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Children's Self-Regulation during Reward Delay

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CHILDREN'S SELF-REGULATION DURING REWARD DELAY

A Thesis Presented

by

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ABSTRACT

CHILDREN'S SELF-REGULATION DURING REWARD DELAY

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Individuals who display high levels of reward sensitivity are motivated by and respond to reward related cues, thus exhibiting more approach-motivated behaviors. A majority of the research on physiological indices of reward sensitivity in relation to self-regulatory abilities has focused on adults or adolescents, with relatively little work examining these associations in children. Thus, the current study sought to examine whether a common neural measure of reward sensitivity, left frontal electroencephalogram (EEG) asymmetry, assessed in early childhood was predictive of children's later self-regulation abilities in the context of reward delay. Emerging inhibitory control skills were also examined as a potential moderator of the association between reward sensitivity and self-regulation. The frontal asymmetry measure of reward sensitivity was assessed at Time 1, when children were between the ages of 4 and 7 years old. The Time 2 visit occurred 18-24 months later, at which point children completed a flanker task to assess inhibitory control and a lock-box task to measure two components of self-regulation: behavioral control (i.e., task effort and attentional focus) and emotion regulation (i.e., expressions of anger). Children with average levels of reward sensitivity showed the highest levels of overall effort (collapsed across low, moderate, and high effort scores) and the lowest levels of weak effort. Additionally, inhibitory control moderated the relation between reward sensitivity and effort such that children with low reward sensitivity and strong inhibitory control showed the highest levels of overall and moderate effort as well as the lowest levels of weak effort. There were no significant associations between reward sensitivity, inhibitory control, and attentional focus or anger expression. These results suggest that EEG frontal asymmetry is a useful physiological marker of reward sensitivity when predicting specific types of regulatory abilities in children.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Overview

Self-regulation is broadly conceptualized as maintaining control over one's actions, emotions, and thoughts in order to accomplish specific goals (Nigg, 2017). This ability has been linked to important outcomes such as an individual's physical health, academic success, social life, and illicit behavior (Jacobson, Williford, & Pianta, 2011; Lillard & Peterson, 2015). Examining factors that influence self-regulation in children can guide understanding of how this ability develops and better inform interventions aimed at promoting adaptive self-regulation.

Across infancy and early childhood, caregivers typically aid children through the process of regulation. Between the ages of 3 and 7 years old, children are expected to learn how to initiate and implement self-regulation techniques effectively with decreasing levels of adult support (Diamond, 2002; Montroy, Bowles, Skibbe, McClelland, & Morrison, 2016). During this transition, children often have difficulty employing regulatory abilities consistently, particularly in the face of certain contextual factors, such as rewarding stimuli. However, not all children respond to rewards in the same way due to differences in levels of reward sensitivity. The current study examined the influence of reward sensitivity and emerging inhibitory control skills on children's ability to regulate their behaviors and emotions in the context of reward delay.

Self-Regulation and Reward Delay

Reward delay involves tempting an individual with an immediate reward while simultaneously offering a delayed reward (Casey et al., 2011). Delay of gratification experiments are the most common examples of testing reward delay in children. These experiments are based on Mischel's classic studies (Mischel, 1958; Mischel & Metzner, 1962) in which children were offered small immediate rewards or larger delayed rewards. In Mischel's studies, the rewards were food, but toys or stickers can be used because they are also especially desirable to children. The main variable of interest is the length of time that children wait for the larger reward if they choose to wait at all.

Variations on the original experiments have attempted to influence children's performance in the task and modulate their self-regulation. Some variations ask children to use external distractors such as toys to increase their wait times (Mischel, Ebbesen, & Zeiss, 1972), whereas other variations show that children can implement internal distraction techniques such as controlling thoughts about the reward or themselves (Karniol et al., 2011; White & Carlson, 2016). These variations have shown to extend children's wait times by encouraging them to focus on an item or a thought that is unrelated to the reward. Different versions of the task also manipulate the presence or absence of the immediate and delayed rewards, with wait times typically increasing when immediate rewards are absent and delayed rewards are present (Mischel & Ebbesen, 1970).

A common component of these tests is that the delay is self-imposed, meaning that the children decide how long they will wait. However, other variations have tested whether presenting the delay as externally imposed can influence wait time. In an externally imposed delay, the researcher explains that the child must wait to receive the larger reward, rather than being allowed to choose if they want to wait. Children in a self-imposed delay condition show better self-regulation ability by waiting longer than children in an externally imposed delay when the larger reward is present (Miller & Karniol, 1976). The authors attribute these results to the idea that children are motivated to wait for the reward in the self-imposed delay condition, but they are more focused on tolerating the delay itself in the externally-imposed delay condition.

However, further manipulation of these factors has not been examined in young children. Additional exploration of the influence of these factors will provide insight into how motivation can impact children's self-regulation. Thus, the current study examined a reward delay context in which the reward was present and, from the standpoint of the child, the delay seemed self-imposed. In actuality, the delay was externally-imposed and the reward was also inaccessible, providing a novel reward delay context in which to examine important components of children's self-regulation in service of retrieving rewards.

Self-imposed reward delay paradigms show good test-retest reliability (Beck, Schaefer, Pang, & Carlson, 2011) as well as strong predictive validity for various outcomes. For instance, studies have shown that children who wait longer for a larger reward display higher intelligence, better health outcomes, and fewer sleep problems in later childhood (Bub, Robinson, & Curtis, 2016; Duckworth, Tsukayama, & Kirby, 2013). Eigsti and colleagues (2006) also showed that children who waited for a larger reward as preschoolers showed more efficient performance in an inhibitory control task, as evidenced by faster reaction times and higher accuracy, in late adolescence.

In addition, the wait times in Mischel's original snack delay studies predict differences in behavioral and neural responses to rewarding stimuli 40 years later (Casey et al., 2011). Specifically, individuals who did not wait for the larger reward as children showed enhanced impulsivity in response to rewarding cues (i.e., happy faces in an emotional go/no-go task) and greater activation in the ventral striatum, which has been linked with reward and immediate choice behaviors in adults (Galvan et al., 2005; McClure, Erikson, Laibson, Lowenstein, & Cohen, 2007). These findings suggest that individuals' responses to rewards are relatively stable and can interfere with self-regulation in adulthood. The stability of response to reward was further investigated in the current study, which examined whether children's reward sensitivity could predict their regulatory abilities in a reward delay context.

Reward Sensitivity

When people are strongly influenced and motivated by rewarding stimuli, they are considered high in reward sensitivity (Kim, Yoon, Kim, & Hamann, 2015). This sensitivity is governed by the behavioral activation system, or BAS. The BAS is most active in individuals who are high in approach and display intense responses to positive or novel stimuli (Martin & Fox, 2006). Physiological research has indicated that the BAS is linked with the amygdala which facilitates appetitive responses to reward-related stimuli (Gray, 1987) The BAS is typically associated with happiness and joy, but anger and aggression are also commonly associated with this system when a reward cannot be obtained (Depue & Iacono, 1989).

The counterpart to the BAS is the behavioral inhibition system, or BIS. The BIS and BAS are distinct yet also interconnected systems, and they are active in every person across different contexts. However, the BIS is more active in individuals who are high in avoidance and show withdrawal and strong aversive responses to negative or novel stimuli (Avram, Baltes, Miclea, & Miu, 2010; Coan & Allen, 2003). The BIS has been linked with activation in the amygdala as it responds to biological, fear related impulses and motivates a person to fight, flee, or freeze (Davis & Whalen, 2001). However, the connection between the BIS and regulatory behaviors has been the focus of research for decades. Only recently has attention begun to shift to the BAS in order to get a better understanding of how it also influences regulatory abilities.

Originally, these two systems were mainly examined in animal models. However, the development of self-report measures assisted in the application to humans as well (Amodio, Master, Yee, & Taylor, 2008). One commonly used and well-validated measure is the BIS/BAS Scale (Carver & White, 1994; Eisenberg & Morris, 2003). This questionnaire includes one subscale for the BIS (punishment sensitivity) and three subscales for the BAS (drive, fun seeking, and reward responsiveness). Reward sensitivity has also been examined through self-report on the Sensitivity to Punishment/Sensitivity to Reward Questionnaire (SPSRQ; Torrubia, Avila, Molto, & Caseras, 2001). These two measures are highly correlated (Alloy et al., 2012), suggesting that there is a positive association between the BAS and reward sensitivity.

Additional support for the link between the BAS and reward sensitivity can be found in more objective measures of reward sensitivity, such as frontal alpha asymmetry. Frontal asymmetry is a measure of EEG that refers to differing levels of neural activity between the left and right hemispheres of the brain (Fox, 1994). Frontal asymmetry is calculated by taking the natural log of each hemisphere's power score (which are the inverse of neural activation) and then subtracting scores at left sites from those at right sites (Lopez-Duran, Nusslock, George, & Kovacs, 2012).

Left frontal asymmetry scores correlate with BAS scores, leading researchers to suggest that the asymmetry is a neuronal marker for BAS activity and thus reward sensitivity (Amodio et al., 2008). In addition, the BAS has been linked with a reward-sensitive neural network comprised of the limbic system and the frontal cortex (Depue & Iacono, 1989). Researchers also suggest that left frontal asymmetry reflects asymmetric dopaminergic signals from the striatum (Berridge, España, & Stalnaker, 2003).

Left frontal asymmetry represents greater levels of approach behavior, whereas right frontal asymmetry has been linked with avoidance and withdrawal behavior in adults (Pizzagalli, Sherwood, Henriques, & Davidson, 2005; Sutton & Davidson, 1997). Children who display more neural activity in the left hemisphere during rest also show higher levels of approach or reward-sensitive behavior (Fox, Henderson, Rubin, Calkins, & Schmidt, 2001; Putnam & Stifter, 2005). However, this sensitivity to rewards can lead to behavioral problems. Children who are high in approach are also more likely to have difficulties with self-regulation that are externalizing in nature, such as aggression, oppositional problems, and antisocial behavior (Fox, Henderson, Marshall, Nichols, & Ghera, 2005; Rybak, Crayton, Young, Herba, & Konopka, 2006).

In contrast, individuals with more neural activity in the right hemisphere are more likely to display avoidance behavior (Avram et al., 2010; Coan & Allen, 2003). Individuals who are high in avoidance are more likely to have self-regulation issues that are internalizing in nature, such as anxiety, depression, and withdrawal (Demerdzieva & Pop-Jordanova, 2015; Rapport, Denney, Chung, & Hustace, 2001). Internalizing problems may reflect high levels of self-regulation abilities that are not being used in an adaptive manner (i.e., overregulation), whereas externalizing problems may provide evidence of low levels of self-regulation abilities.

Frontal asymmetry provides a reliable and stable continuous measure of reward sensitivity, thus it is important in the examination of children's self-regulation abilities (Fox et al., 2001; Müller, Kühn-Popp, Meinhardt, Sodian, & Paulus, 2015). However, research has been limited in assessing direct connections between left frontal asymmetry and self-regulation skills exhibited in the context of reward. In addition to examining how individual differences in reward sensitivity are linked to regulatory behavior in the face of reward, it is critical to understand how cognitive control factors, such as inhibitory control, influence the ability to regulate behavior adaptively when receipt of a reward is delayed.

Inhibitory Control

Inhibitory control is defined as the conscious and deliberate process of suppressing prepotent responses or actions (Carlson & Wang, 2007; Nigg, 2017; Spiess, Meier, & Roebers, 2015). Inhibitory control skills begin to emerge late in infancy, followed by significant development between 3 and 6 years of age (Hala, Hug, & Henderson, 2003). Even though these skills continue to develop into early adulthood (Cuevas et al., 2014), it is critical to study them during childhood because these skills are linked to other cognitive abilities and important behavioral outcomes.

Strong inhibitory control skills have been correlated with positive outcomes in childhood as well as adulthood (Brooker, Kiel, & Buss, 2016; Wiebe, 2014). Wolfe and Bell (2003) demonstrated that children's inhibitory control skills show a moderate positive correlation with attention focusing as well as moderate negative correlations with expressions of anger and approach. Carlson and Wang (2007) also showed a positive correlation between inhibitory control skills and the regulation of emotions, such that children with strong inhibitory control skills were better at regulating both positive and negative emotions. For preschool children who are high in negative emotionality, better inhibitory control skills can also have a protective effect against aggressive behavior (Suurland et al., 2016).

In comparison, weaker inhibitory control skills have been associated with poor self-regulation and negative life outcomes (Kochanska, Murray, & Harlan, 2000). Lower inhibitory control skills have also been linked with more frequent displays of anger (Gagne & Goldsmith, 2011), as well as increased risk for anxiety problems among children who are low in approach behavior (White, McDermott, Degnan, Henderson, & Fox, 2011). When paired with high negative emotionality, poor inhibitory control skills can also lead to more physical aggression in both boys and girls (Suurland et al., 2016).

Research on the associations between children’s inhibitory control and reward sensitivity is rare, but some research indicates that children as well as adults tend to show better inhibitory control when receiving a reward is contingent on performance (O’Connor, Rossiter, Yücel, Lubman, & Hester, 2012; Qu, Finestone, Qin, & Reena, 2013). Among adolescents, high BAS scores and poor inhibitory control skills have been linked with substance abuse, but stronger inhibitory control skills wash out this association (Kim-Spoon et al., 2016). In addition, toddlers who showed lower inhibitory control skills, higher approach behaviors, and less positive affect were shown to be at a higher risk for externalizing behavioral problems in kindergarten (Buss, Kiel, Morales, & Robinson, 2014).

One study specifically using frontal asymmetry as a measure of reward sensitivity has shown that infants with greater left frontal asymmetry exhibit poorer inhibitory control skills later in childhood (He et al., 2010). However, no work to date has examined the joint influence of reward sensitivity and inhibitory control on self-regulation abilities in the context of reward delay. When challenged by a reward delay, inhibitory control may be adaptive for children who are particularly sensitive to rewarding stimuli because suppressing impulses is essential for success in this context.

Current Study

The current study was part of a longitudinal project that examined how children with and without hyperactivity symptomology process emotions. The study consisted of two visits with 18-24 months in between each visit, and children were between the ages of 4 and 7 years old at the first visit. At Time 1, children completed behavioral tasks assessing emotion reactivity and caregivers completed questionnaires pertaining to children's behaviors and emotions. In addition, children's baseline EEG was recorded. At Time 2, caregivers and children were interviewed by the researcher and caregivers answered additional questionnaires. Children also completed three behavioral tasks: a go/no-go task, a flanker task, and a lock-box task.

The first aim of the current study was to examine whether reward sensitivity, measured by frontal EEG asymmetry, predicts behavior and emotional reactivity in the lock-box task, which represents a reward delay context. The second aim was to examine whether inhibitory control moderated associations between reward sensitivity and behavioral and emotional reactivity in a reward delay context.

Based on previous research, it was expected that children high in reward sensitivity would show more expressions of anger, as well as higher levels of effort and attentional focus during the lock-box task (Depue & Iacono, 1989; Kim et al., 2015; Martin & Fox, 2006). It was also expected that inhibitory control skills would help children maintain better regulation of their emotions (Carlson & Wang, 2007; Suurland et al., 2016), such that children with high reward sensitivity and high inhibitory control skills would display less anger.

CHAPTER 2

METHOD

Participants

Sixty-eight children participated in the first phase of the study (Lugo-Candelas, Flegenheimer, Harvey, & McDermott, 2017). The current study focused on data from 35 children (11 females), who were between the ages of 4 and 7 years old at Time 1. Children were excluded due to attrition (n = 13) and incomplete data (n = 20). The sample was 77% European-American, 3% Asian-American, and 20% multiethnic.

Children were originally recruited based on their hyperactivity symptomology as identified by parent responses to the Diagnostic Interview Schedule for Children (NIMH DISC-IV; Shaffer et al., 2000). If children were taking ADHD medication, their parents were asked to halt administration 48 hours before the scheduled laboratory visit. Before participation, parents also had to confirm that their children did not have intellectual disabilities, hearing or visual impairments, receptive language delay, cerebral palsy, epilepsy, autism, or psychosis.

Procedure

The Institutional Review Board of UMass Amherst approved this project. Participants were recruited through a child study database and advertisements in doctors' offices, community centers, and local preschools. A graduate research assistant conducted phone interviews, including the ADHD and ODD sections of the NIMH DISC-IV (Shaffer et al., 2000) and other questions addressing inclusion criteria, to determine eligibility for the study.

Time 1. Upon arrival, a research assistant described study procedures to the parent and the child. Parents provided signed consent and children gave verbal assent. The child was fitted with an EEG cap and completed two emotion reactivity tasks while his or her parent answered questionnaires. After the tasks, children's baseline EEG was recorded. Children received small toys and families were also given $20 as compensation. In addition, families of children with high levels of hyperactivity symptoms were offered four complimentary parent-training sessions.

Time 2. Parents and children returned to the lab 18-24 months after their Time 1 visit. A research assistant described the study procedures, and parents as well as children provided signed consent. Parents and children were interviewed by the researcher, and parents answered additional questionnaires. Children completed a go/no-go task, a flanker task, and a lock-box task. Children also received toys and families were given $20 as compensation.

Measures

Psychophysiological recording. Data were collected during a baseline interval at Time 1 during which children were asked to sit still with their eyes open for one minute and then sit still with their eyes closed for another minute. This pattern was repeated twice for a total of 4 minutes of baseline data collection.

Raw EEG activity was continuously recorded from a 64-electrode Neuroscan Quick-cap using SCAN 4.5 software (Compumedics Neuroscan, Charlotte, NC). A midline electrode posterior to Cz was used as the reference electrode and a midline electrode anterior to Fz was used as the ground electrode. Baseline EEG activity was amplified at 1000Hz through a Neuroscan Synamps 2 amplifier set for high and low band pass at 0.01 to 100 Hz respectively. Impedances were kept under 10 kΩ. Vertical electro-oculogram (VEOG) was recorded from electrodes above and below the child's left eye, and these recordings were used to edit out blink artifacts (Gratton, Coles, & Donchin, 1983). Two electrodes placed on the left and right mastoids were used to re-reference off-line to an average mastoid, and data were filtered with a 30 Hz filter (24db/Oct). EEG epochs that exceeded -150 or 150 microvolts were removed.

Data were filtered to include the alpha frequency band (8-13 Hz), and data were extracted from frontal sites F7 and F8. Frontal EEG asymmetry scores were calculated by first transforming the power scores using the natural log function. Left power (F7) was then subtracted from right power (F8) to create the frontal asymmetry score. Alpha power has shown inverse relations to activation, such that a negative asymmetry score indicates greater right frontal activation and a positive asymmetry score indicates greater left frontal activation. Some participants only had partial frontal asymmetry data, thus frontal asymmetry scores were average scores of EEG data recorded during the eyes open and/or eyes closed sessions of the baseline interval. Eyes open and eyes closed frontal asymmetry scores from these sites correlate highly ($r = .71$, $p > .001$).

Flanker task. The flanker task was completed at Time 2. The task was created with E-Prime software and presented on a computer screen. Children responded with a two-button controller or two keys on the keyboard. This child-friendly version used five brightly colored fish as the stimuli (McDermott, Perez-Edgar, & Fox, 2007). Children were asked to judge the direction (left or right) of the middle fish, which was either swimming in the same direction (congruent) or in the opposite direction (incongruent) as all of the other fish. Children were asked to press the corresponding button (left or right) to give their response. The measure of inhibitory control was based on children's accuracy on incongruent trials during this task.

Lock-box task. The lock-box task was completed at Time 2. This task was based on a similar task from the laboratory temperament assessment battery (LabTab; Goldsmith, Reilly, Lemery, Longley, & Prescott, 1995). For this task, the child was asked to choose a toy as compensation and a research assistant locked the toy in a clear plastic box. The research assistant then gave the child a set of keys to unlock the box and left the room. However, none of the keys worked because the research assistant had hidden the real key. After 5 minutes, the research assistant returned with the real key and unlocked the box for the child to retrieve the toy.

Video recordings were later coded for the presence of behaviors and emotional expressions in 10-second epochs. The following behaviors were coded: problem solving, effort, behavioral distraction, attentional distraction, help-seeking, focus, soothing, and disruptive behavior. The following emotional expressions were coded: anger, sadness, happiness, and frustrated smile. Each variable measure represented the proportion of time the child engaged in that behavior or displayed that emotional expression.

Task effort was coded for proportion of weak effort (WE; i.e., looking at keys or keyhole), moderate effort (ME; i.e., turning keys in the keyhole), or intense effort (IE; i.e., shaking keys hard in the keyhole). A composite score of effort was calculated by weighting each level of effort as such: Effort = WE + 2ME + 3IE. Attentional focus was calculated by reverse coding attentional distraction, or subtracting the proportion of attentional distraction from 1. Intraclass correlations (ICC; McGraw & Wong, 1996) were used to assess agreement between coders' judgements of effort (ICC = .68), attentional focus (ICC = .94), and anger (ICC = .53).

Data Analysis

Using IBM SPSS Statistics, a series of regressions were conducted. For each regression, a lock-box self-regulation measure (i.e., effort, attentional focus, and anger) was regressed separately onto reward sensitivity (i.e., frontal asymmetry score). Inhibitory control (i.e., incongruent flanker trial accuracy) was also included as a moderator in the three regression models for each measure of self-regulation (i.e., effort, attentional focus, and anger). Independent variables were mean centered and were used to create the interaction term. Simple slopes analyses were conducted to probe significant interactions between reward sensitivity and inhibitory control (Aiken & West, 1991; Schubert & Jacoby, 2004). Analyses examined levels of inhibitory control one and two standard deviations above and below the mean.

CHAPTER 3

RESULTS

Descriptive Statistics

The current study focused on a subset (n = 35) of the original sample of 68 children. The children who were excluded from the current study did not differ in age, gender, or race from the children who were included in this study (ps > .856). Descriptive statistics for all variables are presented in Table 1. For several variables, their distributions were not normal: weak effort ($p < .001$), moderate effort ($p = .004$), intense effort ($p < .001$), attentional focus ($p < .001$), and anger ($p < .001$).

Correlations among variables are presented in Table 2. Overall effort is negatively correlated with weak effort ($p < .001$) and positively correlated with intense effort ($p < .001$). Moderate effort is negatively correlated with weak effort ($p < .001$) and intense effort ($p = .004$), but it is also positively correlated with age at Time 2 ($p = .049$). Intense effort is negatively correlated with age at Time 1 ($p = .030$) and Time 2 ($p = .015$). Attentional focus is positively correlated with age at Time 1 ($p = .037$) and Time 2 ($p = .045$).

Scores more than three standard deviations above or below the mean were considered outliers. There were outliers on two different measures: intense effort and attentional focus. Exclusion of these scores did not impact the significance of the results, thus they were included in all analyses.

Predicting Children’s Regulation of Effort

There was not a significant relation between frontal asymmetry scores at Time 1 and children’s overall effort (collapsed across the three categories: weak, moderate, and intense) during the lock-box task at Time 2 (*B* = -.04, *SE* = .14, *p* = .794, *ß* = -.05). Examination of a scatter plot of the data prompted an analysis of a quadratic effect of frontal asymmetry. The quadratic term was significant (*B* = -.85, *SE* = .36, *p* = .024, *ß* = -.39), revealing that children with average levels of frontal asymmetry showed the highest levels of overall effort (Figure 1).

The inhibitory control score was included as a moderator. The main effect of frontal asymmetry (*B* = -.02, *SE* = .13, *p* = .854, *ß* = -.03) and the main effect of inhibitory control (*B* = .003, *SE* = .003, *p* = .304, *ß* = .17) were not significant, but the two-way interaction (*B* = -.03, *SE* = .01, *p* = .010, *ß* = -.45) was significant.

Simple slopes analyses revealed that the association between frontal asymmetry and effort was significant at levels of inhibitory control one standard deviation above (*B* = -.38, *SE* = .18, *p* = .039, *ß* = -.48), two standard deviations above (*B* = -.74, *SE* = .28, *p* = .013, *ß* = -.92), and two standard deviations below the mean (*B* = .69, *SE* = .30, *p* = .028, *ß* = .86; Figure 2). The association was not significant at the level of inhibitory control one standard deviation below the mean (*B* = .33, *SE* = .19, *p* = .091, *ß* = .42). Children low on left frontal asymmetry and high on inhibitory control skills showed the highest levels of overall effort. Children low on left frontal asymmetry and low on inhibitory control skills showed the lowest levels of overall effort.

Weak effort. Further examination of each level of effort during the lock-box task yielded significant findings. There was not a significant relation between frontal asymmetry scores at Time 1 and children’s weak effort during the lock-box task at Time 2 (*B* = -.03, *SE* = .09, *p* = .751, *ß* = -.06). Examination of a scatter plot of the data prompted an analysis of a quadratic effect of frontal asymmetry. The quadratic term was significant (*B* = .51, *SE* = .23, *p* = .037, *ß* = .36), revealing that children with average frontal asymmetry scores showed the lowest levels of weak effort (Figure 3).

Inhibitory control was then included as a moderator. The main effect of frontal asymmetry (*B* = -.04, *SE* = .08, *p* = .653, *ß* = -.07) and the main effect of inhibitory control (*B* = -.003, *SE* = .001, *p* = .094, *ß* = -.26) were not significant, but the two-way interaction (*B* = .02, *SE* = .006, *p* = .001, *ß* = .56) was significant.

Simple slopes analyses revealed that the association between frontal asymmetry and weak effort was significant at levels of inhibitory control one standard deviation above (*B* = .25, *SE* = .10, *p* = .021, *ß* = .49), two standard deviations above (*B* = .54, *SE* = .17, *p* = .003, *ß* = 1.05), one standard deviation below (*B* = -.32, *SE* = .11, *p* = .007, *ß* = -.63), and two standard deviations below the mean (*B* = -.61, *SE* = .18, *p* = .002, *ß* = -1.18; Figure 4). Specifically, children low on left frontal asymmetry and low on inhibitory control skills showed the highest levels of weak effort. Children low on left frontal asymmetry and high on inhibitory control skills showed low levels of weak effort.

Moderate effort. There was not a significant relation between frontal asymmetry scores at Time 1 and children's moderate effort during the lock-box task at Time 2 (*B* = .12, *SE* = .10, *p* = .250, *ß* = .20). Analysis of a quadratic effect also yielded non-significant results (*B* = -.24, *SE* = .28, p = .392, *ß* = -.15).

Inhibitory control was then included as a moderator. The main effect of frontal asymmetry (*B* = .12, *SE* = .09, *p* = .213, *ß* = .20) and the main effect of inhibitory control (*B* = .003, *SE* = .002, *p* = .069, *ß* = .29) were not significant, but the two-way interaction (*B* = -.02, *SE* = .007, *p* = .006, *ß* = -.45) was significant.

Simple slopes analyses revealed that the association between frontal asymmetry and moderate effort was strongest at levels of inhibitory control two standard deviations above (*B* = -.42, *SE* = .20, *p* = .041, *ß* = -.71), one standard deviation below (*B* = .38, *SE* = .13, *p* = .007, *ß* = .65), and two standard deviations below the mean (*B* = .66, *SE* = .21, *p* = .004, *ß* = 1.10; Figure 5). The association was not significant at the level of inhibitory control one standard deviation above the mean (*B* = -.15, *SE* = .12, *p* = .227, *ß* = -.26). Children low on left frontal asymmetry and high on inhibitory control skills showed the highest levels of moderate effort. Children low on left frontal asymmetry and low on inhibitory control skills showed the lowest levels of moderate effort.

Intense effort. There was not a significant relation between frontal asymmetry scores at Time 1 and children's intense effort during the lock-box task at Time 2 (*B* = -.08, *SE* = .07, *p* = .261, *ß* = -.20; Figure 10). Analysis of a quadratic effect also yielded non-significant results (*B* = -.29, *SE* = .19, *p* = .138, *ß* = -.26). Inhibitory control was then included as a moderator. The main effect of frontal asymmetry (*B* = -.07, *SE* = .07, *p* = .329, *ß* = -.18), the main effect of inhibitory control (*B* = .000, *SE* = .001, *p* = .741, *ß* = -.06), and the two-way interaction (*B* = -.003, *SE* = .006, *p* = .624, *ß* = -.09) were all non-significant.

Predicting Children's Attentional Focus

There was not a relation between frontal asymmetry scores and children's attentional focus during the lock-box task (*B* = .03, *SE* = .08, *p* = .724, *ß* = .06). Inhibitory control was also included as a moderator in the equation. The main effect of frontal asymmetry (*B* = .02, *SE* = .09, *p* = .830, *ß* = .04), the main effect of inhibitory control (*B* = .002, *SE* = .002, *p* = .194, *ß* = .24), and the two-way interaction (*B* = -.006, *SE* = .006, *p* = .371, *ß* = -.16) were all non-significant.

Predicting Children's Anger

There was not a relation between frontal asymmetry scores at Time 1 and children's angry expressions during the lock-box task (*B* = -.06, *SE* = .08, *p* = .454, *ß* = -.13). Inhibitory control was also included as a moderator in the equation. The main effect of frontal asymmetry (*B* = -.07, *SE* = .09, *p* = .406, *ß* = -.15), the main effect of inhibitory control (*B* = .002, *SE* = .002, *p* = .334, *ß* = .18), and the two-way interaction (*B* = -.004, *SE* = .007, *p* = .558, *ß* = -.11) were all non-significant.

CHAPTER 4

DISCUSSION

The current study examined the longitudinal association between children's frontal alpha asymmetry and self-regulation abilities in a reward delay context. Left frontal asymmetry has been considered a trait-like representation of individuals' reward sensitivity. It was hypothesized that greater reward sensitivity would be associated with better regulation abilities aimed at obtaining reward (i.e., higher levels of effort and attentional focus) in a reward delay context but not more efficient emotion regulation abilities (i.e., fewer expressions of anger). Based on prior research, it was expected that children who were high in reward sensitivity would show the most effort and attention, but they would not be able to regulate their anger effectively and thus exhibit more frequent expressions of anger during the reward delay task (Depue & Iacono, 1989; Kim et al., 2015; Martin & Fox, 2006). However, it was expected that inhibitory control would moderate this association such that children high in reward sensitivity and high in inhibitory control would display effective regulation of their anger (Carlson & Wang, 2007; Suurland et al., 2016).

Results indicated significant associations between children's reward sensitivity and behavior regulation. Children who only had average reward sensitivity at Time 1 displayed the most overall effort during the lock-box task. Inhibitory control skills also moderated the association between reward sensitivity and effort. Children with low reward sensitivity and high inhibitory control skills showed the greatest levels of overall and moderate effort as well as the lowest levels of weak effort. However, children who had high reward sensitivity and low inhibitory control skills also displayed a similar pattern of results. Results for intense effort, attentional focus, and anger were not significant.

The quadratic associations for reward sensitivity in predicting children's effort during the lock-box task suggest that extreme levels of reward sensitivity may impair effort. Children with very low and very high reward sensitivity displayed the lowest levels of overall effort and the highest levels of weak effort. The quadratic association was unexpected, and it was also surprising that children who were high in reward sensitivity would show such low levels of effort when in the presence of reward (Kim et al., 2015; Martin & Fox, 2006). These results may indicate that children at the extremes of reward sensitivity quickly lost interest in obtaining the reward, possibly because they were too frustrated to continue (Depue & Iacono, 1989, Miller & Karniol, 1976) or because the reward was not motivating enough (Wilson, Andrews, & Shum, 2017). Future work incorporating physiological measures of autonomic reactivity would help to delineate these potential mechanisms.

Alternatively, this pattern of behavior may also represent an adaptive response to failure in the reward delay context. Instead of acting aggressively through displays of intense effort (i.e., "shaking keys hard in the keyhole"), these children are seemingly waiting patiently for the researcher to return. Further investigation into this behavior may yield more interesting findings with a larger sample size. In order to deal with the delay, children who are very high or very low in reward sensitivity may be redirecting their thoughts to focus on something else and to avoid thinking about the blocked reward (Casey et al., 2011; Mischel et al., 1972). This technique could possibly be a learned response to combat frustration or boredom during the wait. The addition of a brief child report questionnaire at the end of the study would provide more clarity on children's thoughts and experiences during the lock-box task.

The interactions between reward sensitivity and inhibitory control in the predictions of effort during the lock-box task also conflicted with the original hypothesis. According to previous research, it was unexpected that inhibitory control played a significant role in children's behavior regulation but not their emotion regulation (Carlson & Wang, 2007; Suurland et al.., 2016). Following a similar hypothesis, it was expected that strong inhibitory control skills would have been adaptive for children who were high in reward sensitivity by prompting more effort (Kim-Spoon et al., 2016). However, these children displayed low levels of overall and moderate effort as well as high levels of weak effort. In contrast, children who were high in reward sensitivity and had poor inhibitory control skills showed high levels of overall and moderate effort and low levels of weak effort.

A possible explanation for these patterns of results is that inhibitory control skills are playing a critical role that was not fully captured with the current coding scheme for the lock-box task. Weak effort was described as "looking at keys or keyhole." Further examination of the video recordings may require the development of a separate code for strategy. It could be that the children who were spending more time looking at the keys and the keyhole are in fact trying to determine which keys were most likely to fit, thus showing a high level of cognitive effort that is not currently coded. More research on the association between reward sensitivity and inhibitory control will be necessary to clarify this pattern of results. Future directions should examine whether children report using any strategies in order to find the right key and whether they suggest suppression of an automatic behavior (i.e., trying all the keys) in support of a more goal-relevant behavior (i.e., looking for the key that matches the lock).

There were no significant effects of reward sensitivity on children's regulation of their attentional focus during the lock-box task, regardless of the inclusion of inhibitory control as a moderator. This result was not anticipated because the BAS is highly active in reward contexts and motivates a person to gain access to the reward (Alloy et al., 2012). In the lock-box task, this system would have motivated children to attend to the task at hand and reach their goal of unlocking the box for their reward. Based on research examining the connection between left frontal alpha asymmetry and the BAS (Amodio et al., 2008), recording EEG during this task would provide valuable insight into how concurrent neurophysiological activity relates to attention and motivation in a reward delay context.

It was expected that children with high reward sensitivity would display more anger during the lock-box task because they were being blocked from the reward (Depue & Iacono, 1989). However, there was not an effect of reward sensitivity on children's emotion regulation. In addition, there was not an effect when including inhibitory control as a moderator in the prediction of emotion regulation. Previous research suggested that inhibitory control may positively influence children's emotion regulation abilities (Carlson & Wang, 2007; Gagne & Goldsmith, 2011; Wolfe & Bell, 2003). However, these studies focused on preschool children, and the children in our study were school-aged when they completed the lock-box task. Thus, they simply may have had more mature and effective emotion regulation abilities that were not influenced by reward sensitivity or inhibitory control. For older children, it is possible that the reward needs to be more potent (Wilson et al., 2017). In addition, perhaps this task is simply not challenging enough to elicit negative affect and does not require emotion regulation from children in middle childhood (Duckworth et al., 2013).

Research on neural markers of emotion regulation suggests that there is a link between inhibitory control and emotion regulation. Studies using fMRI technology have revealed that the anterior cingulate cortex (ACC) is highly active during incongruent trials of the flanker task (Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999), which are thought to engage inhibitory control skills. The ACC has also been linked with affect and emotion processing (Bush, Luu, & Posner, 2000). Thus, it was expected that performance on incongruent trials would moderate the association between children's reward sensitivity and their emotion regulation. The absence of a significant association in this study provides evidence contrary to prior research, yet a larger number of participants may help to reveal a connection between reward sensitivity, inhibitory control, and emotion regulation. Future studies should also examine inhibitory control as a broader construct by using more than one type of task to measure this skill.

In addition to having a small group of participants, this study was also limited by substantial attrition between the two visits, thus starting out with a larger number of participants at the first time point in future studies would help offset potential attrition. Additional research should also measure all three variables at three different time points in order to examine the stability of reward sensitivity measured in early childhood. Such a design would more closely follow the developmental trajectory of inhibitory control during key developmental periods, such as the "5-to-7-year shift" when children's cognitive abilities undergo significant improvement (Sameroff & Haith, 1996).

Future directions for research on children's self-regulation in reward delay contexts should also take a multimodal approach and collect additional physiological measures of reward sensitivity. For example, measurement of autonomic reactivity, such as heart rate variability, would be helpful in examining reward sensitivity. Gatzke-Kopp and colleagues (2015) found an increase in heart rate but not skin conductance among children with externalizing problems when they were blocked from getting a reward. Assessment of vagal tone during delay of gratification has also yielded interesting results, such that high vagal tone in children from poverty backgrounds and low vagal tone in middle-class children were associated with lower ability to wait less during a 10-minute food reward delay (Sturge-Apple et al., 2016). As externalizing problems are more common among individuals who show high reward sensitivity (Fox et al., 2005), it would be fruitful to assess several measures of autonomic reactivity in order to examine physiological markers of reward sensitivity and to identify at-risk individuals.

In conclusion, the current study provided evidence of an association between children's reward sensitivity, as measured by frontal asymmetry, and their behavior regulation during a reward delay paradigm. Additionally, the study showed that the link between reward sensitivity and behavior regulation is influenced by children's inhibitory control skills. However, there were no associations between reward sensitivity (or inhibitory control) and anger or attentional focus. These findings suggest that there is a complex association between children's reward sensitivity, their emerging cognitive skills, and their ability to regulate their behavior in a reward delay context. Future research, including several physiological measures of reward sensitivity and multiple assessments of regulatory abilities, may prove beneficial in the understanding of the development of problem behaviors as well as possible points of intervention.

Table 1. Descriptive Statistics for All Variables

	M	*SD*	Range
Time 1 Age (in years)	6.40	.81	4.25 - 7.67
Time 2 Age (in years)	8.13	.82	6.13 - 9.45
Frontal Asymmetry	.07	.25	-.58 - .57
Inhibitory Control	76.83	13.09	48.26 - 98.04
Effort Composite	1.88	.20	1.34 - 2.42
Weak Effort	.10	.13	0 - .50
Moderate Effort	.79	.15	.42 - .96
Intense Effort	.07	.11	0 - .52
Attentional Focus	.87	.12	.38 - 1.00
Anger	.11	.12	0 - .44

Table 2. Correlations Among Variables

	1	2	3	4	5	6	7	7.1	7.2	7.3	8	9
1. Gender	--											
2. Race	-.18	--										
3. Age (Time 1)	.22	-.16	--									
4. Age (Time 2)	.19	-.16	.97***	--								
5.Frontal Asymmetry	-.25	.10	.05	.05	--							
6. Inhibitory Control	-.16	.19	.21	.26	.17	--						
7. Effort Composite	-.13	-.22	-.07	-.11	-.05	.10	--					
7.1 Weak Effort	-.08	.21	.04	.05	-.06	-.19	-.80***	--				
7.2 Moderate Effort	.22	-.23	.33	.34*	.20	.26	.29	-.71***	--			
7.3 Intense Effort	-.26	-.01	-.37*	-.41*	-.20	-.10	.70***	-.26	-.47**	--		
8. Attentional Focus	-.13	.02	.36*	.34*	.06	.22	-.07	-.002	.25	-.28	--	
9. Anger	.17	-.21	.24	.31	-.13	.14	-.11	-.07	.15	-.19	.01	--

Note: * $p < .05$, ** $p < .01$, *** $p < .001$

Figure 1. The quadratic relation between frontal asymmetry and children's overall effort during the lock-box task.

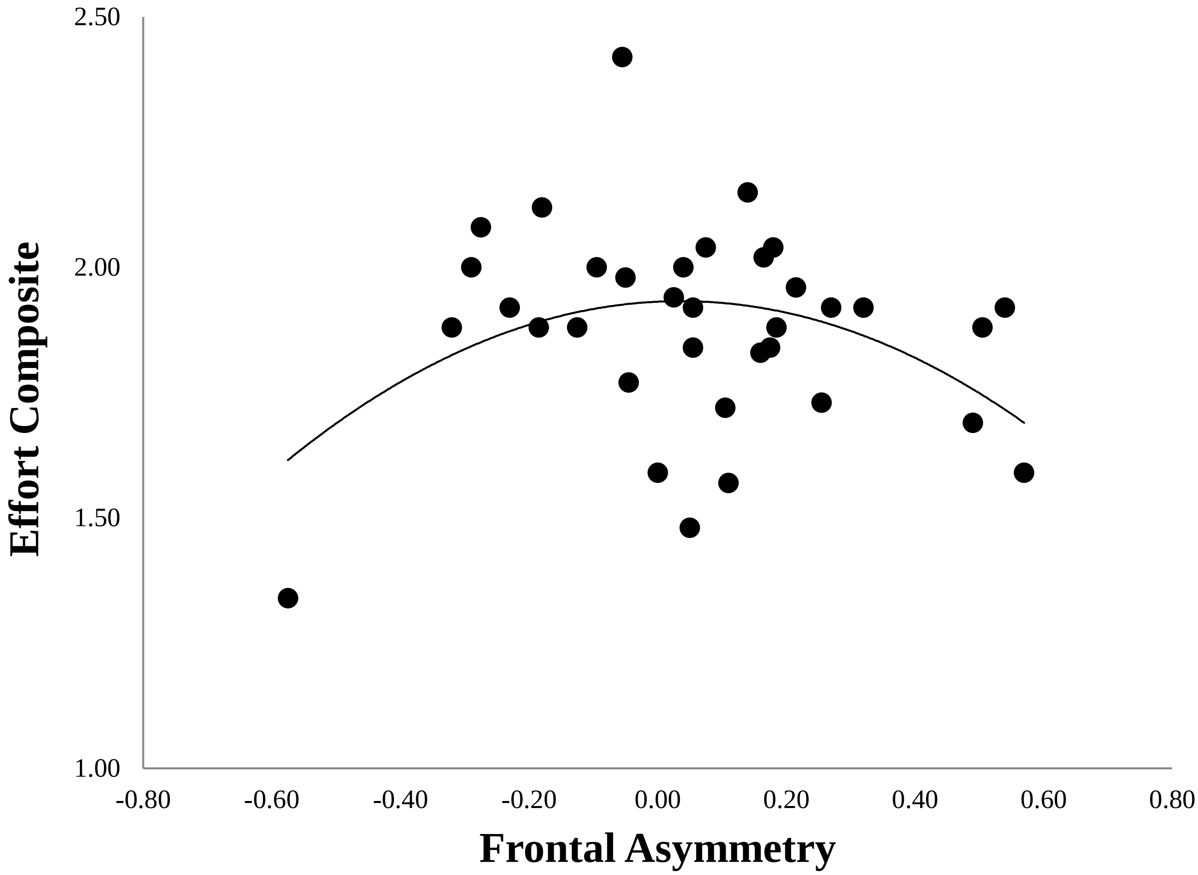


Figure 2. The interaction between frontal asymmetry scores and inhibitory control skills in predicting children's overall effort during the lock-box task. Note: * $p < .05$, ** $p < .01$, *** $p < .001$.

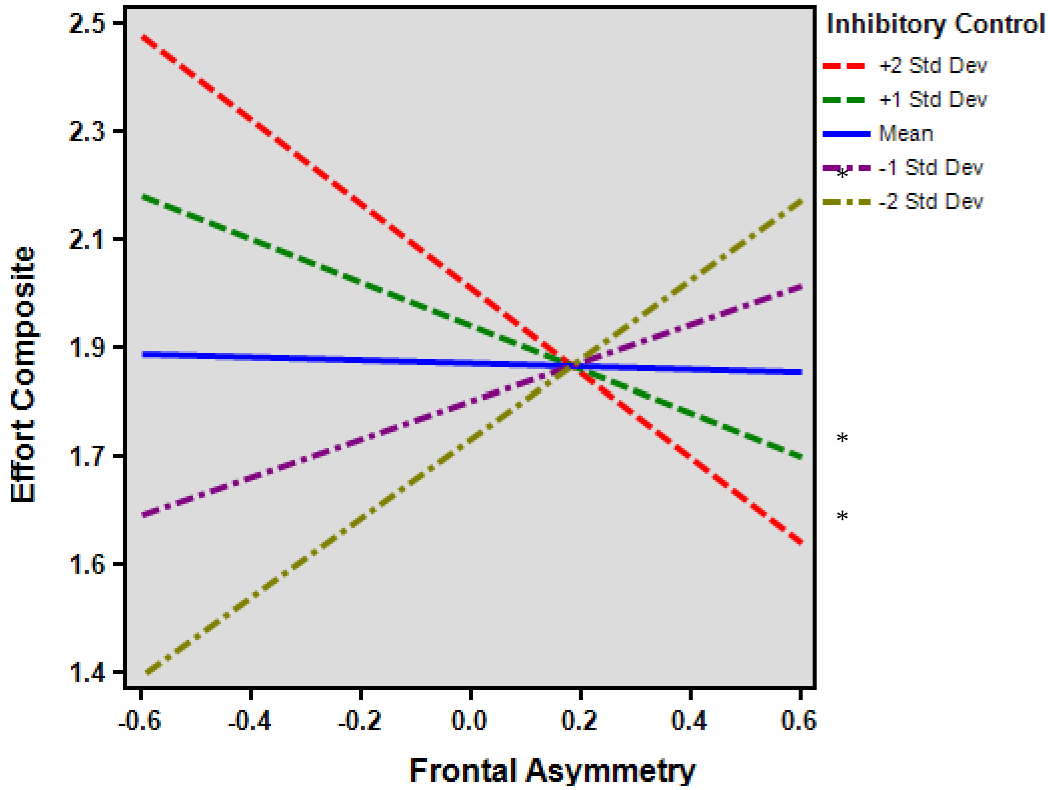


Figure 3. The quadratic relation between frontal asymmetry and weak effort during the lock-box task.

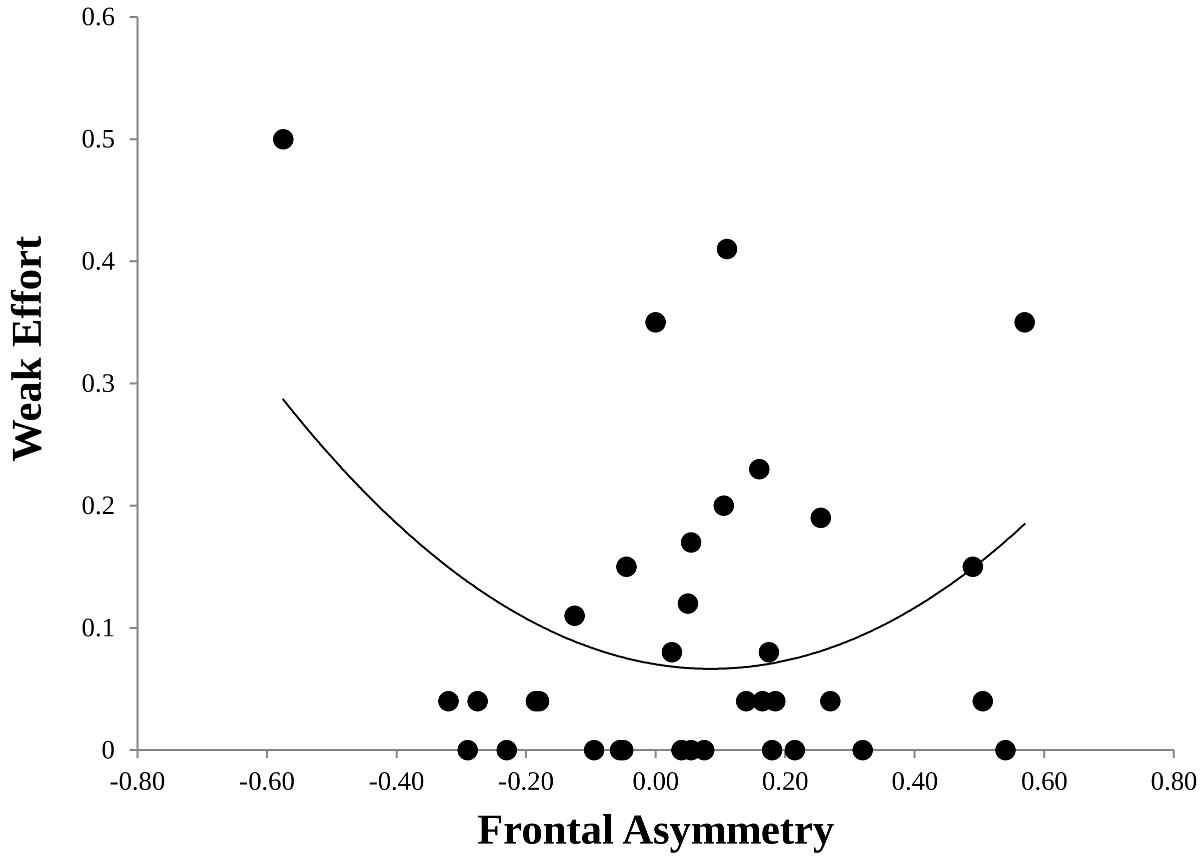


Figure 4. The interaction between frontal asymmetry and inhibitory control skills in predicting children's weak effort during the lock-box task. Note: * $p < .05$, ** $p < .01$, *** $p < .001$.

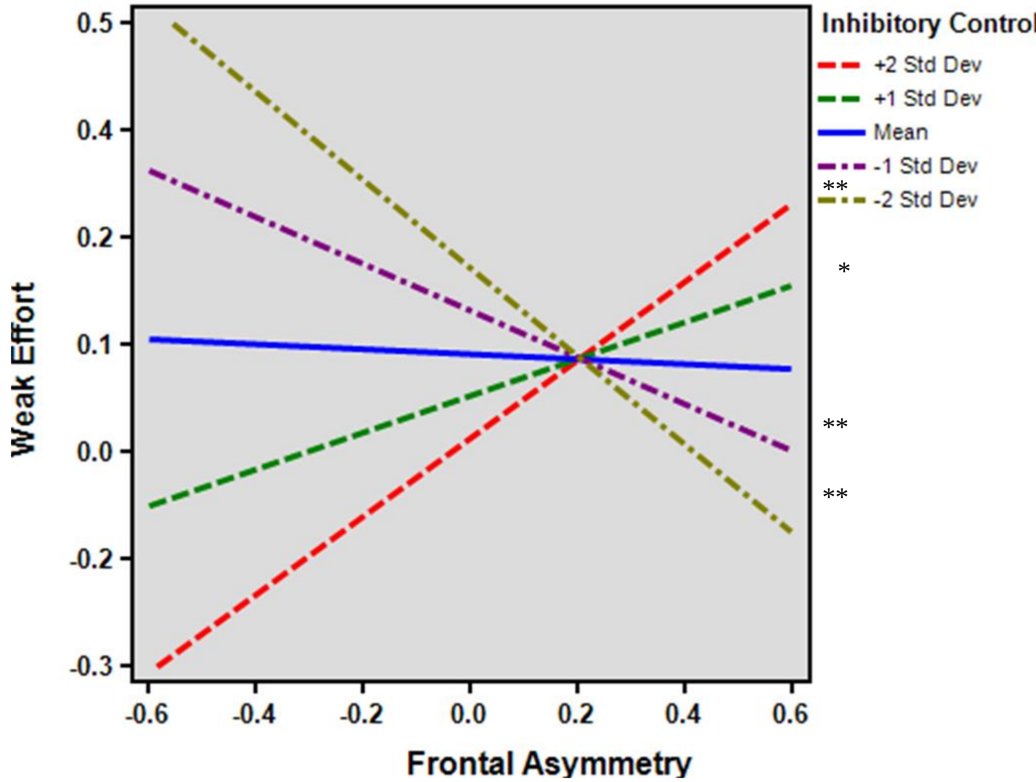
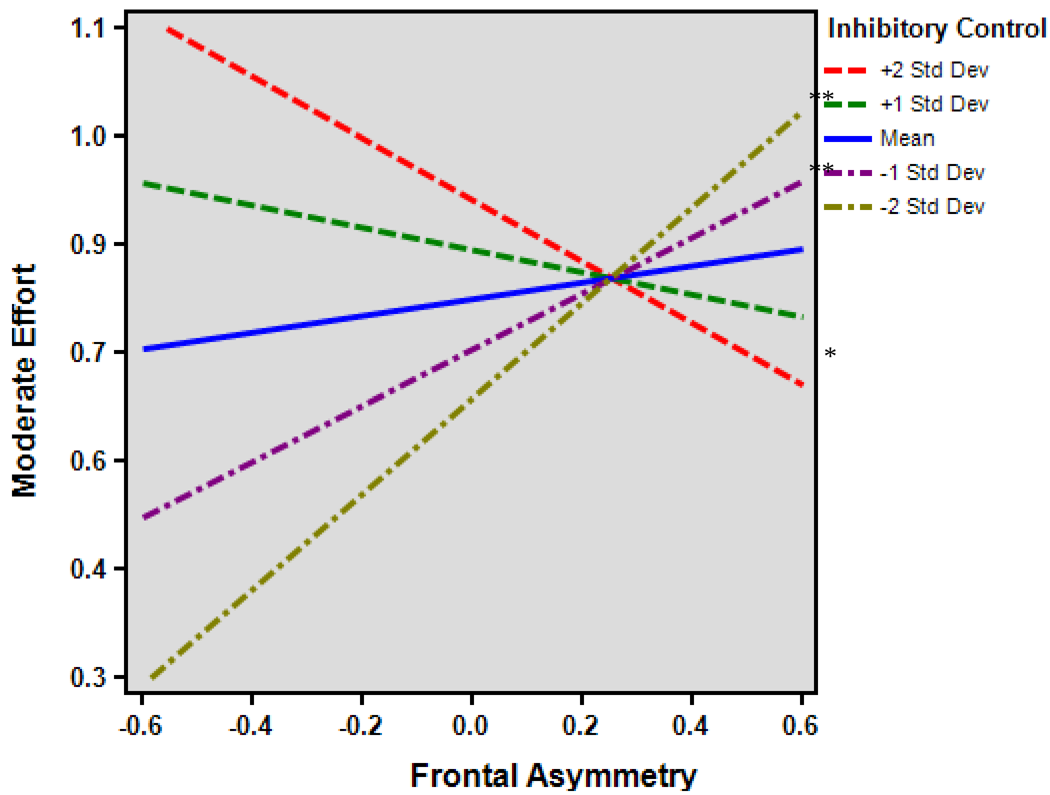


Figure 5. The interaction between frontal asymmetry and inhibitory control skills in predicting children's moderate effort during the lock-box task. Note: * $p < .05$, ** $p < .01$, *** $p < .001$.



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