EXPLORATION OF THE BIDIRECTIONAL ASSOCIATION BETWEEN MATERNAL ANXIETY AND CHILDREN'S COGNITIVE CONTROL: AN ELECTROCORTICAL STUDY

An Undergraduate Research Scholars Thesis

by

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RESEARCH COMPLIANCE CERTIFICATION

Research activities involving the use of human subjects, vertebrate animals, and/or biohazards must be reviewed and approved by the appropriate Texas A&M University regulatory research committee (i.e., IRB, IACUC, IBC) before the activity can commence. This requirement applies to activities conducted at Texas A&M and to activities conducted at non-Texas A&M facilities or institutions. In both cases, students are responsible for working with the relevant Texas A&M research compliance program to ensure and document that all Texas A&M compliance obligations are met before the study begins.

We, Ashley Walker[1], Anahid Akbaryan[2], Reese Burkey[3], and Peter Ramirez[4]., certify that all research compliance requirements related to this Undergraduate Research Scholars thesis have been addressed with our Faculty Research Advisor prior to the collection of any data used in this final thesis submission.

This project required approval from the Texas A&M University Research Compliance & Biosafety office.

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ABSTRACT

Exploration of The Bidirectional Association Between Maternal Anxiety and Children's Cognitive Control: An Electrocortical Study

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Cognitive control, or the ability to voluntarily guide one's own behavior, continually improves throughout childhood (Luna et al., 2010). Over time, children move from reflexive and reactionary behaviors to greater control over volitional responses to environmental signals (Derryberry & Rothbart, 1988). Such shifts reflect developmental increases in proactive forms of cognitive control, where children are self-directed in their intentions to recruit cognitive control in anticipation of needing it for a task (Munakata et al., 2012). Better cognitive control in children positively predicts important life outcomes, such as success in school and the workplace (Blackwell & Munakata, 2014; Coldren, 2013). Postpartum anxiety syndromes, which affect 8.5% of mothers, negatively affect the development of cognitive control in offspring (Goodman et al., 2016; Reck et al., 2008). However, focus on unidirectional effects from mother to child ignores the true nature of the mother-child dyad, which comprises numerous bidirectional associations. Indeed, offspring characteristics that may make parenting more difficult can impact the course of maternal anxiety symptoms (Brooker et al., 2023), though such an association has not been investigated with regard to children's developing cognitive control. The present study examined bidirectional associations between maternal anxiety symptoms and children's cognitive control between children ages three and five years. During annual assessments, mothers completed surveys to measure anxiety symptoms. Scales from three separate surveys were used to form a latent variable reflecting maternal anxiety at each age. Electroencephalography (EEG) data was collected from children at each age during a computerized Go/No-Go Task. Event-related potentials were derived to assess cognitive control. We hypothesize that greater maternal anxiety will predict less cognitive control in children at subsequent assessments. We hypothesize that lower cognitive control in children will predict higher levels of maternal anxiety at subsequent assessments. This perspective offers a powerful and novel insight into the bidirectional relation between maternal and child development that can be leveraged to enhance outcomes for both members of the dyad.

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NOMENCLATURE

EEG	Electroencephalography
EF	Executive Functioning
ERP	Event-Related Potential
GADQ-IV	General Anxiety Questionnaire
PSWQ	Penn State Worry Questionnaire
SIAS	Social Interaction Anxiety Scale

INTRODUCTION

Decades of existing literature has studied the impact of children's exposure to postnatal depression while largely overlooking the impact of maternal postnatal anxiety on children's development (Glasheen et al., 2010). Moreover, empirical work on maternal anxiety and child outcomes has largely focused on emotional outcomes and almost exclusively considers how maternal anxiety symptoms influence the development of negative emotion in young children. As a result, there is a significant gap in our understanding of how children's cognitions may be impacted by maternal symptoms, even though critical periods of cognitive development in young children almost fully overlap with a critical period for the influence of maternal anxiety symptoms. In addition, a dearth of information exists regarding the role of children's cognitive control on maternal development, despite evidence that child characteristics can impact the trajectory of anxiety symptoms in mothers over time (Brooker et al., 2023). Most existing literature provides significant findings supporting maternal anxiety rates' impact on children's cognitive functioning; however, this creates a gap in understanding how children's cognitive control can affect the development of maternal anxiety. Given these limitations in the extant literature, this study aims to approach this relationship as a bidirectional one.

1.1 Cognitive Development During the Preschool Years

A major task of development in young childhood is the acquisition of cognitive control, defined as the ability to intentionally engage and effectively command attentional and/or behavioral focus to important information in response to varying goals and tasks. Cognitive control utilizes lower levels of executive functioning (EF), such as working memory and response inhibition, to provide active consolidation of goals and a means to achieve them, therefore, enabling higher EF (Nigg, 2017; Casey et al., 2001). Arguably the most well-established critical period for developing cognitive control in young children is early childhood when volitional control over behavior increases and children can override their own prepotent behavioral and attentional tendencies (Rothbart et al., 2004; Kopp, 1982). Though the developmental period for cognitive control is notably protracted, cognitive control skills demonstrate normative increases as children mature, increasingly enabling children to modify their own behaviors without assistance from environmental support systems (Munakata et al., 2012).

In children, the development of cognitive control enables the appropriate inhibition of distractions and impulses, essential to advancing necessary skills such as task completion and goal setting. In its infant form, cognitive control is primarily reactive in form and reflects the ability to retrieve relevant task information when needed. However, throughout the preschool years, children become increasingly proactive in their ability to control their behaviors in the service of task completion and goal fulfillment (Luna et al., 2010). It was found that an increased delay of gratification, an ability that is essential to cognitive control, at age four predicted consistently higher levels of cognitive control ten years later (as measured by the Go/No-Go Paradigm) (Eigsti et al., 2006).

In addition, among typically developing six-year-old children, cognitive control techniques exist to modulate emotional reactivity (Terwogt et al., 1986). Children that develop these self-control practices are often proven to be more successful in school, as well. Children’s academic performance is positively correlated with cognitive control when studied using a linguistic task (Coldren, 2013). Cognitive control can be quantified as early as age two using EEG recordings during a task that necessitates cognitive control (Hoyniak, 2019).

A variety of methods have been used to mark cognitive control in children, but perhaps the most notable of all is the use of electroencephalography (EEG) and corresponding event-related potentials (ERP). EEG has been a commonly used tool for tracking cognition throughout development due to its high temporal resolution and usability in young children. ERPs are a time-sensitive segment of EEG activity that respond to specific stimuli. ERPs are thought to be a product of a multitude of cortical pyramidal neurons firing in synchrony in response to a stimulus (Sur, 2009). Depending on the time after stimulus onset, ERPs can be utilized to represent various facets of human cognition and sensation processing. Specifically, the N200, or the N2, wave is a negative deflection peaking approximately 200 to 500 ms after presenting the stimulus. For the purposes of this study, we primarily analyzed EEG data through the N2 component.

The N2 wave is a marker of cognitive control. In children, greater (or more negative) N2 amplitudes are associated with decreased levels of cognitive control (Lamm et al., 2014). Although cognitive control increases over time, N2 amplitudes tend to decrease across childhood as scalp thickness increases and cognitive control abilities are honed (Lamm et al., 2006). Young children with histories of disruptive behaviors have been seen to have differentiation in N2 amplitude when compared to children with lower histories of disruptive behaviors (Grabell, 2017). The existing literature suggests that N2 amplitudes will decrease as children age, which should signify an increase in cognitive control. Thus, there is an inverse relationship between N2 amplitude and cognitive control.

1.2 Development of Cognitive Control is Impacted by Maternal Anxiety Symptoms

The development of cognitive control in young children is subject to the influences of the early environment. Because mothers comprise a substantial portion of the early environment, maternal characteristics and behaviors have significant effects on nearly all aspects of child development, including cognitive control. Consequently, maternal stress and mood play an important role in child development and have been areas of interest in developmental psychology for some time. Despite this, however, the effect of maternal anxiety symptoms on children's cognitive development has yet to be extensively studied, as the majority of existing literature has focused on maternal depression. However, maternal anxiety symptoms from the prenatal period well into early childhood (e.g., ages three-five) years overlap with critical periods for the development of cognitive control. Late-stage prenatal anxiety can lead to poorer cognitive development when measured between 12 and 36 months of age (Brouwers et al., 2001. Ibanez et al., 2015). At least one study found that maternal anxiety in the first three months postpartum was negatively associated with children's cognitive development, with maternal anxiety symptoms being linked to poorer language and problem-solving skills by age two (Zelkowitz et al., 2011). One theory as to why maternal anxiety may affect cognitive development is that anxious mothers may not be as responsive to their child's needs. Infants and toddlers require frequent feedback and response from their caretakers in order to meet important developmental milestones, and it is likely that a decrease in responsiveness from the child's caretaker will stunt their development. It is thought that responsiveness is an important factor in encouraging infant engagement which, in turn, is important for learning vital skills early in life. This is supported by research showing that higher maternal responsiveness is positively associated with a child's ability to form simple sentences by 13 months (Tamis-LeMonda & Bornstein, 2002). Furthermore, lower maternal responsiveness is linked to greater difficulty in learning and discrimination tasks in infancy (Bornstein et al., 1989).

1.3 Development of Maternal Anxiety Symptoms

Anxiety disorders are common among postpartum women, with an estimated 8.5% of postpartum mothers experiencing one or more anxiety disorders (Goodman et al., 2016). Despite these high numbers, postpartum anxiety disorders have been understudied compared to postpartum depression (Goodman et al., 2016). This is true both with regard to etiology and treatment. For example, in recent years, an increasing number of studies have examined preventative programs for postpartum depression, but very few testing studies researching preventative programs for postpartum anxiety (Reck et al., 2008). This lack of focus on maternal anxiety is significant, considering the estimated rates of DSM-IV disorders were 11.1% for postpartum anxiety disorders and only 6.1% for postpartum depression disorders (Reck et al., 2008). Postpartum anxiety disorders can extend into the preschool years and beyond. Maternal anxiety is not linear; it may fluctuate or change as children develop over time. Each period of motherhood may affect the mother in different ways through exposure to various stressors related to the age and development of the child. We hope to expand our research past the scope of postpartum anxiety, which is the period of infancy from birth to six to eight weeks old; rather, we will be focusing on children in the preschool age range, children from three to five years old.

Though developmental work is heavily focused on young children, maternal anxiety symptoms exhibit their developmental trajectories and are, therefore, likely to be subject to environmental influences that shape their changes over time. Because of this, it is important to understand the developmental relationship between cognitive control and maternal anxiety and how they affect one another.

1.4 Development of Maternal Anxiety is Impacted by Children's Cognitive Control

We will be exploring this relationship as a bidirectional one, meaning we wish to explore not just how maternal anxiety might affect a child's cognitive control but also the inverse of this relationship. In a cross-sectional study exploring the relationship between reaction-time of five-year-olds and the antenatal anxiety levels of the mother, it was found that children with mothers that reported high levels of antenatal anxiety performed more variably in tasks than those with less-anxious mothers (Loomans et al., 2011). While this is a significant finding, it does not address the longitudinal aspects of the child's development on the mother's anxiety levels. Children that lack cognitive control could see temperament issues that could impact maternal stress and anxiety levels. Previous literature has supported this relationship, finding that during the infancy periods, increasing maternal stress levels were associated with increased levels of child negative affectivity over time (Pesonen et al., 2008).

The current research reveals that inhibited development of cognitive control early in life will follow a similar pattern continuing into adolescence. This negative pattern is exponentiated in children with developmental disorders such as autism or attention deficit hyperactivity disorder (ADHD). Low levels of control, manifesting as restlessness, emotional instability, and shortened attention span, perpetuate symptoms of externalizing disorders in children (ADHD, Conduct Disorder, and Oppositional Defiant Disorder) (Kray & Ferdinand, 2013). Development of cognitive control has even been linked to the development of empathy and lowered levels of maladjustment; meaning, inhibited development of cognitive control could potentially display deficient empathy in children, garnering a multitude of parental challenges. Furthermore, lack of self-regulation (which encompasses cognitive control and emotional regulation) has been correlated with a particularly strong likelihood for eventual adolescent substance abuse, and deviancy, aggression, and antisocial behavior in children (Rothbart et al., 2004). A meta-analysis was conducted to determine associations between parenting stress and ADHD in children. Results from 22 published studies found that parents of children with ADHD experienced more stress than parents of nonclinical children (Theule et al., 2013). With the DSM-IV already estimating rates of postpartum anxiety disorders at 11.1%, it is likely that increased rates of maternal anxiety in mothers of preschool-aged children would be seen when children display more aggressive and antisocial temperaments (mediated by lowered levels of cognitive control); however, there is a current gap in the literature in support of this assumption, so the present study attempts to close that gap.

1.5 The Current Study

Children's cognitive control is a positive predictor of academic and career success later in life. (Blackwell & Munakata, 2014; Coldren, 2013). The current literature primarily highlights how children are impacted by maternal anxiety symptoms in the postnatal period; our research aims to explore this relationship in the preschool age range. Furthermore, the impact of children’s cognitive control on maternal anxiety has not been extensively explored. Previous literature shows how the development of cognitive control in offspring is negatively affected by postpartum anxiety syndromes, which affect 8.5% of mothers (Goodman et al., 2016; Reck et al., 2008). However, the mother-child dyad, which is composed of a number of bidirectional associations, is not accurately described when it focuses exclusively on the unidirectional effects from mother to child. There is evidence to suggest that certain characteristics of offspring can contribute to the severity of maternal anxiety symptoms (Brooker et al., 2023), even though such associations have not been studied in relation to children's developing cognitive control. Understanding this bidirectional association will increase our understanding of development in the mother-child dyad and will also help destigmatize maternal anxiety and its effects on children. It is often mothers who are blamed for children's deficits; however, the causes of the deficits, as well as their effects on mothers, are rarely considered.

We address this gap in the literature by examining the bidirectional associations between maternal anxiety symptoms and children's cognitive control between three and five years of age. Surveys were administered to mothers during annual assessments to measure anxiety symptoms. A latent variable reflecting maternal anxiety at each age was constructed using these three separate surveys. In addition, electroencephalography (EEG) data was collected from children at each age during a computerized Go/No-Go task. Event-related potentials were derived to assess cognitive control. These measures of cognitive control and maternal anxiety together were used to assess the bidirectional association and development of these factors in the preschool years.

We hypothesize that greater maternal anxiety will predict less cognitive control in children at subsequent assessments. We also hypothesize that lower cognitive control in children will predict higher levels of maternal anxiety at subsequent assessments. This perspective offers a powerful and novel insight into the bidirectional relationship between maternal and child development. This insight can be leveraged to enhance outcomes for both members of the dyad.

METHODS

2.1 Participants

Data from this study was gathered from participants recruited during the Study of Preschoolers' Attention, Cognition, and Emotion (SPACE) study originally conducted by Montana State University (Mistry-Patel & Brooker, 2022). Families were recruited from the greater Bozeman area of Montana through a mix of media advertisements, recruitment events, and mailings. Eligible families must have had a child that was three years of age at the time of recruitment. Children in the sample were screened for developmental disorders, with all participants showing typical development. Furthermore, eligible children must have had no history of neurological impairment within their immediate family. Participants from the study included 121 preschool children and their mothers. Preschoolers were 59% female. Data was collected from preschoolers at three different ages - 3.5 years (n = 108; M_{age} = 3.59, SD = 0.15), 4.5 years (n = 98; M_{age} = 4.57, SD = 0.15), and 5.5 years (n = 91; M_{age} = 5.52, SD = 0.12). Mother ages ranged from ages 19.75 to 45.84 years (M_{age} = 34.53) at the initial age three visit. The majority of mothers (95.6%) identified as White and Non-Hispanic (98.2%), while 1.8% identified as Asian, 1.8% identified as American Indian or Alaska Native, and 0.9% identified as biracial (American Indian/Alaska Native and White).

2.2 Measures

2.2.1 Maternal Anxiety

2.2.1.1 GAD-Q

The General Anxiety Questionnaire (GADQ-IV) is a 14-item self-report diagnostic measure based on the diagnostic criteria of Generalized Anxiety Disorder in the DSM-IV (Moore et al., 2014). The first six questions on the questionnaire pertained to whether the participant experiences excessive amounts of worry. Questions one through four are answered dichotomously (yes/no). Question five provides blanks where the participant can list the topics they most frequently worry about. Question six more specifically inquires if the participant has excessively worried the past six months; if the participant answers no, here they have finished the questionnaire; if they answer yes, then the participant continues to answer eight more questions. The last eight questions further inquire into if the participant experiences symptoms that are typically present in a diagnosis of Generalized Anxiety Disorder. The first six questions are answered dichotomously (yes/no) while the last two are answered on a 9-point Likert scale. The internal consistency of the GADQ-IV used in our study was excellent ($\alpha = .910$).

2.2.1.2 SIAS

The Social Interaction Anxiety Scale (SIAS) is a 20-item questionnaire that measures fears of social interaction. Sample items for the questionnaire include "I have difficulty making eye contact with others," and "When mixing socially, I am uncomfortable." Each item is rated on a 5-point Likert scale ranging from 0 ("Not at all characteristic or true of me") to 4 ("Extremely characteristic or true of me"). Scores from the items are then totaled up with higher scores indicating a more intense fear of social interaction. (Carleton et al., 2009). Internal consistency was high for participants ($\alpha = .860$).

2.2.1.3 PSWQ

The Penn State Worry Questionnaire (PSWQ) is a 15-item questionnaire designed to measure worry. Participants are asked to read statements that pertain to the occurrence and pervasiveness of worry. Sample items include "I am always worrying about something," and "My worries overwhelm me." Individuals are then asked to rate how strongly they relate to each statement. Each item is scored on a 5-point Likert scale ranging from 1 (“Not at all typical of me”) to 5 (“Very typical of me”). Scores are then totaled up, with higher scores indicating more intense and pervasive worry (Meyer et al., 1990). Internal consistency was high for participants at age three (α = .954), age four (α = .952), and age five (α = .954).

2.2.1.4 Latent Variable

Our measure of maternal anxiety utilized a latent variable model composed of self-report data collected from three different questionnaires: the General Anxiety Questionnaire (GADQ-IV), the Social Interaction Anxiety Scale (SIAS), and the Penn State Worry Questionnaire (PSWQ). Each questionnaire was intended to measure a unique aspect of maternal anxiety - social anxiety (SIAS), generalized anxiety (GADQ-IV), and worry (PSWQ). A latent variable measure was calculated at child age three, age four, and age five and was used to assess the covariance across the three different scales. This shared covariance is the latent variable, which in our study, we have coined “maternal anxiety.”

2.2.2 Cognitive Control

2.2.2.1 Go/No-Go Task

At each laboratory visit, children completed a modified Go/No-Go task to assess cognitive control. Before starting the task, an experimenter provided instructions to the child using laminated pictures of either a spaceship or an asteroid. Children were also presented with a response button on a table in front of them. The experimenter then instructed the child to press the button when presented with an asteroid (the Go stimulus) and to “wait” when presented with a spaceship (No-Go stimulus). After demonstrating an understanding of the task using the laminated pictures, children were then instructed to complete two practice blocks, each consisting of 10 trials of the task on a computer. After completing the practice blocks, children moved on to the experimental blocks of the go/no-go task. The task consisted of two experimental blocks, each consisting of 40 trials, resulting in a maximum number of 80 trials per participant. Before participating in each block, children were instructed to respond as quickly as they could. Participants were also awarded after the completion of each block with a sticker. Trials within the experimental blocks were pseudorandomized in a manner ensuring around 60% of the trials were go-trials. Every trial started with a fixation cross being displayed in the center of the monitor for 200 ms. Following this, the stimulus was presented for a duration of 1200 ms. The fixation cross was then presented again for 300-800 ms before the next trial. All stimuli were presented at the center of a 23-inch computer monitor using the Presentation stimulus delivery software (Neurobehavioral Systems; Berkeley, CA). If participants consecutively provided two correct responses, stimulus presentation time decreased by 50 ms via an automated procedure. Similarly, if participants consecutively provided two incorrect responses, stimulus presentation time was increased by 50 ms. This procedure maintained an error rate of 50% and ensured task difficulty was equated across all participants.

2.2.2.2 EEG

Continuous electroencephalography (EEG) data was collected during trials via a 64-channel cap placed on the child prior to the start of the task. EEG data was gathered using the BrainVision recorder software.

2.2.2.3 N2 Measure/ERP

The N2 component of EEG has been found to reflect changes in cognitive control over the course of development. N2 waves and grand averages were gathered through the BrainVision Analyzer Software.

2.3 Procedures

In the original study conducted at Montana State University, preschoolers visited the laboratory at the three ages mentioned above. Two weeks prior to each visit, the mothers were mailed the three questionnaires listed above and brought the completed questionnaires to the lab on the day of the visit. During the laboratory visit, the mother read and completed Institutional Review Board-approved consent documents allowing for the collection and analysis of data for each lab visit. After consent was obtained, the child was capped for electroencephalography (EEG) data collection and completed the Go/No-Go Task described above. Following this activity, the mom and child participated in various behavioral paradigms as part of the lab visit.

RESULTS

We used structural equation modeling (SEM) to test our hypotheses. A root mean square model error of approximation (RMSEA) confirmed that our data fit our proposed model well (Figure A.2).

3.1 Maternal Anxiety Over Time

Our model showed that maternal anxiety was stable across the three ages over time. Specifically, maternal anxiety at age three was predictive of maternal anxiety at age four, and maternal anxiety at age four was predictive of maternal anxiety at age five (Figure 1).

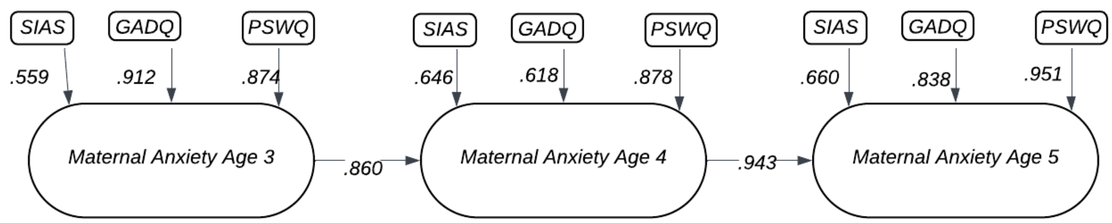

Figure 1: Stability of Maternal Anxiety Over Time

3.2 Cognitive Control Over Time

Our model displayed that the preschooler's cognitive control, measured by the N2 component, was stable over time across the three ages. Specifically, preschoolers' cognitive control at age three was predictive of cognitive control at age four, and cognitive control at age four was predictive of cognitive control at age five (Figure 2).

Figure 2: N2 Stability Over Time

3.3 Effect of Maternal Anxiety

Our model revealed that maternal anxiety at age three was not a significant predictor of preschoolers' cognitive control at age four (λ = .171). Furthermore, maternal anxiety at age four was not a significant predictor of preschoolers' cognitive control at age five (λ =.019).

3.4 Cognitive Control Over Time

Our model displayed that preschoolers' cognitive control at age three was not a significant predictor of maternal anxiety at age four (β = -.075). Additionally, preschoolers' cognitive control at age four was not a significant predictor of maternal anxiety at age five (β = -.061).

CONCLUSION

4.1 Stability of Maternal Anxiety

Our finding that maternal anxiety at age three was predictive of maternal anxiety at age four and, in turn, age five reveals the stability of maternal anxiety over time in our model. This means that across the three ages the means and variances of maternal anxiety were constant. For example, a mother with higher anxiety levels at child age three is likely to maintain a similar level of anxiety at child ages four and five. These findings are consistent with previous literature showing that maternal anxiety symptoms remain stable throughout the first five years postpartum (Ahmed et al., 2019). This is also supported by research showing that trait anxiety, which is defined as one's tendency to feel anxious across numerous situations and is related to several anxiety-related disorders, has long-term stability (Usala & Hertzog, 1991). Unfortunately, research on maternal anxiety is somewhat limited, but there have been several studies that began to examine the main causes of maternal anxiety and its trajectories. Some of the most heavily researched factors in the development of maternal anxiety is the socioeconomic class of mothers and level of social support available to them. One study found that mothers of a lower socioeconomic class were more likely to have higher levels of anxiety postpartum (Britton, 2008). Furthermore, another study found that mothers who exhibited greater anxiety symptoms within the first month postpartum were more likely to have less social support (Buist et al., 2011). These findings aren't particularly surprising when considering what is entailed in raising a child. Mothers of lower socioeconomic statuses are more likely to have difficulty affording the essentials such as diapers, food, and clothing for their child, making it more difficult to access daycares and other forms of childcare. This may also restrict the mother's ability to access mental health resources that could aid in reducing anxiety. A lack of social support can also increase maternal anxiety as mothers may feel as if they have fewer avenues available to ask for help when it comes to various issues, such as finding someone to babysit their child while at work or social functions. These factors are also unlikely to rapidly change within the first few years postpartum and, as such, likely contribute to the stability of maternal anxiety. As a final note, our findings may also point to the potential significance of implementing early anxiety interventions for mothers. Since maternal anxiety seems to be stable long-term, implementing anxiety-reducing interventions early on may lead to an overall decrease in maternal anxiety postpartum.

4.2 Stability of Child N2 Over Time

Our finding that a preschooler's cognitive control, as measured by the N2 component, at age three was predictive of a preschooler's cognitive control at age four and, in turn, age five reveals the stability of cognitive control over time in our model. This means that across the three ages, the means and variances of cognitive were constant. A high N2 at age three would correlate with a similarly high N2 at age four and so on – indicating stability over time and not allowing room for major fluctuations in the averages. Only a few articles to date have discussed the stability of child event-related potential (ERPs) in longitudinal studies. Prior literature has identified the N2 and ERN as two ERPs that account for cognitive control skills. The N2 is collected just prior to a correct response after stimulus onset, while the ERN immediately follows an error. In one of these articles, it was found that mean ERN amplitudes did not have statistically significant stability from ages three to four due to increased variability between the averages (Brooker, 2018). However, a study conducted with slightly older children – between ages 8 to 13 and 10 to 15 – found that ERN was stable across those two-year spans (Meyer et al., 2014). This could be due to the difficulty of gathering EEG data from younger participants and perhaps also allude to more developed cognitive skills later in adolescence. This indicates the novelty of our findings having significant stability in children as young as three years old. Our finding that there was stability in the N2 component from age three to four and from age four to five further expands the field's knowledge in early-life cognitive processes and response inhibition.

4.3 Maternal Anxiety Predicting N2 and N2 Predicting Maternal Anxiety

Although a significant predictive association was not found bidirectionally between maternal anxiety and child N2 longitudinally, both maternal anxiety and child N2 were stable over time. In our model, the stability of N2 over time increased when we also accounted for maternal anxiety (Figure A.1), which suggests that if maternal anxiety is accounted for, the N2 is more stable. Potentially, this implies that there may be a relationship between maternal anxiety and children's cognitive control over time, but perhaps in a way that was different from what we explored. Further exploration into other variables, such as maternal depression, maternal stress, or other disorders commonly comorbid with maternal anxiety, could make clearer the specific bidirectional associations between maternal anxiety and children's cognitive control. Most notably, our finding of the significant stability of the N2 over age three, age four, and age five is relevant to the field of developmental psychology and has not been found in any study to date that we are aware of. Knowing that this stability is present longitudinally and that it increased when maternal anxiety was considered warrants further research into other potential variables that may also have an impact on the stability.

4.4 Limitations

Due to the novelty of our subject of research, we encountered a few limitations that could be improved upon in future work. It is well-known that cognitive development is not necessarily linear, and that environmental changes may not reflect in cognitive development until years later. Furthermore, we note that there could be a developmental delay between testing for cognitive control in one age group and then the subsequent maternal anxiety rates in the next age group. More significant results could be found by expanding the window of interest past the preschool years further into adolescence. Another limitation of this study was its small sample size. Future research should utilize a larger sample of mothers and their children to further solidify results as well as replications of the current results.

Furthermore, this research relied on a sample of community families, which raises concerns about whether the observed values comprise the full range of potential maternal anxiety risk. The sample that was recruited for this study was adequately reflective of the sociodemographic, racial, and ethnic diversity in recruitment; however, a more diverse sample is needed to enhance generalizability in future studies.

In addition, our study utilized self-report data as the sole measure of maternal anxiety which commonly has constraints. For instance, because the mothers in this study were answering questions pertaining to general anxiety (GADQ-IV), social anxiety (SIAS), and worry (PSWQ) in the questionnaires they took, it is a possibility that they may have been hesitant to reveal the full extent of their feelings, due to the sensitive nature of these topics.

In future studies, our model could be strengthened by utilizing other physiological measures of anxiety risk (e.g., heart rate variability, skin conductance) as well as a composite of the three questionnaires (GADQ-IV, SIAS, & PSWQ) to assess maternal anxiety. However, these measures remain to be reliable and valid measures of anxiety. Further, our study's ability to measure neural activity in preschoolers using EEG collection was a novel strength. We were able to specially analyze this EEG data for the N2 neural marker, which has rarely been done in studies with preschool-age children. The significant stability we sound in this N2 over time offers relevant insight to the field of developmental psychology.

4.5 Future Directions

Our findings greatly contribute to the field of child cognition and development. Knowing the association between maternal anxiety rates and children's cognitive control allows for the potential for an increased understanding of maternal anxiety diagnoses and their subsequent causes. Additionally, this research sets the stage for further understanding of children's cognitive control and the implications it may have on development and future adulthood.

It is known that there are ways to help decrease the effects of maternal anxiety. For example, one study found that satisfaction with spousal support had an important effect on lowering anxiety. This relates to the idea that mothers feel less stressed when they feel a higher feeling of parental self-efficacy (Razurel et al., 2017). With the help of the spouse, parenting can be more manageable and effective, and the mother may feel an increase in their parental self-efficacy. With this in mind, there is a strong need for further research on the patterns of maternal anxiety from pregnancy to parenthood (Grant et al., 2008). Further examining the mother-child dyad may help with the development of new interventions that not only help alleviate symptoms of maternal anxiety, but also aid the child's cognitive development.

Furthermore, additional controls could be added, such as sex, considering there may be a difference in cognitive control development between young girls and boys. Considering this difference may provide additional information that could be helpful to parents raising different sexes of children. One significant consideration would include a study discussing the effect that maternal depression may have on children's cognitive control, as opposed to maternal anxiety. Maternal depression and maternal anxiety often overlap and can affect mothers simultaneously.

Because of this, our findings on maternal anxiety are notable and can be used to increase understanding of the mother-child dyad. Finally, it is important to address how different parenting styles and behaviors may influence the relationships between cognitive control and maternal anxiety. This can include whether the child was placed in a preschool or daycare program, if the child comes from a single-parent household, or if the child has siblings. Controlling for these differences may provide a clearer understanding of this bidirectional association.

In sum, this work offers novel insights into the relationships between maternal anxiety and children's cognitive control over time. Using our measures of maternal anxiety and N2, we have shown that maternal anxiety is stable over time and that increases in maternal anxiety predict increases in maternal anxiety later on from ages three to five. Similarly, we have shown that N2 is stable over time, and increases in N2, or cognitive control, predict increases in N2 later on from ages three to five. This study provides a basis for future longitudinal research identifying the relationships between maternal anxiety and children's cognitive control and the factors that influence these variables.

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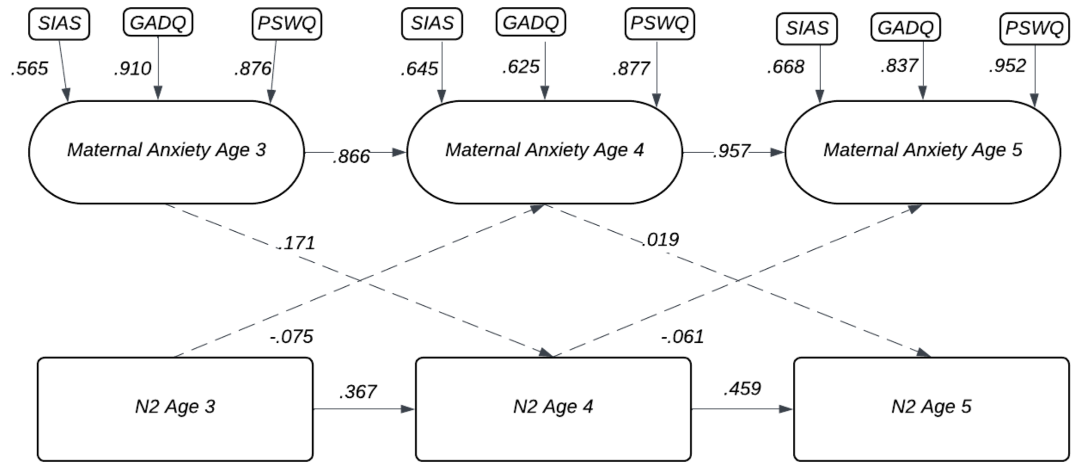
APPENDIX



Note. For readability, only primary pathways are shown in the figure. Dashed paths are nonsignificant.

Figure A.1: Visualization of the Experimental Paradigm

```
RMSEA (Root Mean Square Error Of Approximation)
          Estimate                             0.127
          90 Percent C.I.                      0.099  0.156
          Probability RMSEA <= .05             0.000
```

Figure A.2: RMSEA

STANDARDIZED MODEL RESULTS

STDYX Standardization

		Estimate	S.E.	Est./S.E.	Two-Tailed P-Value
MANX3	BY				
PSWQ3		0.874	0.043	20.563	0.000
SIAS3		0.559	0.075	7.427	0.000
GADQ3		0.912	0.039	23.433	0.000
MANX4	BY				
PSWQ4		0.878	0.045	19.671	0.000
SIAS4		0.646	0.071	9.141	0.000
GADQ4		0.618	0.081	7.645	0.000
MANX5	BY				
PSWQ5		0.951	0.027	34.873	0.000
GADQ5		0.838	0.043	19.414	0.000
SIAS5		0.660	0.066	10.014	0.000
MANX4	ON				
MANX3		0.860	0.048	17.864	0.000
MANX5	ON				
MANX4		0.943	0.042	22.427	0.000
N24	ON				
N23		0.372	0.113	3.304	0.001
N25	ON				
N24		0.457	0.102	4.496	0.000

Figure A.3: Values Denoting Stability of Maternal Anxiety and N2 Over Time

STANDARDIZED MODEL RESULTS

STDYX Standardization

	Estimate	S.E.	Est./S.E.	Two-Tailed P-Value
MANX3 BY				
PSWQ3	0.876	0.042	21.022	0.000
SIAS3	0.565	0.075	7.585	0.000
GADQ3	0.910	0.038	23.902	0.000
MANX4 BY				
PSWQ4	0.877	0.045	19.569	0.000
SIAS4	0.645	0.070	9.188	0.000
GADQ4	0.625	0.080	7.786	0.000
MANX5 BY				
PSWQ5	0.952	0.027	34.965	0.000
GADQ5	0.837	0.043	19.378	0.000
SIAS5	0.668	0.065	10.279	0.000
MANX4 ON				
MANX3	0.866	0.049	17.759	0.000
MANX5 ON				
MANX4	0.957	0.044	21.976	0.000
MANX4 ON				
N23	-0.075	0.101	-0.750	0.453
MANX5 ON				
N24	-0.061	0.075	-0.809	0.419
N24 ON				
MANX3	0.171	0.131	1.310	0.190
N25 ON				
MANX4	0.019	0.129	0.147	0.883
N24 ON				
N23	0.367	0.113	3.254	0.001
N25 ON				
N24	0.459	0.104	4.418	0.000

Figure A.4: Values Denoting Cross-Leg Relationships Between Maternal Anxiety and N2 Over Time