites F4 & F3 | 1, 46 | .010 | .740 | .394 |
| Sites F2 & F1 | 1, 47 | .038 | 2.660 | .110 |

**Correlations among Variables**

Frontal asymmetry during the conflict and neutral trials was correlated with the behavioral, personality, and manipulation check variables. Because the effect of trial type on frontal asymmetry was strongest at sites F6 & F5, asymmetry scores from these sites were used. First, the relationship between frontal asymmetry and behavioral outcome variables was examined (see Table 12). Greater right frontal asymmetry during conflict trials related to lower number of points scored during the conflict trials ($r = -.29$, $p = .04$). Additionally, greater right frontal asymmetry during conflict trials related to more cards flipped during conflict trials ($r = .31$, $p = .03$). Frontal asymmetry during neutral trials did not relate to neutral score or number of cards flipped on neutral trials.

Table 12. Correlations between Frontal Asymmetry (F65) and Behavioral Variables in Study 2.

| Variables | Conflict F65 | Neutral F65 |
|---|---|---|
| 1.Conflict Score | -.29* | -.23 |
| 2. Neutral Score | -.12 | -.05 |
| 3. Conflict Cards Flipped | .31* | .23 |
| 4. Neutral Cards Flipped | .27 | .18 |
| 5. Self-Reported Loss Anxiety | -.17 | -.21 |
| 6. Self-Reported Motivation | -.08 | -.10 |
| 7. Self-Reported Negative Affect Towards Loss | -.06 | -.17 |

* = $p < .05$, ** = $p < .01$

Next, correlations were run between frontal asymmetry and personality variables (see Table 13). The only significant relationship was found between neutral trial asymmetry and positive urgency (likely a spurious relationship).

Table 13. Correlations between Frontal Asymmetry (F65) and Personality Variables in Study 2.

| Variables | Conflict F65 | Neutral F65 |
|---|---|---|
| 1. BAS | .13 | .14 |
| 2. BIS | .21 | .06 |
| 3. PUM | .22 | .21* |
| 4. NUM | .09 | .13 |
| 5. Lack of Premeditation | -.23 | -.16 |
| 6. Lack of Perseverance | .03 | .08 |
| 7. Sensation Seeking | .09 | .15 |

* = $p < .05$, ** = $p < .01$

Last, correlations were run between behavioral, manipulation check, and personality variables (see Table 14). Higher trait behavioral approach (BAS) related to more cards flipped over on neutral trials. Higher positive urgency related to more cards flipped over on conflict trials.

Table 14. Correlations between Behavioral, Personality, and Manipulation Check Variables in Study 2.

| Variables | Conflict Score | Neutral Score | Conflict Cards Flipped | Neutral Cards Flipped |
|---|---|---|---|---|
| 1. BAS | -.22 | .10 | .21 | .29* |
| 2. BIS | -.08 | -.07 | .13 | .20 |
| 3. PUM | -.17 | -.18 | .31* | .20 |
| 4. NUM | -.05 | -.09 | .17 | .25 |
| 5. Lack of Premeditation | -.16 | -.18 | .10 | .04 |
| 6. Lack of Perseverance | -.08 | -.13 | .11 | .18 |
| 7. Sensation Seeking | .03 | .03 | .10 | .03 |
| 8. Self-Reported Loss Anxiety | .06 | -.18 | -.04 | .13 |
| 9. Self-Reported Motivation | .01 | -.10 | -.10 | .05 |
| 10. Self-Reported Negative Affect Towards Loss | .22 | -.04 | -.07 | .09 |

* = $p < .05$, ** = $p < .01$

## DISCUSSION STUDY 2

In Study 2, participants achieved a higher score in the conflict trials than in the neutral trials, as predicted. However, the other behavioral index of number of cards turned over was in the opposite direction of predictions; participants flipped more cards in neutral than in conflict trials. Participants were more likely to flip cards over in a careless manner when they knew the score would not affect their reward. In contrast, on conflict trials the participants behaved more cautiously when balancing concerns between making sure they gained enough points and being sure not to encounter a loss card with a relatively high loss value. This led participants to turn over fewer cards in the conflict condition, but ultimately to also achieve higher score.

The hypothesized frontal asymmetry results were in the predicted direction but not significant. Similar concerns may be at play with Study 2 as with Study 1. Perhaps the manipulation was not strong enough to produce drastically different neural results in the randomly presented design and a blocked design of a conflict game and a no-reward game would better capture the frontal asymmetry differences. It is also possible that the complexity of the task contributed to the current results. The motivations of approach and avoidance motivation were complex and subtle and another simpler version of the task may have better manipulated a straightforward approach-avoidance conflict.

Although the predicted main effect of trial type on frontal asymmetry was not significant, frontal asymmetry to conflict trials related to task performance. Frontal asymmetry in the conflict condition related to both higher total reward score and lower number of reward cards flipped.

Greater right frontal asymmetry predicted higher scores in the game suggesting that those who engaged more motivational control to maximize benefits in the game also exhibited higher right frontal asymmetry. Previous theories of frontal asymmetry that posit right frontal asymmetry as an indicator of negative affect or withdrawal motivation would predict that those who performed worse in the task and experienced negative feelings of loss would have had higher right frontal asymmetry. They would also hypothesize that those motivated greater by the reward would show higher left frontal asymmetry due to approach motivation. These correlational results somewhat support a model linking right frontal asymmetry to control.

Personality measures in the current study predicted behavioral task performance. Those higher in behavioral approach sensitivity flipped more cards on neutral trials, but not conflict trials. The BAS scale indexes a person's tendency to engage in goal-directed, reward seeking behavior. Likely due to their overall tendency towards approach behaviors, those higher in BAS tended to flip more cards when loss aversion was not at play in the neutral trials. BAS did not relate to cards flipped on reward trials, suggesting that the task parameters of wanting to score high on reward trials might have overruled their personality tendencies. In contrast, number of cards flipped on reward trials was predicted by positive urgency, or the tendency to act impulsively when in a positive emotional mood. Impulsive personality traits predicted poorer performance on reward trials. For those whom are low in motivational control (e.g. high in impulsivity), the allure of gaining more points may have led them to ignore feelings of loss aversion and flip more cards over.

Participants self-reported loss anxiety, motivation to win a reward, and negative affect upon encountering a loss card did not relate to behavioral outcome variables of number of cards turned over or total score. Because the total score is purported to reflect level of engaged motivational control where participants with better control were able to achieve higher scores, it is unusual that their motivation or loss anxiety did not relate to their final score. It is possible that the participants' self-report at the end of the study did not accurately reflect their feelings during the completion of the task, and more timely assessment of emotional experience would reveal a relationship between self-report and behavioral performance. Participants were already aware of their final score by the time that they reported their motivation and anxiety, and perhaps knowing their final performance affected their reported experience.

## GENERAL DISCUSSION

In Study 1, I manipulated an approach-avoidance conflict by creating a reward paradigm where participants were incentivized to view disgust-inducing pictures for longer periods of time in order to gain a reward. Participants reported experiencing disgust, withdrawal, and negative affect in response to the disgust pictures compared to the neutral pictures. Participants' self-reported disgust while viewing the photos predicted more times escaping from the disgust reward photos. Additionally, participants who were more motivated to gain a reward tended to report viewing the pictures for a longer period of time. Higher self-reported motivation to get a reward also predicted less escaped pictures in the disgust reward condition. Thus, the task seemed to successfully create a state of approach-avoidance conflict in which negative affect and motivation towards reward interacted with one another. However, frontal asymmetry was not significantly different in the predicted disgust reward condition. Importantly, for the trials evoking an approach-avoidance conflict (e.g. reward disgust trials), there was a relationship between right frontal asymmetry and number of escaped photos. This relationship was not significant for no reward disgust pictures, suggesting that when greater motivational control is engaged in the face of conflicting approach and avoidance urges, higher right frontal asymmetry predicts behavioral outcomes of greater control.

A second study was run to evoke a second kind of approach-avoidance conflict using a risk-taking task. In this task, participants ultimately attained a higher total score for approach-avoidance conflict trials compared to neutral trials. Participants also turned over more cards in the neutral trials than in the conflict trials, indicating a more cautious approach to conflicting reward trials and a more careless approach to neutral trials that could not result in a reward. Although participants exhibited greater right frontal asymmetry for conflict compared to neutral trials, this difference did not reach statistical significance. However, right frontal asymmetry during reward trials was related to a higher total reward score and fewer cards flipped in the conflict trials. These behavioral indicators of better motivational control related to greater right frontal asymmetry, hypothesized to index motivational control.

The current results found correlational evidence in support of the hypothesis that motivational control during approach-avoidance conflicts underlies right frontal asymmetry. Importantly, these studies did not support the competing model that right frontal asymmetry is a marker of avoidance motivation. If this was the case, we would have seen a main effect of disgust images compared to neutral images on frontal asymmetry in Study 1. The null results of trial type combined with correlational analyses revealing that right frontal activity was related to better motivational control during conflict trials indicate that right frontal asymmetry may be more closely tied to motivational control than avoidance. In Study 2, previous models would predict that self-reported negative affect would predict right frontal asymmetry during the conflict trials, but that was not the case. Additionally, the finding that higher scores on the conflict trials related to greater right frontal asymmetry during these trials supports the motivational control model of frontal asymmetry. Past valence or approach/avoidance models would have predicted that attaining approach-motivated rewards would have related to greater left frontal asymmetry, but my findings instead point to the role of motivational control in facilitating this positive outcome. The current studies do not show evidence in favor of a valence-based or approach-avoidance based model of frontal asymmetry.

How can the null results of condition on frontal asymmetry help to advance theory of the motivational correlates of neural activation? The current studies employed two novel tasks that have never been used to examine frontal asymmetry. Although the predicted effect of condition in the current studies did not show differences between the conditions, in both studies behavioral outcomes were correlated with frontal asymmetry during key trials of the task. In Study 1, right frontal asymmetry during trials evoking approach-avoidance conflict related to enhanced performance in the task (e.g. less escaped photos when a reward is on the line). Similarly, in Study 2 more optimal performance in the task (e.g. higher reward score obtained) related to greater right frontal asymmetry during approach-avoidance conflict trials.

EEG asymmetry is a dynamic, complex measure influenced by a myriad of state and trait processes (Hagemann, Naumann, Thayer, & Bartussek, 2002). Frontal asymmetry is frequently studied as a correlate of cognitive task performance, personality variables, and emotional processes (Reznik & Allen, 2018). Thus, it is common that frontal asymmetry findings are relationships between variables rather than differences between conditions. It may be that examining frontal asymmetry as a predictor of behavioral outcomes is a better methodological approach than examining broad differences between conditions. Many of the hallmark past findings in the frontal asymmetry literature rely on correlations with personality and behavior rather than differences in conditions (for a review, see Harmon-Jones and Gable, 2018).

Although EEG provides superior temporal resolution to other neuroimaging techniques and can detect rapid millisecond level changes in electrical brain activation, effects can still differ in a randomized versus blocked design (Pfabigan, Zeiler, Lamm, & Sailer, 2014). It is possible that the nature of the design of the two studies did not fully separate activation from the conditions. In the picture viewing reward task, trials were randomly presented with disgust and neutral trials and reward and no reward trials all presented in the same block. Intertrial intervals provided some break between trials, but the influence of randomly presented stimuli could have carried over from trial to trial in a way that separate blocks may have eliminated. Across different tasks, perhaps a blocked design with reward trials (e.g. conflicting trials) separated from no reward trials (e.g. pure avoidance motivation) would be better suited for contrasting conflict and avoidance motivation.

Conflicts between approach and avoidance motivations are inherent to daily life and development of the motivational control necessary to choose between a myriad of behavioral options is essential. Yet not enough is known about the neural patterns that orchestrate and successfully override these motivations. Theories about the meaning of frontal asymmetry have rapidly advanced from a valence-based model (Tomarken, Davidson, and Henriques, 1990) to an approach-avoidance motivation model (Harmon-Jones, 2004) to a model of motivational control (Gable, Neal, & Threadgill, 2018). Further research is needed as neuroimaging tools develop to continue refining theories of mind-brain relationships.

As methods for studying neural activation advance, the use of neural measures to advance psychological theory will become increasingly applicable. However, understanding the localization of specific psychological processes to a particular brain region is an important step in eventually using neuropsychological methods in refining our psychological theories (Cunningham, 2010). Psychological processes, such as motivation and emotion, cannot occur without accompanying brain activation. Yet the mystery of the ways in which the human brain orchestrates thoughts, feelings, and behaviors is only beginning to be understood and can only be discovered with incremental advances using a variety of methods and cautious interpretation of results (Cacioppo & Bernston, 1992; Poldrack, 2011). The current dissertation project sought to elucidate one area of study within physiological psychology: frontal hemispheric asymmetry and emotive processes. Although the main condition differences in frontal asymmetry were null, much can still be gained from the secondary correlational analyses in the current data. In situations of conflict between approach and avoidance motivations when maximal reward is the desired result, the right frontal cortex is involved in exercising motivational control and facilitating favorable outcomes.

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