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THE ROLE OF EEG ASYMMETRY AND BEHAVIORAL INHIBITION IN ATTENTIONAL BIASES TO THREAT

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ABSTRACT

Behavioral inhibition (BI) is an early-childhood temperamental trait linked to social withdrawal and the emergence of anxiety in adolescence. BI, in turn, has been linked to a pattern of greater electroencephalogram (EEG) activity in the right hemisphere over the frontal lobe. A separate line of research has linked right frontal EEG asymmetry to anxiety and social withdrawal. The two studies presented here investigate the moderating role of brain electrophysiology and childhood temperament on attentional bias to threatening stimuli. This analysis is based on a newly-emerging line of work suggesting that attention biases to threat may play a causal role in the emergence of anxiety. To do so we examine attention shifting ability using two versions of the Posner task modified to include emotional input. In the two studies, EEG asymmetry and behavioral inhibition scores of children ages 4-7 years and 9-12 years were assessed and then compared to children's performance on the affective Posner task. In the first version, children were given positive and negative feedback on their performance. In the second version, children were shown angry and neutral faces as attention cues. Our first aim for both of these studies was to determine the magnitude of the impact of valid and invalid attention cueing on performance (known as the validity effect) as a function of feedback (study 1) and emotion faces (study 2). Results indicate that the cost of invalid cueing is greater than the benefit for valid trials, regardless of trial type. In terms of individual differences, the cost and benefits of cueing were magnified in children with right EEG asymmetry, particularly in the face of negative feedback. Although the pattern was similar in study 2, the findings were non-significant, likely due to sample size. The findings suggest that underlying biological markers of risk (i.e., EEG asymmetry) may be associated with difficulties controlling selective attention in the face of negative or threatening stimuli. These preliminary exploratory data may serve as the foundation for future larger-scale studies.

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Chapter 1

Introduction

We are constantly faced with the choice to either attend to or ignore stimuli in our environment, a process which is regulated through the underlying mechanism of selective attention. We pick and choose what environmental stimuli to attend to based on their salience and relevance to our current goals. Concerns about our physical and mental health as well as emotions play an influential role in this selection process. Emotions can sometimes distract us from relevant information by leading us to focus only on those stimuli that are the most emotionally salient, often because they are physically or psychologically arousing (Pérez-Edgar & Fox, 2005). For example, we might focus our attention only on the negative content when we are receiving constructive criticism. Others, in contrast, might choose to focus on positive comments and frame criticism as areas for improvement. Our emotional biases toward salient aspects of our environment in combination with our ability to selectively attend to one stimulus over another serve to guide our behavior.

A great deal of research studying emotional biases in attention focuses on a specific pattern of selective attention known as attentional-bias to threat (MacLeod, Mathews & Tata, 1986). An attentional-bias to threat is the tendency to selectively attend to a stimulus that is perceived as threatening over other environmental stimuli (MacLeod & Mathews, 1985). Attentional-biases to threat can serve both adaptive and maladaptive functions. In a dangerous environment, attention to threat serves to alert us to potential dangers and allows us to avoid them. However, attention to negative stimuli in a non-threatening environment can often distract us from more relevant stimuli, causing us to perseverate on negative aspects of our environment.

Research suggests that attentional-biases to threat can interfere with the deployment of attention by making it more difficult to disengage from negative stimuli. This maladaptive deployment of selective attention has consequences for attention shifting and emotional self-regulation. For instance, Pérez-Edgar and Fox (2003) found that the inability to ignore irrelevant emotion-related information during an emotional Stroop task is linked to poor self-regulation in children. The emotional Stroop task displays a series of words related to emotions that are printed in different colors. In this task the child must name the color in which the word is written, a process that requires focusing on the color of the word and not its meaning. The results of this study imply that attentional biases in children who have difficulty regulating emotions may lead them to have trouble shifting attention from negative stimuli to the task at hand. This finding is significant because it implies that attentional biases and emotional regulation are interconnected.

It is clear that individual differences in attentional biases exist among children. Some children are more prone to focus their attention on threatening stimuli than others. One factor that has been theorized to play a role in the development of these biases is temperament. Studies have shown that the temperament trait behavioral inhibition may be linked to attentional-biases to threatening or negative stimuli (Fox et. al., 2005). Behavioral inhibition is defined as a child's initial response to novel situations or people and is usually characterized by social withdrawal. Children with behavioral inhibition exhibit more withdrawal behaviors and less approach behaviors, particularly in novel situations (Fox et. al., 2005). Strong evidence suggests that children who are behaviorally inhibited have trouble shifting their attention away from threatening stimuli and are prone to interpreting environmental stimuli as more threatening. For example, one study found that teacher-rated shyness correlated negatively with students' ability to shift attention during school (Eisenberg et. al., 1998). This finding is consistent with the findings from a study of anxious individuals' performance on emotional Stroop task. Specifically, individuals with anxiety are slower to name the color of an anxiety provoking word when compared to a neutral word (Williams et. al., 1996). This is most likely due to the fact that anxious individuals have difficulty disengaging attention from anxiety provoking stimuli.

The process of engaging and disengaging attention involves several neural mechanisms. While we have very clear research linking specific neural mechanisms to basic attention processes, we do not yet know how specific perturbations in these brain-based mechanisms may be linked to maladaptive patterns in attention biases to threat. The discovery of specific patterns of brain activity that are linked to maladaptive behavior may facilitate the identification of at-risk individuals and may also have important implications for treatment. Currently, researchers are using a cognitive technique called attention bias modification (ABM) which has been found to aid in disengagement from threat in children (Eldar et. al., 2012). However, the mechanism underlying ABM training remains unknown. One theory is that this training changes brain activity which in turn affects behavior. More research involving brain activity needs to be conducted in order to strengthen this theory.

Researchers have taken particular interest in the study of right frontal EEG asymmetry and its relation to selective attention. EEG asymmetry is the difference in activity across the right and left side of the brain as measured by an electroencephalogram. Right frontal EEG asymmetry has been found to correlate with shyness and is thought to be a part of an attentional response to negative stimuli (Fox & Davidson, 1984). In an emotional Stroop task study, participants with right EEG asymmetry took longer to name the color of negative affective words, implying that right frontal brain activity is correlated with attentional biases to threatening and negative stimuli (MacLeod, 1991).

Researchers have also found that frontal EEG asymmetry is a good predictor of approach and withdrawal behaviors in children and adults. According to Henderson, Fox and Rubin (2001), the right frontal lobe is involved with gross motor movement, autonomic reactivity, and the expression of negative affect, all of which are aspects of social withdrawal behavior. Increased right frontal lobe activity has been found to correlate with negative affect and withdrawal behavior, while increased left frontal lobe activity is known to correlate with positive emotional states as well as approach behavior (Harmon-Jones, Gable & Peterson, 2009). For example, studies have shown that infants who exhibit withdrawal behaviors also have patterns of right frontal EEG asymmetry (Fox et. al., 1991). This pattern of EEG asymmetry and withdrawal behavior has been linked to anxious child temperament and behavioral inhibition. In an experiment conducted by Henderson and colleagues (2001), right EEG asymmetry and negative affect were found to predict social wariness in children, strengthening the link between EEG asymmetry and the development of anxious and withdrawal behaviors.

Many researchers have used the emotional Stroop task to study attentional biases. However, there are several drawbacks to using this method. The emotional Stroop task cannot reveal the subcomponents of attention such as engagement and disengagement. Additionally, the Stroop task relies heavily on reading ability which makes it poorly suited for assessing young children whose reading level may delay their response times. Researchers have also used the dot probe task to examine the relationship between EEG asymmetry and study selective attention. One version of the dot probe that is used to study attentional biases to threat uses faces as cues. In this task two stimuli, a neutral face and an angry face, are presented on a screen. After the stimuli disappear, a dot is presented in one of the locations of the original stimuli and participants have to indicate with a button where the dot appeared. One study that is currently under review (Pérez-Edgar et. al.) measured EEG asymmetry at baseline and during a speech preparation task designed to induce stress and compared these findings to performance on a dot-probe task using positive and negative facial cues. Findings from this study did not find a correlation between baseline EEG asymmetry and attentional bias to negative facial cues on a dot-probe task. However, increases in right frontal EEG asymmetry from baseline during the stressful speech preparation condition correlated with attentional biases to negative facial cues. The authors suggest that these findings imply that changes in right EEG asymmetry reflect the individual's response to threat which is evident in the assessment of attention bias.

Neither the emotional Stroop task nor the dot-probe task untangle how attention is being disengaged and shifted. Specifically, the emotional Stroop task and dot-probe cannot measure how attention is engaged, disengaged and reengaged during a task. Michael Posner designed the Posner task to measure attention orienting which includes disengagement and attention shifting (Posner & Boies, 1971). Researchers have made changes to the original Posner task in order to examine how emotion interferes with attention shifting. The affective Posner task is variation of the original Posner and can provide us with more answers as to how quickly attention is being shifted and when attention shifting is disrupted.

In this task a cue is presented in one of three adjacent boxes. Next, the target is presented in either the same box (valid) or different box (invalid). In one version of this task participants are then given positive and negative feedback, eliciting an emotional response. In another version emotion is conveyed by using affective faces as the initial cueing stimulus. During invalid trials, participants must shift their attention from the location of the invalid cue to the location of the target. One would expect people who have difficulty shifting attention during invalid trials to have longer reaction times than those who do not have difficulty shifting their attention. When a neutral cueing condition is added to this task in the form of cue in the center of the screen, the cost of invalid cueing (the difference in reaction times between invalid and neutral trials) has been shown to account for the difference in reaction times between valid and invalid trials (known as the validity effect) (Nobre, Sebestyen, & Miniussi, 2000). In an affective Posner task that gave positive or negative feedback after each trial, the validity effect increased when temperamentally shy children were presented with negative feedback (Pérez-Edgar & Fox, 2005). The presence of the validity effect and the greater cost of cue-type for invalid trials in the presence of negative stimuli indicate that negative conditions interfere with the regulation of attention in children with shy temperaments.

There are several variations of the affective Posner task that have been used to study attentional biases. One such method is to create stress by giving negative feedback regarding the individual's performance on the task. Pérez-Edgar and Fox (2005) used this method in their study of behaviorally inhibited children and found that the validity effect increased when children were given negative feedback. Another variation of the affective Posner task involves using emotional facial cues, much like the dot-probe task. Angry faces are thought to be perceived as more threatening than happy or neutral faces (Bar-Hiam, Morag & Glickman, 2011). Therefore, one would expect individuals with attentional biases to threat to have slower responses to angry faces during the invalid trials. In a study conducted by Miskovic and Schmidt (2010), frontal EEG asymmetry was measured at baseline and compared to performance on a modified version of the Posner task using happy and angry faces as cues. Participants with baseline right EEG asymmetry had slower reaction times in response to angry facial cues but not happy facial cues. This finding indicates that participants with right EEG asymmetry show an attentional bias to negative stimuli which interferes with their ability to control their selective attention during the Posner task.

Study 1

The first of the two current studies investigates the moderating effect of right frontal EEG asymmetry and behavioral inhibition on performance during a modified affective Posner task. The aim of this study is to investigate the relationships between temperament, brain activity and attention regulation. Children were given positive feedback for one half of the trials and negative feedback after the other half of the trials. Behavioral inhibition (BI) scores and EEG asymmetry at baseline were also measured. As background for our study, we examined the relation between

EEG asymmetry and both categorical and continuous BI scores in order to confirm previous research linking right EEG asymmetry to withdrawal behaviors.

Our first aim was to determine the magnitude of the validity effect for negative trials versus positive trials. Our second aim was to determine if the cost-benefit relationship of cue-type differs between positive and negative trials. We are interested in the size of the validity effect and effect of cue-type because these measures may indicate why children with withdrawal behaviors are having trouble shifting attention in their broader environment (Eisenberg et. al., 1998). Third, we looked to see if continuous EEG score correlates with the validity effect across positive and negative trials. Our fourth aim was to see if EEG score correlates with cue type across positive and negative trials. Lastly, we aimed to see whether there is a greater validity effect for children with BI in both positive and negative trials than children without BI, and if BI score correlates with cue type across positive and negative trials.

Based on the background literature, we expect to find a negative correlation between EEG asymmetry and BI scores because right EEG asymmetry is indicated by a negative asymmetry score. In regards to our main research questions, first we expect there will be a larger validity effect for negative trials than positive trials. In the negative trials, we expect to see a larger cost of invalid cueing and in the positive trials we expect to see a greater benefit of valid cueing. Second we predict that children with right frontal EEG asymmetry will show a larger validity effect in negative trials than children with left frontal EEG asymmetry. The EEG groups will differ in positive trials as well, with the right frontal EEG asymmetry group performing worse. However we do not expect these differences to be as large as the differences in negative trials. We predict EEG asymmetry to correlate negatively with the validity effect in both positive and negative trials. We also expect the cost of cue type to correlate negatively with right EEG across positive and negative trials. Finally, we expect that children with BI will show a greater validity effect in negative trials than non-BI children. The BI groups will also differ in positive trials as well, but the difference will not be as large. We expect to find a positive correlation between BI score and validity effect across positive and negative trials. We also expect to find the cost-benefit relation to differ more for BI vs. non BI children in negative trials than in positive trials because we expect that these children will have more trouble shifting attention in invalid trials.

Study 2

The second current study also investigates the moderating effect of right frontal EEG asymmetry and behavioral inhibition on performance on a modified affective Posner task with the same goal to investigate the relationships between temperament, brain activity and attention regulation. However, in this study all of children are classified as behaviorally inhibited. This allows us to focus on the behaviors and brain patterns of a population at risk. This is an ongoing study and the sample size is currently small. Thus these analyses are exploratory in nature. In this study, children were shown angry face cues and neutral face cues during the trials and did not receive positive and negative feedback on their performance. Angry faces were shown because they can be perceived as threatening and thus affect the reaction times of children who have an attentional bias to threat (Bar-Hiam, Morag & Glickman, 2011). As in study 1, behavioral inhibition (BI) scores and EEG asymmetry at baseline were also measured. In this study we also examined the relation between EEG asymmetry and continuous BI scores in order to confirm previous research relating right EEG asymmetry to withdrawal behaviors. Our first aim was to determine if the magnitude of the validity effect differs for angry trials versus neutral trials. We wanted to determine how the presence of threat affects reaction times across valid and invalid trials. A larger validity effect for angry trials may help to indicate why children with withdrawal behaviors are having trouble shifting attention. Second, we examined the relation between EEG score and the validity effect across angry and neutral trials. We also examined how EEG score correlates with the effect of threat across valid and invalid trials. The effect of threat (angry trial reaction times minus neutral trial reaction times) will give a number greater than zero in both invalid and valid trials.

Based on the literature, we expect to find a negative correlation between right frontal EEG asymmetry and BI score. Regarding our main research questions, first we expect there will be a larger validity effect for angry trials than neutral trials. Second, we predict that children with right frontal EEG asymmetry will show a larger validity effect in angry trials than children with left frontal EEG asymmetry. We predict frontal EEG asymmetry to correlate negatively with the validity affect in both angry and neutral trials. We also expect the effect of threat size to correlate negatively with frontal EEG asymmetry across valid and invalid trials. Finally, we expect to find a positive correlation between BI score and validity effect across angry and neutral conditions. We also expect to find a correlation between the effect of threat size and BI because we expect that severely BI children will have more trouble with shifting attention in invalid trials.

Chapter 2

Methods Study 1

Participants

The participants in this study were 54 children (27 male and 27 female) between the ages of 4 to 7 (M_{AGE}=5.53, SD=0.668). Children were selected based on their parents' ratings on the Colorado Child Temperament Inventory (CCTI; Buss & Plomin, 1984; Rowe & Plomin, 1977) and the Behavioral Inhibition Questionnaire (BIQ; Bishop et. al., 2003). Both questionnaires are 30-item surveys that ask the parent to rate their child's behavior on a Likert scale. Data collected from these questionnaires focused primarily on shyness, attentional control and behavior in risk and novel situations. The sample chosen from this data had a large range of scores in order to ensure that the sample contained children with different types of temperament. (CCTI: $M_{Shyness}$=2.39, SD=1.22, Range=1.00 to 4.80; BIQ: M_{Total}=92.4, SD=41.4, Range=37 to 171). Based on previous work examining BI distribution, children with a total BI score greater than 118 were designated as high BI for categorical analyses. Correlational analyses retained the continuous BI score. Of the 54 children, there was one missing BI score. Of the remaining 53 children, 15 were designated BI and 38 were designated non-BI.

Affective Posner Task

Participants sat 40 cm in front of a 16-in computer monitor and were shown a series of cues and targets on the screen. The cue, which was a small blue box, appeared first on the screen. This cue was presented for 200 ms inside of a larger white box located either on the left or on the right side of the screen. After the cue disappeared from the screen, the target, which was a smaller white box, appeared in one of the two positions on the screen for 200 ms. If the target appeared in the same position as the cue, this was considered a valid trial. If the target appeared in a different position from the cue, this was considered an invalid trial. Trials in which the cue was presented in the central box were considered control trials. The participants were instructed to press a button on a small response box that corresponded with the position of the target box on the screen. A total of 100 trials were conducted. During the first 50 trials, participants received positive feedback after every 10 responses. During the second set of trials, the participants received negative feedback after every 10 responses. Out of the total number of trials, 40% were valid, 40% were invalid and 20% were control. Upon completion of the task, the participants were told that the computer had malfunctioned and the negative feedback was a mistake. The entire task required approximately total of 12 minutes to complete.

Calculation of Validity Effect for Posner Task

The validity effect is seen when reaction times are slower for invalid trials. Validity was calculated by subtracting the reaction times for valid trials from the reaction times for invalid trials. A large validity effect indicates that children are having greater difficulty shifting their attention during the invalid trials.

Calculation of Cost- Benefit for Posner Task

Cost refers to the longer in reaction times that are observed in invalid trials when compared to neutral trials. Higher costs and slower reaction times for invalid trials indicate that there is difficulty in switching attention from one cue to another. Cost was calculated by subtracting the reaction times of the invalid trials from the reaction times of the neutral trials. Benefit refers to the faster reaction times that are observed in valid trials when compared to neutral trials. Benefit was calculated by subtracting the reaction times of the valid trials from the reaction times of the neutral trials. Children with accuracy rates less than 66% (N=8) were excluded from the analyses. Thus analyses involving the Posner task had an actual N of 46.

Electroencephalogram (EEG) Recording

EEG recordings were taken with the Lycra NeuroScan Quick-cap system (NeuroScan, Texas, USA) using 64 EEG and EOG channels that were referenced to an electrode 2 cm posterior to Cz. Electrodes placed below the left eye were used to capture vertical eye movements (VEOG), and electrodes placed on the external canthi of each eye were used to capture horizontal eye movements (HEOG). All electrode impedances were kept below 10 K ohms. The EEG data was digitized at a 500 Hz sampling rate (High pass 0.10 Hz; Low pass 40 Hz) and any unreliable signals were discarded. The data was then re-referenced to produce an average reference configuration. Some EEG data contaminated with eye movement and motor artifact were removed from all channels using predetermined parameters (e.g., signal ±100 μV). This data was then submitted to a discrete Fourier transform using a 1-s Hanning window with 50% overlap between consecutive windows.

EEG Asymmetry Calculation

Baseline EEG recordings were taken across the entire scalp while the participants' eyes remained open for two minutes and also while the participant's eyes were closed for two minutes. Data from the F3 (left frontal lobe) and F4 (right frontal lobe) electrodes were used in analysis. Asymmetry scores were calculated by subtracting the natural log of the alpha power of F3 from the natural log of the alpha power of F4. Research has shown that alpha asymmetry has an inverse relationship to brain activity (Davidson, 2004). Therefore, positive asymmetry scores signify greater right-sided alpha power and thus higher activity in the left frontal region. Comparatively, a negative asymmetry score signifies greater left-sided alpha power and higher right frontal activity. Analyses were completed twice. First, EEG asymmetry score was included as a continuous variable. Second, groups were created based on pattern of right ($N=17$; Score < 0) or left ($N=20$; Score ≥ 0) EEG asymmetry. The dual analyses allowed us to see if the relations observed reflected a linear pattern or qualitative group differences.

Of the original 54 children, 17 did not provide viable EEG data due to either refusal or poor signal quality. The remaining 37 children did not differ from the excluded children on the core study measures (*p*'s > .05). See Table 1 for demographic and background information on the children included in the current study. For analyses involving both EEG asymmetry and the Posner task, the total N=34.

Chapter 3

Methods Study 2

Participants

Participants in this ongoing study were 18 children (4 male and 14 female) between the ages of 9 to 12 (M_{AGE}=10.39, SD=1.04). Children were selected based on parental responses to the Behavioral Inhibition Questionnaire (BIQ; Bishop et. al., 2003). The BIQ is a 30-item survey that asks parents to rate their child's behavior on a 1-7 Likert scale. Data collected from this questionnaire focused primarily on shyness, attentional control and behavior in risk and novel situations. Scores can range from 30 to 210. The sample was chosen from a larger group of children (N=160, M_{total}=88.60, SD=31.68, Range 30 to 182). The sample was chosen to be in the top 20% of the BI distribution based on previous work (White, 2013). Thus, children with a total BI score greater than 118 were designated as high BI (BIQ: M_{Total}=133.76, SD=16.61, Range=103 to 163). Correlational analyses retained the continuous BI score.

Electroencephalogram (EEG) Recording

EEG recordings were taken with a 128-channel EGI Electrode Net. Electrodes placed below the left eye were used to capture vertical eye movements (VEOG), and electrodes placed on the external canthi of each eye were used to capture horizontal eye movements (HEOG). All electrode impedances were kept below 50 K ohms. The EEG data was digitized at a 250 Hz sampling rate (High pass 0.10 Hz; Low pass 40 Hz) and any unreliable signals were discarded. The data were then re-referenced to produce an average reference configuration. EEG data contaminated with eye movement and motor artifact were removed from all channels using predetermined parameters (e.g., signal ±100 μV). The data were then submitted to a Fast Fourier Transform using a 1-s Hanning window with 50% overlap between consecutive windows.

EEG Asymmetry Calculation

Baseline EEG recordings were taken across the entire scalp while the participants' eyes remained open for two minutes and also while the participant's eyes were closed for two minutes. Because EGI does not use the standard 10/20 nomenclature system, we calculated the equivalent of the F3 (left frontal lobe) and F4 (right frontal lobe) electrodes based on scalp location. For F3 we averaged over the following electrodes: 19, 20, 24, 23, 27, 28. For F4 we averaged over electrodes 3, 4, 117, 118, 123, 124. Asymmetry scores were calculated by subtracting the natural log of the alpha power of F3 from the natural log of the alpha power of F4. Analyses were completed twice. First, EEG asymmetry score was included as a continuous variable. Second, groups were created based on pattern of right (N=13; Score < 0) or left (N=6; Score ≥ 0) EEG asymmetry. The dual analyses allowed us to see if the relations observed reflected a linear pattern in EEG asymmetry or qualitative group differences.

Affective Posner Task

Participants sat 40 cm in front of a 16-in computer monitor and were shown a series of cues and targets on the screen. The cue, which was an angry or neutral face, appeared first on the screen. The faces were taken from the NimStim Face Stimulus Set (Tottenham et. al., 2009) with 5 female faces and 5 male faces used in both angry and neutral categories. The facial cue was presented for 500 ms inside of a larger white box located either on the left or on the right side of the screen. After the cue disappeared from the screen, the target, which was a smaller white box, appeared in one of the two positions on the screen for 1000 ms. If the target appeared in the same position as the face cue, this was considered a valid trial. If the target appeared in a different position from the face cue, this was considered an invalid trial. The participants were instructed to press a button on a small response box that corresponded with the position of the target box on the screen. Trials were divided into 5 blocks of 40 trials for a total of 200 trials. Out of the total number of trials, 33 were angry-valid, 66 were angry-invalid, 33 were neutral-valid, and 66 were neutral-invalid. The entire task required 7 minutes to complete.

Calculation of Validity Effect for Posner Task

The validity was calculated by subtracting the reaction times for valid trials from the reaction times for invalid trials. A large validity effect indicates that children are having greater difficulty shifting their attention during the invalid trials. Validity scores were calculated separately for both angry and neutral faces.

Calculation of Effect of Threat

In order to determine if the reaction times were slower in the angry trials relative to neutral trials, the effect of threat score was calculated by subtracting the reaction times of the neutral trials from the reaction times of the angry trials. This was calculated separately for both valid and invalid trials.

Chapter 4

Results Study 1

EEG Asymmetry and Behavioral Inhibition

Consistent with our expectations based on the background literature, there was a negative correlation between BI and EEG asymmetry with eyes open, $r(36) = -0.206$, $p=0.228$. Although this correlation was in the expected direction, it was not significant. BIQ score means were compared between both left asymmetry and right asymmetry groups with eyes opened $t(27) = 0.135$, $p=0.89$. Although in the expected direction, the mean BIQ score of the two EEG asymmetry groups were not found to be significantly different (see Table 1).

Validity Effect

To test our first hypothesis predicting a larger validity effect in negative trials than positive trials, we ran a paired samples t-test. We expected to find a larger validity effect in negative trials because we expected that the cost for invalid trials would be greater in the negative block. The mean for positive trials was M=23.70 and the mean for negative trials was M=26.79, $t(45)= -0.34$, $p=0.73$. Although this finding was not significant, it was in the predicted direction, with the mean validity effect for negative trials greater than the mean validity effect for positive trials.

Cost-Benefit in Positive vs. Negative Feedback Trials

We then looked to see if there were differences in the cost and benefits of cueing. We also looked to see if cueing differed across positive and negative feedback using a repeated-measures ANOVA with a 2 (cost vs. benefit) X 2 (positive vs. negative feedback) design. As predicted, we found main effect of cue-type $F(1,45) = 18.97$, $p < .001$. The mean effect of invalid cueing (cost) was significantly greater than the advantage derived from a valid cue (benefit), M=-20.8ms, SE=6.16 versus M=4.40, SE=5.62. In negative trials the average cost (-23.01 ms) was greater than that of the average cost (-18.67 ms) in positive trials. Additionally, the benefit for positive trials (5.03 ms), was greater than the benefit for negative trials (3.78). Although these differences are small, they are consistent with our predicted direction. The interaction between cue-type (cost vs. benefit) and feedback was not significant F(1,45) = 0.118, p=0.78. These results indicate that the cost is much greater for invalid trials than the benefit is for valid trials, regardless of the feedback.

Table 1. Means (SD) of demographic, BIQ scores, EEG asymmetry and validity effect for study participants. Sex is presented as male/female. Data are presented for the full sample in the first column, followed by EEG asymmetry (right and left) scores in the next two columns. The last column contains the correlation between overall EEG asymmetry scores and the row variables.

	All Subjects	Right Frontal EEG Asymmetry	Left Frontal EEG Asymmetry	Overall EEG Asymmetry Score
Age	*M*=5.61, *SD*=0.63	*M*=5.53 *SD*=0.52	*M*=5.79 *SD*=0.70	0.079
Gender	24/21	6/9	8/6	-0.232
BIQ Score	*M*=90.71, *SD*=41.76	*M*=81.67 *SD*=40.96	*M*=79.57 *SD*=42.38	-0.137
Validity Effect for Positive Feedback	*M*=23.70 *SD*=51.07	*M*=8.87 *SD*=46.24	*M*=36.28 *SD*=63.43	0.292
Validity Effect for Negative Feedback	*M*=26.79 *SD*=48.65	*M*=42.53 *SD*=49.24	*M*=-6.10 *SD*=46.90	-0.013
N	41	15	14	29

Validity Effect for EEG Asymmetry Groups in Positive vs. Negative Trials

To test our second hypothesis predicting a larger validity effect for children with right EEG asymmetry in negative and positive feedback trials, we ran a 2 (right vs. left EEG asymmetry) X 2 (positive vs. negative feedback) ANOVA. There was no main effect found for feedback or asymmetry, but there was a significant interaction between feedback and asymmetry $F(1,27) = 14.31$, $p = .001$. The mean validity score for right EEG asymmetry groups in positive feedback trials was M=8.88 (S =14.25) while the mean validity score for right EEG asymmetry groups in negative feedback trials was M=42.54 (SD=12.43). The opposite effect was observed for left EEG asymmetry groups. The mean validity score for left EEG asymmetry groups in positive feedback trials was M=36.28 (S =14.75) while the mean validity score for left EEG asymmetry groups in negative feedback trials was M=-6.10 (SD=12.86). There is a negative validity effect for left EEG asymmetry groups for negative trials which means that reaction times improved significantly when these children were given negative feedback. In contrast, when right EEG asymmetry groups were given negative feedback, their reaction times slowed significantly. These findings are consistent with our hypothesis that the validity effect would be greater for right EEG asymmetry groups in negative feedback trials than for left EEG asymmetry groups.

Cost-Benefit for EEG Asymmetry Groups in Positive vs. Negative Trials

In order to see if there were differences in the costs and benefits of cueing for right EEG asymmetry versus left EEG asymmetry groups in positive and negative feedback trials, we ran a 2 (cost vs. benefit) X 2 (positive vs. negative feedback) X 2 (right vs. left EEG asymmetry) ANOVA. As expected, we found a main effect of cue-type $F(1,27) = 6.18$, $p < .01$. There were no main effects for EEG asymmetry or feedback. We did find a 3-way interaction between feedback, cue-type and EEG asymmetry $F(1,27) = 14.31$, $p<.001$.

To further examine this complex interaction, we ran separate ANOVAs for positive and negative feedback trials. As expected, a main effect for cue-type was found in positive feedback trials $F(1,27) = 4.85$, $p<.05$, but there was no significant effect for EEG asymmetry. In negative feedback trials a main effect was found for both cue type and EEG asymmetry. The mean cost for right EEG asymmetry groups was M=-32.88, SD=13.20, while the mean benefit was M=9.66, SD=13.70. These findings indicate that there is a huge cost for right EEG asymmetry groups in negative feedback trials with only small benefit. The mean cost for left EEG asymmetry groups was M=-2.27, SD=13.66, while the mean benefit was M=-8.37, SD=14.18. These findings are consistent with the validity effect results and indicate that left EEG asymmetry groups improved in negative feedback trials.

Validity Effect for BI vs. non-BI in Positive vs. Negative Trials

To test our third hypothesis that children with BI will have a greater validity effect in negative trials than children without BI, we ran an ANOVA with a 2 (BI vs. nonBI) X 2 (positive vs. negative feedback) design. We did not find a main effect for validity for children with BI in positive or negative trials $F(1,45)=0.40$, $p=0.529$.

Cost-Benefit for BI vs. non-BI in Positive vs. Negative Trials

We then looked to see if there were differences in the costs and benefits of cue-type for BI versus non-BI children in positive and negative feedback trials. We ran an ANOVA with a 2 (cost vs. benefit) X 2 (positive vs. negative feedback) X 2 (Bi vs. non-BI) design. Again, we found a main effect for cue type $F(1,45)=15.99$, $p<.001$, but we did not find a main effect for positive versus negative feedback $F(1,45)=0.095$, $p=0.76$.

Correlation for BI and Posner Task

Finally, we looked to see if categorical BI groups correlated with cue-type on the Posner task across both positive and negative trials. We did not find a significant correlation between BI score and cue-type in positive or negative trials.

Chapter 5

Results Study 2

EEG Asymmetry and Behavioral Inhibition

Consistent with our expectations based on the background literature, there was a negative correlation between BI and EEG asymmetry, $r(19) = -0.111$, $p=0.661$. Although this correlation was in the expected direction, it was not significant likely due to the small sample size. BIQ score mean was not found to differ significantly between left asymmetry (M= 136.20) and right asymmetry (M=135.08) groups. One of the most interesting findings was the distribution of left and right EEG asymmetry groups. Out of 19 participants, 13 children displayed right EEG asymmetry and only 6 children displayed left EEG asymmetry.

Validity Effect in Angry Versus Neutral Trials

To test our first hypothesis predicting a larger validity effect in angry trials than neutral trials, we ran a paired samples t-test. The mean for neutral trials was M=4.194 and the mean for angry trials was M=9.347, $t(19)= -0.583$, $p=0.567$. Although this finding was not significant, it was in the predicted direction, with the mean validity effect for angry trials greater than the mean validity effect for neutral trials.

Validity Effect and EEG Asymmetry in Angry and Neutral Trials

To test our second hypothesis that children with right frontal EEG asymmetry will show a larger validity effect in angry trials than children with left frontal EEG asymmetry, we ran a 2 (angry vs. neutral) X 2 (right vs. left EEG asymmetry) ANOVA. We did not find any significant main effects for face emotion $F(1,18)=0.048$, $p=0.829$ or asymmetry $F(1,18)=0.001$, $p =0.971$. We also did not find a significant interaction between face emotion and asymmetry $F(1,18)=0.00$, p=0.992. Contrary to our expectations, we found no significant correlation between the validity effect in neutral trials and EEG asymmetry, r(19) = 0.064, p=0.794, nor did we find a significant correlation between the validity effect in angry trials and EEG asymmetry r(19) = 0.194, p=0.426. We also ran a paired sample t-test, to compare the validity effect in angry and neutral trials across EEG asymmetry groups. In left EEG asymmetry groups the mean validity effect for neutral trials was M=-8.74 and the mean validity effect for angry trials was M=9.39, t(19)= -.831, p=0.453. In right EEG asymmetry groups the mean for neutral trials was M=8.45 and the mean for angry trials was M=10.94, t(19)= -0.247 , p=0.809. Although these results are not significant, they are in the expected directions. The mean validity effect was larger for right EEG asymmetry groups across both angry and neutral trials. Within the right EEG asymmetry group, the mean validity effect was larger for angry trials.

Effect of Threat and EEG Asymmetry in Valid vs. Invalid Trials

In order to test our third hypothesis that the effect of threat would be greater in right EEG asymmetry groups across both valid and invalid trials, we ran a 2 (angry and neutral valid vs. angry and neutral invalid trial) X 2 (left vs. right EEG asymmetry) ANOVA. We did not find any significant effects for face emotion, F(1,18)=0.048, p=0.82, or for EEG asymmetry, F(1,18)=0.652, p=0.430. We also did not find a significant interaction between face emotion and asymmetry, F(1,18)= 0.00, p=0.992. Contrary to expectations, we did not find a correlation between the threat effect and EEG asymmetry in valid trials, r(19)=-0.064, p=0.794, or invalid trials, r(19)=0.065, p=0.790. We also ran a paired sample t-test to compare the effect of threat in valid and invalid trials across left and right EEG asymmetry groups. In left EEG asymmetry groups the mean effect of threat for valid trials was M=-11.23 and the mean effect of threat for invalid trials was M=6.90, t(19)=-0.831, p=0.453. In right EEG asymmetry groups the mean effect of threat for valid trials was M=5.63 and the mean effect of threat for invalid trials was M=8.12, t(19)=-0.247, p=0.809. Although these results are not significant, they are in the expected directions. The threat effect is greater in invalid trials and in right EEG asymmetry groups.

Validity Effect and Behavioral Inhibition

Inconsistent with our expectations, we found a negative correlation between the validity effect and total BIQ score in both angry, r(19)=-0.133, p=0.589, and neutral, r(19)=-0.104, p=0.671, trials. However, this correlation was very small and not significant.

Effect of Threat and Behavioral Inhibition

Inconsistent with our expectations, we found a negative correlation between the effect of threat and total BIQ score in both congruent r(19)=-0.199, p=0.415 and incongruent r(19)=-0.291, p=0.226 trials. However, this correlation was very small and not significant.

Table 2. Means (SD) of demographic, BIQ scores, EEG asymmetry and validity effect for study participants. Sex is presented as male/female. Data are presented for the full sample in the first column, followed by EEG asymmetry (right and left) scores in the next two columns. The last column contains the correlation between overall EEG asymmetry scores and the row variables.

	All Subjects	Right Frontal EEG Asymmetry	Left Frontal EEG Asymmetry	Overall EEG Asymmetry Score
Age	*M*=9.89 *SD*=2.59	*M*=10.36 *SD*=1.00	*M*=8.43 *SD*=4.48	-0.581
Gender	6/15	5/9	1/5	0.222
BIQ Score	*M*=135.75 *SD*=16.98	*M*=135.08 *SD*=20.24	*M*=138.67 *SD*=9.22	-0.010
Validity Effect for Angry Trials	*M*=9.94 *SD*=31.16	*M*=10.94 *SD*=27.56	*M*=11.43 *SD*=42.37	0.209
Validity Effect for Neutral Trials	*M*=8.69 *SD*=43.50	*M*=8.45 *SD*=41.62	*M*=9.17 *SD*=55.36	0.252
Effect of Threat for Valid Trials	*M*=3.70 *SD*=33.25	5.62 *SD*=36.07	*M*=-2.32 *SD*=31.14	0.058
Effect of Threat for Invalid Trials	*M*=4.93 *SD*=24.05	*M*=8.12 *SD*=20.48	*M*=-0.48 *SD*=33.50	-0.110
N	20	14	6	20

Chapter 6

Discussion and Conclusions

The current studies examined the moderating effects of EEG asymmetry and behavioral inhibition on performance on two versions of the affective Posner task. Overall, right EEG asymmetry was associated with worse performance on the Posner task in invalid trials. Specifically, the validity effect (invalid – valid trials) was greater for children in the right EEG asymmetry groups in negative feedback trials in Study 1 and angry trials for Study 2. Although these findings were not significant in Study 2, they were still in the expected directions. These results are consistent with prior research that has found children with right EEG asymmetry perform worse under conditions with high levels of negative affect (Miskovic & Schmidt, 2010).

In the first study, the results revealed a main effect of cue-type. Specifically, the cost of invalid cueing was greater than the benefit of valid cueing, regardless of feedback type. This effect was also found to differ between positive and negative trials. The cost of invalid cueing was greater in negative trials and the benefit of valid cueing was greater in positive trials. However, the magnitude of the benefit of valid cueing was still not as large as the magnitude of the cost of invalid cueing. These findings were particularly evident in children with right EEG asymmetry. There was a large cost of invalid cueing for right EEG groups in negative feedback trials while there was a negative cost for left EEG asymmetry groups. A negative cost for the left EEG asymmetry groups implies that these children responded even faster to invalid cues under negative conditions. Taken together these findings indicate that children with right EEG asymmetry take much longer to shift their attention from the invalid cue to the target, especially during negative feedback trials. The stress of poor performance evaluation, combined with invalid cueing, most likely is leading children with right EEG asymmetry to perform much worse than their left EEG asymmetry counterparts because children with right EEG asymmetry appear to be less capable of dealing with stress. Indeed, the findings with the left EEG asymmetry group suggest that these children are enhancing their performance in the face of the task—it is being treated as a challenge, rather than a potential threat.

When behavioral inhibition was considered, there was a main effect of cue-type. Once again, the cost of invalid trials was greater than the benefit of valid trials. There was no correlation between cue-type and behavioral inhibition. Additionally, there was a negative correlation between EEG asymmetry and behavioral inhibition as expected, but it was not significant. One explanation for these findings is that the number of children with behavioral inhibition in the first study was too small to produce significant findings.

The second study was conducted as an exploratory analysis and although none of the findings were significant, many of them were in the expected directions. The mean validity effect for angry trials was greater than the mean validity effect for neutral trials. This effect was seen in both right and left EEG asymmetry groups with right EEG asymmetry groups performing worse than left EEG asymmetry groups in angry trials. Although these findings are not significant, they are consistent with the expectation that children with right EEG asymmetry have more difficulty shifting attention away from negative stimuli. Additionally, the effect of threat for invalid trials was greater in children with right EEG asymmetry, but the effect of threat for valid trials was smaller for right EEG asymmetry. This finding implies that children with right EEG asymmetry attend to negative stimuli more and are thus quicker to respond to valid angry cues and slower to respond to invalid angry cues.

Perhaps the most interesting finding from Study 2 was that out of a sample of only 19 children, 13, or approximately 68 percent, had right EEG asymmetry. This distribution varies greatly from the distribution of right and left EEG asymmetry in the total population, where one typically finds greater levels of left asymmetry or no asymmetry in EEG activity (Harmon-Jones, Gable & Peterson, 2009). Our sample was unique in that it consisted of children who were all classified as having behavioral inhibition. Thus, the range of scores used in this analysis may have been restricted, further decreasing the likelihood of detecting a significant finding. Again, there was a negative (but not significant) correlation between EEG asymmetry and behavioral inhibition. Taken together these findings confirm what prior research has suggested: that behavioral inhibition and right EEG asymmetry are linked. As this study grows and more participants are recruited, it is very possible that this relationship will reach significance.

Limitations

The largest limitation for both of these studies was the sample size. A small sample size made it more difficult to reach significance for many of our findings. Future research should attempt to replicate study 1 with a larger sample. As was previously stated, study 2 was only a preliminary analysis of what will become a much larger study. It is our hope that as more participants are recruited the link between behavioral inhibition, EEG asymmetry and Posner performance will become stronger.

Another possible limitation of this study is that EEG asymmetry was measured at baseline only. Other studies have only found an association between right EEG asymmetry and attentional biases to threat when EEG asymmetry is measured during stressful conditions and not at baseline. For example, Pérez-Edgar and colleagues found that an increase in right EEG asymmetry between baseline and a stressful speech condition was associated with an attentional bias for angry faces (Pérez-Edgar et. al., in review). These findings give support to the capability model of EEG asymmetry that posits that EEG asymmetry reflects an individual’s ability to adapt and marshal psychophysiological resources in order to respond to the situation at hand (Coan, Allen, & McKnight, 2006 as cited in Pérez-Edgar et. al., in review). Our study measured EEG asymmetry at baseline in an attempt to investigate the dispositional model of EEG asymmetry. This model suggests that EEG asymmetry represents an individual’s tendency toward withdrawal or approach behaviors at a trait level, across contexts (Coan & Allen, 2004b as cited in Pérez-

Edgar et. al., in review). Had both of our studies measured patterns in EEG asymmetry in the face of stress, it is possible that we could have more directly assessed individual differences in response to threat, as reflected in patterns of EEG asymmetry. This may have strengthened the association between right EEG asymmetry and attentional biases to threat.

Future Research

Based on the findings from these studies, it is likely that right EEG asymmetry plays a role in attentional biases to threat. This has significant implications for attention bias modification (ABM) research. Proponents of ABM suggest that this technique can be used to treat anxiety by modifying attentional biases to threat (Bar-Haim, Morag & Glickman, 2011). If ABM is effective in facilitating disengagement from threatening stimuli, we should expect children who have had this treatment to have faster reaction times on the Posner task, particularly for invalid trials and in negative affective conditions, relative to their performance before ABM. However, we do not understand the relation between underlying brain activity and ABM. In order to investigate this relation, researchers should measure EEG asymmetry before and after treatment. If ABM training changes brain activity, children with right EEG asymmetry before treatment may be expected to display EEG asymmetry shifts toward left asymmetry after treatment. If, on the other hand, EEG asymmetry acts as a marker reflecting susceptibility to ABM interventions, we may expect that the magnitude of the ABM effect may differ as a function of EEG asymmetry patterns. These two alternatives are open empirical questions that need to be addressed.

Summary

These studies suggest that right EEG asymmetry, and possibly behavioral inhibition, is involved in attentional biases to threatening stimuli. The data show that children with right EEG asymmetry are slower to respond to invalid cueing under negatively affective conditions. This implies that children with these particular brain activity patterns have difficulty disengaging from negative or irrelevant stimuli and focusing on more relevant stimuli. The current findings suggest underlying pattern of brain activity at rest may serve as a marker for broad patterns of behavior that may shape socioemotional profiles in childhood.

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Education

B.S., Psychology 2013, Schreyer Honors College, The Pennsylvania State University, State College, PA

Honors and Awards

- **President's Freshman Award** (Spring 2010)
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- **Phi Kappa Phi Honor Society** (Spring 2012 – present)
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Research Experience

Cognition, Affect and Temperament Lab (Spring 2012-Spring 2013)

- Coded videos for behavior, analyzed fMRI quality, entered and verified data
- Thesis: studied link between brain EEG activity, behavioral inhibition and attentional-biases to threat in children

Anxiety and Depression Clinical Research (Fall 2011-Spring 2012)

- Trained in diagnostic interviewing, recruited participants for fMRI study of generalized anxiety disorder

Peter Arnett Clinical Laboratory (Summer 2011-Fall 2011)

- Complied questionnaires and developed protocol for pilot study of neuropsychological aspects of multiple sclerosis

Posters and Presentations
The Role of EEG Asymmetry and Behavioral Inhibition in Attention Biases to Threat
Psi Chi Research Conference **(**Spring 2013)

Extra-Curricular Activities

Penn State Cross Country Club (Fall 2009 -Spring 2013)
Vice President (Spring 2012-Fall 2013)

- Organized trips to competitions, fundraisers, and daily practices for 160 member team, attended weekly planning meetings
- Competed in NIRCA Regionals and Nationals
- Raised money for THON through fundraising and sidewalk solicitations

Webmaster/Merchandise Chair (Spring 2011-Fall 2012)

Penn State Dance Marathon (THON)
Dancer (Spring 2013)

- Danced in dance marathon for 46 hours without sleeping or sitting

Rules and Regulations Committee (Spring 2011)

- Attended weekly meetings, provided security during THON weekend

OPPerations Committee (Spring 2010)

- Attended weekly meetings, set up, cleaned up trash, and tore down event

Pre-Med Volunteer, Abington Memorial Hospital (Summer 2012)

- Shadowed physicians in the ER and participated in weekly panel discussions