PSYCHOSOCIAL DEPRIVATION AND WORKING MEMORY: A PRELIMINARY INVESTIGATION OF NEURAL EFFICIENCY

by

ZEHUA CUI

(Under the Direction of Assaf Oshri)

ABSTRACT

Developmental cognitive neuroscience is an interdisciplinary field seeking to elucidate the neural basis of cognitive development. With the advent of functional magnetic resonance imaging (fMRI), researchers have greatly informed our understanding of brain mechanisms subserving complex neurocognitive processes, such as working memory. Extant neuroimaging research has revealed core functional neuroanatomical underpinnings of working memory, a fundamental executive function that underlies youth's cognitive and behavioral development. Despite the knowledge gained on the links between working memory-associated neural and behavioral response, current investigations of brain-behavior relations are often devoid of environmental contexts, and thus leave out knowledge of individual differences. Specifically, little research has examined how exposure to adverse rearing environments accounts for variability in the brain-behavior relation. This variability in the brain-behavior relation is conceptualized as neural efficiency. Psychosocial deprivation, characterized by an absence of cognitive and positive social stimulation, has been shown to compromise children's neurocognitive development. Hence, informed by an ecological approach to developmental neuroscience, the primary aim of the present study is to investigate if psychosocial deprivation serves as a moderator in the association between neural response and behavior during a working memory task (i.e., neural efficiency). To investigate this research aim, I utilized data from the Adolescent Brain Cognitive Development study, which includes neuroimaging and self-report survey data from children (N = 11, 878, M_{age} = 9.48, 47.8% female, 52.0% White) and their primary caregivers. All study hypotheses were tested within a structural equation modeling framework. Results showed that psychosocial deprivation significantly attenuated the positive association between working memory-related neural activation within the frontoparietal network and attendant behavioral performance. Additionally, psychosocial deprivation significantly intensified the negative association between neural deactivation within the default mode network and behavioral performance during working memory challenges. These results suggest that psychosocial deprivation can compromise children’s working memory-related neural efficiency. Prevention and intervention programs may promote neural efficiency among children in deprived environments by creating a more cognitively and socially stimulating environment and providing working memory training.

INDEX WORDS: Early life stress; Psychosocial deprivation; Working memory; Neural efficiency; Neural compensation; Preadolescence; Frontoparietal network; Default mode network

PSYCHOSOCIAL DEPRIVATION AND WORKING MEMORY: A PRELIMINARY INVESTIGATION OF NEURAL EFFICIENCY

by

ZEHUA CUI

B.A., Shanghai University, China, 2012

A.M., the University of Chicago, 2014

A Dissertation Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

DOCTOR OF PHILOSOPHY

ATHENS, GEORGIA

2022

PSYCHOSOCIAL DEPRIVATION AND WORKING MEMORY: A PRELIMINARY INVESTIGATION OF NEURAL EFFICIENCY

by

ZEHUA CUI

Major Professor:	Assaf Oshri
Committee:	Steven Kogan
	Lawrence Sweet

Electronic Version Approved:

Ron Walcott
Vice Provost for Graduate Education and Dean of the Graduate School
The University of Georgia
August 2022

ACKNOWLEDGEMENTS

First and foremost, I am deeply grateful to my primary advisor, Dr. Assaf Oshri, for his mentorship, support, and patience during my doctoral study. I have learned so much from his knowledge and insights in research on youth development of risk and resilience. I am also thankful for Dr. Oshri’s unending encouragement for me to develop as a confident and independent scientist. I would also like to extend my immense gratitude to my committee members Dr. Steven Kogan and Dr. Lawrence Sweet, for providing their guidance and encouragement, as well as imparting great knowledge in their respective field. I also would like to thank Dr. Emilie Smith for her continuous support during my doctoral study and sharing her insights with me on critical issues related to positive youth development.

I am also extremely thankful for the friendship, encouragement, and support from my peers in HDFS and past and current members at YDI (Alp, Ava, Cory, Cullin, Erinn, Linhao, Landry, Rabeeh, Sihong). I have learned so much from working alongside you all. I am exceedingly grateful for my parents who have always believed in me, and for the love and support from my boyfriend Xiao Qiu who has always been by my side, pushing through graduate school together.

Last but certainly not least, I would like to acknowledge the generous support of the Graduate School and the Presidential Graduate Research Fellowship. It was such a great honor to receive this award and I am grateful for this incredible opportunity to pursue my doctoral study at the University of Georgia.

TABLE OF CONTENTS

Page

LIST OF TABLES

Page

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Understanding the neurobiological bases of behaviors across the life span is among the fundamental goals of developmental cognitive neuroscience (Munakata, Casey, & Diamond, 2004). The advent of neuroimaging methods, such as functional Magnetic Resonance Imaging (fMRI), provides us with direct quantification and visualization of neural functions (D. B. Clark et al., 2013). Using fMRI, neural activity can be regionally estimated and inferred through blood-oxygen-level-dependent (BOLD) signal — a measure of localized changes in brain blood flow and oxygenation during task engagement (Buxton, 2013; Ekstrom, 2010; Hillman, 2014). Strength and patterns of BOLD signals are typically examined in associations with cognitive and behavioral experimental manipulations (J. E. Chen & Glover, 2015; Glover, 2011). The utilization of fMRI to measure brain function in vivo has greatly illuminated our understanding of neural correlates of cognition and behavior.

Despite the knowledge that scientists have gained on links between brain function and behavior using fMRI methods, a key challenge remains: to account for the heterogeneity in associations between behavior and neural activity. Little research has examined how exposure to adverse rearing environment accounts for variability in the association between brain responses and behavior. The aim of the proposed dissertation is to evaluate whether environmental psychosocial deprivation, a form of early life stress (ELS) moderates the link between neural activity and behavioral performance during a working memory task. To that end, I will first introduce psychosocial deprivation as a critical context that may modulate the link between neural activity and behavior associated with working memory, a critical domain of executive function. Next, I will present neural efficiency as a concept that could shed light on individual differences in this brain-behavior relation. Lastly, I will propose a model in which brain-behavior associations can be more accurately delineated in varying psychosocial contexts, and to explore neural processes that support the preservation of cognitive functioning (e.g., manifested as the maintenance of working memory performance) in a deprived psychosocial context.

Working Memory Related Brain-Behavior Relation

Working memory is broadly defined as a complex cognitive system responsible for the temporary holding and manipulation of information (Baddeley, 1992; Chai, Abd Hamid, & Abdullah, 2018). It is a fundamental executive function involved in information processing, learning, reasoning, problem-solving, planning, and carrying out everyday behaviors (Chai et al., 2018; Cowan, 2008). Extant research has linked deficits in working memory to a range of developmental outcomes among youth, including impulsive decision making, substance use risk, poor social competence, and low academic achievement (McQuade, Murray-Close, Shoulberg, & Hoza, 2013; Oshri, Hallowell, et al., 2019; Rogers, Hwang, Toplak, Weiss, & Tannock, 2011; Romer et al., 2009).

Extant fMRI studies have revealed core functional neuroanatomical underpinnings of working memory, including the dorsolateral prefrontal cortex, inferior parietal lobule, and supplementary motor area (Braver et al., 1997; B. Casey et al., 1995; B. J. Casey et al., 2018; J. D. Cohen et al., 1997; Curtis & D'Esposito, 2003; Owen, McMillan, Laird, & Bullmore, 2005; Owens, Duda, Sweet, & MacKillop, 2018). These bilateral regions comprise nodes of the executive control network (ECN), which serves as a flexible hub supporting diverse cognitive processes and other executive functions (Owens et al., 2018; Zanto & Gazzaley, 2013). In addition to these activated brain areas during working memory tasks (i.e., task-positive regions), a group of brain regions such as the bilateral medial prefrontal cortex, posterior cingulate cortex, and inferior parietal lobe, collectively form the default mode network, which decreases levels of activity during working memory tasks (i.e., task negative regions; Owens et al., 2018). Despite these consistent patterns of neural responses linked to working memory, studies rarely investigate the individual differences in the neural response and behavioral performance relation as a function of exposure to ELS.

Psychosocial Deprivation as a Dimension of ELS

A recent dimensional conceptualization of ELS suggests that early life adversities are classified into three main dimensions – *threat, deprivation, and unpredictability* (McLaughlin, Sheridan, Humphreys, Belsky, & Ellis, 2021; McLaughlin, Sheridan, & Lambert, 2014). The *threat* dimension includes stressful experiences that could pose harm or potential harm to a child's physical integrity, such as physical, emotional, and sexual abuse, as well as domestic and community violence exposure (Liu, Cui, Duprey, Kogan, & Oshri, 2020; Sheridan & McLaughlin, 2014; L. Zhang, Cui, Sasser, Carvalho, & Oshri, 2022). *Unpredictability* encompasses spatial and temporal variation in environmental harshness (e.g., family or community violence; Ellis, Figueredo, Brumbach, & Schlomer, 2009; McLaughlin et al., 2021). *Deprivation*, in particular, *psychosocial deprivation* refers to an absence of cognitive and social stimulation in the rearing environment that is essential to healthy neurocognitive development (e.g., institutional rearing, physical and emotional neglect; Bick, Fox, Zeanah, & Nelson, 2017; McLaughlin, Sheridan, & Lambert, 2014). Children growing up in a psychosocially deprived environment may lack consistent and responsive caregiving, opportunities for adult and peer interaction, as well as enriching cognitive and social experiences in the home and school environment. The lack of environmental stimulation and complexity in psychosocial inputs that characterize deprivation is hypothesized to negatively affect brain regions that support the development of higher-level cognitive processes (McLaughlin, Sheridan, & Lambert, 2014). Therefore, the present study focuses on experience of psychosocial deprivation, as it is expected to be more strongly associated with worse executive function among children than other types of adverse experiences (e.g., threat).

Psychosocial Deprivation as a Context for Altered Brain-Behavior Relations during Working Memory

The negative impact of psychosocial deprivation may be severe as it is documented to exert persistent harmful effects on children's neurocognitive development (Humphreys et al., 2020). Developmental research has greatly improved our knowledge of how ELS, such as psychosocial deprivation, gets "beneath the skin" and casts a lasting influence on one's physiological and neurobiological systems (Berens, Jensen, & Nelson, 2017; Nelson III, Zeanah, & Fox, 2019). A rapidly growing number of studies have elucidated mechanisms, such as altered brain development, through which adversity becomes *"biologically embedded*" (Aristizabal et al., 2020; Berens et al., 2017; Ehrlich, Ross, Chen, & Miller, 2016; Miller, Chen, & Parker, 2011).

From the perspective of biological embedding of ELS, environmental psychosocial deprivation may lead to perturbations in developmental processes by altering children's stress physiology and, consequently, brain development (Berens et al., 2017; Hertzman, 2012). Evidence from psychophysiological and neuroimaging research shows that deprivation can result in dysregulations of children's stress response systems, culminating in disrupted neural development in core brain regions that support children's executive functioning, and in particular working memory (Hanson et al., 2013; Oshri, Hallowell, et al., 2019). In addition to excessive stress, children raised in psychosocially deprived environments lack enriching and stimulating experiences essential for healthy brain and cognitive development (Bick et al., 2017). The absence of critical cognitive stimulation and positive social interactions have been linked to enduring changes in children's neural development subserving executive function (Bick et al., 2017; Eluvathingal et al., 2006; Mehta et al., 2009). Indeed, emerging evidence from both behavioral and neuroimaging research has shown the impact of ELS on youth’s working memory related behavioral performance and neural responses (D. Johnson et al., 2021; Sheridan, Peverill, Finn, & McLaughlin, 2017). Therefore, psychosocial deprivation, a form of ELS, might constitute a putative context to investigate the brain-behavior relation specific to executive function (i.e., working memory).

Brain-Behavior Relations: Neural Efficiency

One core question that helps to advance our inquiry of the heterogeneity in the brain-behavior associations is how efficiently neural activity is translated to behaviors and whether this relative efficiency varies by individual. Neural efficiency describes the degree to which neural responses are elicited to effectively perform a task (Barulli & Stern, 2013; Li & Smith, 2021; Ramchandran, Zeien, & Andreasen, 2019). In the present study, neural efficiency is defined as the strength of the relation between brain function and behavioral performance during a cognitive (i.e., working memory) task. Hypothesis regarding individual differences in neural efficiency have been investigated often with aging populations, but rarely among individuals exposed to ELS (Cabeza et al., 2004; Grady, 2012; Philip et al., 2016; Poldrack, 2015). For instance, multiple studies have shown that increased activation in task-relevant brain regions do not relate to increases in performance among older adults, reflecting decreases in neural efficiency (Colcombe, Kramer, Erickson, & Scalf, 2005; Morcom & Henson, 2018; Zarahn, Rakitin, Abela, Flynn, & Stern, 2007). In a study on ELS and working memory, Philip et al. (2016) found that participants exposed to childhood trauma (i.e., child maltreatment) exhibited greater brain activation in the inferior parietal lobule and inferior frontal gyrus, but worse behavioral performance than the control group.

Individual differences in neural efficiency have also been reported in studies that investigate neural compensatory effects. Neural compensation refers to a process by which greater task-related neural activation is elicited or greater task-unrelated baseline processing is suppressed to support the same level of behavioral performance during cognitive tasks *potentially due to loss of neural efficiency* (Cabeza et al., 2004; Mattay et al., 2006; Philip, Sweet, Tyrka, Price, Carpenter, et al., 2013; Sweet, Rao, Primeau, Durgerian, & Cohen, 2006). For example, Mattay et al. (2006) found that senior study participants had equivalent working memory performance as younger participants, but exhibited greater prefrontal cortical activity. Additionally, Duda, Owens, Hallowell, and Sweet (2019) revealed that older adults who performed well on a working memory task elicited more deactivation relative to baseline in the default mode network. In another neuroimaging study on ELS and working memory, Philip, Sweet, Tyrka, Price, Carpenter, et al. (2013) showed that study participants who were exposed to ELS demonstrated greater deactivation in the task-negative brain regions during a working memory task compared to non-ELS controls. This body of research converges to suggest that the link between neural response and behavior maybe modulated by factors such as aging or exposure to life adversity (Philip et al., 2016; Philip, Sweet, Tyrka, Price, Carpenter, et al., 2013). In addition, the research on neural compensation provides insights into neural mechanisms that individuals invoke to preserve cognitive functioning despite losses of neural efficiency.

The Present Study

A large body of literature has shown that brain-behavior relations can be modulated by individual level differnces such as aging (Grady, 2012). Yet, research that investigates the effect of ELS dimensions, and in particular psychosocial deprivation, on the link between working memory related neural activity and behavioral performance remains scarce. Thus, the present study aims to investigate how neural efficiency in a working memory task is modulated by the context of psychosocial deprivation. Specifically, I will test whether psychosocial deprivation moderates the association between neural responses to a working memory task (in both task-positive and task-negative brain regions) and attendant behavioral performance (See Figure 1).

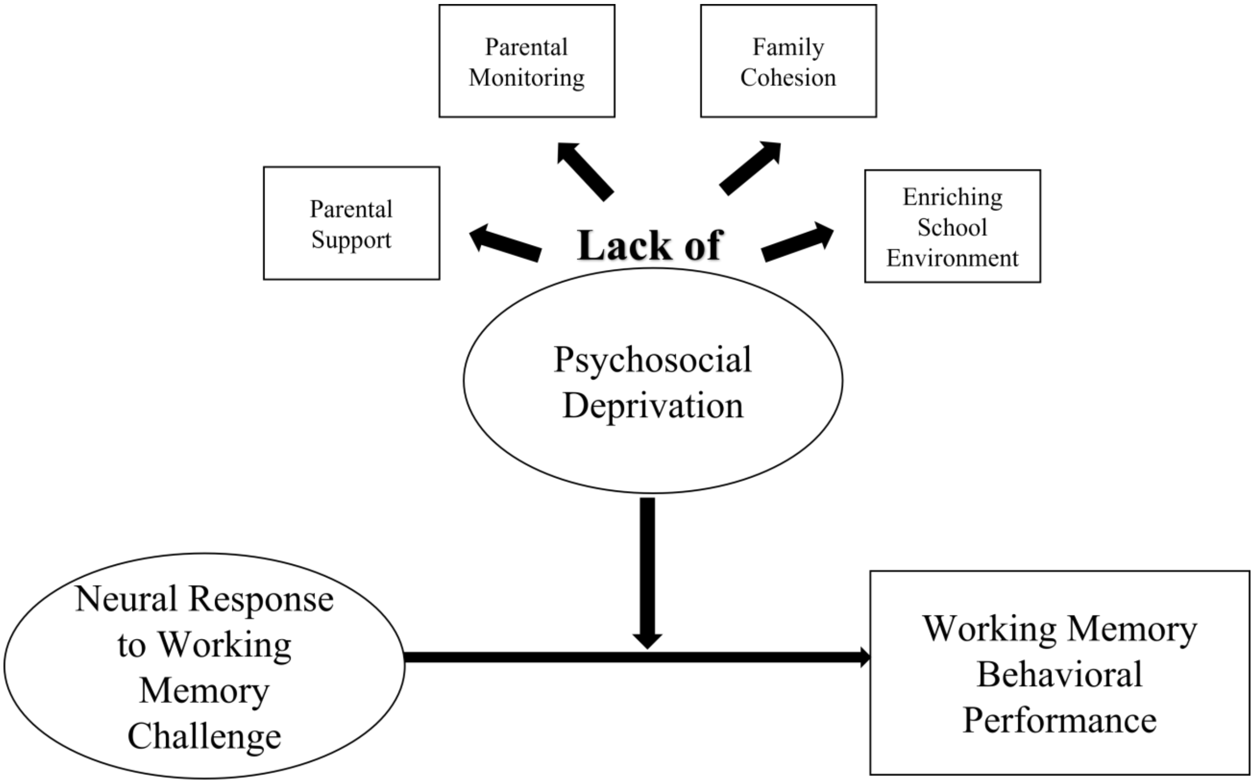


Figure 1. Conceptual framework: Neural efficiency in Psychosocially Deprived Context.

Significance and Overview of Study

Decades of research have made it clear that adverse childhood experiences constitute a critical public health issue as they interrupt normative development, leading to heightened risks for impairment in executive function (Dodaj, Krajina, Sesar, & Šimić, 2017; Lambert, King, Monahan, & McLaughlin, 2017; Masten et al., 2012). These cognitive deficits may subsequently lead to the development of psychopathology across the life span (Huang-Pollock, Shapiro, Galloway-Long, & Weigard, 2017; McDermott et al., 2013; Zelazo, 2020). Studies using nationally representative samples have suggested that adverse childhood experiences contribute to up to 45% of child-onset and over 30% of adult-onset psychiatric disorders (Green et al., 2010; Herzberg & Gunnar, 2020; McLaughlin et al., 2010). Given these grave consequences, it is critical to continue investigating the neurobiological processes disrupted by ELS and identify mechanisms that contribute to the development of resilience. This knowledge will inform prevention and intervention efforts that aim to promote health and well-being among youth growing up in adverse rearing contexts.

In spite of a growing body of research that focuses on psychosocial deprivation and children's development of executive function, gaps in knowledge remain in the literature (Bos, Fox, Zeanah, & Nelson Iii, 2009; McDermott et al., 2013). First, scarce research exists on neural and behavioral correlates of working memory in the context of psychosocial deprivation using community samples of youth. Our understanding of child brain development and functioning following psychosocial deprivation comes primarily from studies on children raised in institutions (McDermott et al., 2013). Nevertheless, psychosocial deprivation constitutes a core dimension of a wide range of experiences that cut across multiple ecological contexts and affects children of diverse backgrounds. Therefore, more research is needed to understand how psychosocial deprivation impacts working memory related neural functioning and behavioral performance utilizing diverse samples of children and youth.

Second, to date, there are few studies incorporating both fMRI and behavioral correlates to investigate brain-behavior relation specific to working memory in the context of psychosocial deprivation among youth (Oshri, Hallowell, et al., 2019; Philip et al., 2016; Philip, Sweet, Tyrka, Price, Carpenter, et al., 2013). Although behavioral research contributes significantly to our knowledge of the impact of psychosocial deprivation on children's executive function, developmental cognitive neuroscience research may further shed light on the underlying neural processes. Furthermore, emerging neuroimaging studies have revealed variations in patterns of neural responses and behaviors during cognitive tasks that assess executive function among youth exposed to ELS (Fava et al., 2019; Lim et al., 2015). These findings highlight the importance of further investigating neural and behavioral correlates simultaneously as well as the role of ELS in modulating brain-behavior relations.

In order to address these gaps in extant literature and provide informative empirical evidence to better support the development of effective prevention and intervention efforts, the present study utilizes data from the Adolescent Brain Cognitive Development Study, which is composed of preadolescent children aged 9-10 (*N* = 11,878). The specific aim of the study is to investigate individual differences in neural efficiency as a result of exposure to psychosocial deprivation. Specifically, I aim to examine how exposures to environmental psychosocial deprivation affect the linkages between neural responses and behavioral output during a working memory task. The current study seeks to augment the literature by further elucidating neural mechanisms that underlie the link between psychosocial deprivation and youth's working memory.

CHAPTER 2

THEORETICAL PERSPECTIVES AND LITERATURE REVIEW

In the current chapter, I will review theoretical and empirical literature that will be used to generate my central thesis: environmental psychosocial deprivation, a form of contextual ELS that moderates the link between neural responses and behavioral performance during a working memory task. To that end, I will present a) an introduction to developmental cognitive neuroscience as an interdisciplinary field that advances our understanding of neurobiological bases of cognition and behavior as well as neural development in context; b) the neural basis of cognition and behavior: the role of working memory in youth's development and the functional neural substrates underlying working memory; c) on individual differences in brain-behavior relations: the concept of neural efficiency; d) on considering development in environmental contexts; e) on theoretical perspectives and models informing research on ELS: rationale for the focus on psychosocial deprivation as a salient context for altered brain-behavior relation during working memory; and f) on current findings of behavioral and neuroimaging research on psychosocial deprivation and working memory.

Developmental Cognitive Neuroscience

In this section, I review developmental cognitive neuroscience as a framework for studying the neural bases of cognition and behavior and neural development in the environmental context.

Developmental Cognitive Neuroscience: Understanding Neurocognitive Processes

Developmental cognitive neuroscience is an evolving interdisciplinary field that is dedicated to studying the relation between neural and cognitive development across the life span (Munakata et al., 2004). It draws upon knowledge and methods from disciplines within psychology, human development, other social sciences, and neuroscience, with the goal of illuminating the neurobiological bases of cognition and behavior across development (Munakata et al., 2004). One of the central questions that developmental cognitive neuroscience attempts to address is how cognitive development is supported by underlying development of brain structures and functions (M. H. Johnson & De Haan, 2015). With the increased accessibility and quality of neuroimaging tools for measuring brain structure and function, as well as, carefully designed behavioral challenges, researchers have made substantial progress in understanding the neural basis of the development of cognitive functions (Wade et al., 2018).

One of the most used brain imaging technologies that shaped the progress of developmental cognitive neuroscience is functional magnetic resonance imaging (fMRI; Matejko & Ansari, 2012). fMRI provides scientists with a noninvasive way to directly quantify and map neural functions in vivo. When a brain region becomes actively engaged in external cognitive stimuli, more oxygen is transported through blood vessels as oxygenated hemoglobin to support these neurons (Matejko & Ansari, 2012). Hence, localized changes in brain blood flow and oxygenation ratio, namely, the blood-oxygen-level-dependent (BOLD) signal detected by fMRI, can then be used to infer changes in brain function. The utilization of fMRI has greatly informed our understanding of brain mechanisms subserving cognitive processes such as language, attention, and memory. For example, in fMRI studies of working memory, participants are often asked to perform a memory challenge with alternating task conditions (e.g., block design with low, high, and no working memory demands). These carefully designed paradigms allow researchers to link brain activity patterns, neurocognitive processes, to behavioral output (Fair, Dosenbach, Moore, Satterthwaite, & Milham, 2021).

In addition to understanding normative neurocognitive development, developmental cognitive neuroscience also investigates how social and environmental factors such as adverse childhood experiences influence neurodevelopmental processes and cognitive functioning (Sheridan & McLaughlin, 2022). A rapidly growing body of literature describes how behavioral performance and variations in patterns of neural activity during neurocognitive tasks (e.g., of executive functions) differ as a result of exposure to environmental adversity (D'angiulli, Lipina, & Olesinska, 2012; Oshri, Hallowell, et al., 2019). One exciting line of inquiry examines the heterogeneity in neurobehavioral functioning despite similar performance on cognitive tasks (Philip, Sweet, Tyrka, Price, Carpenter, et al., 2013). These emerging findings highlight the need to continue to investigate the complex interplay of rearing environment and neural processes in shaping youth's cognitive and behavioral development.

Working Memory: Roles in Development and Neural Underpinnings

In the paragraphs below, I review the role of working memory in development, as well as its neural underpinnings.

The Role of Working Memory in Development

Working memory refers to cognitive processes responsible for the temporary storage and manipulation of small amounts of information used to perform complex cognitive tasks (Baddeley, 1992; Chai et al., 2018; Cowan, 2014; Rosenberg et al., 2020). Working memory plays a central role in youths' cognitive development, as many aspects of cognitive processes depend on one's ability to retain and manipulate information for a relatively short period of time (Cowan, 2014). For example, to make informed decisions, individuals hold multiple pieces of information simultaneously, evaluate them, and generate options (Del Missier et al., 2013). To solve a word problem in math, children need to retain the problem and available numerical information in mind, while figuring out what mathematical operations to use. Therefore, working memory has been regarded as a foundational executive function involved in information processing, problem-solving, learning, reasoning, decision-making, and goal-directed behaviors (Baddeley, 1992; Chai et al., 2018). Extant research shows that there are significant individual differences in working memory, and these differences are predictive of various developmental outcomes, including internalizing and externalizing behaviors, substance use risks, social competence, and academic achievement (Huang-Pollock et al., 2017; Tulsky et al., 2014; Xu, Adam, Fang, & Vogel, 2018).

Indeed, multiple investigations have reported links between working memory and youth's academic and mental health outcomes (Andersson, 2008; Aronen, Vuontela, Steenari, Salmi, & Carlson, 2005; Flouri, Ruddy, & Midouhas, 2017; Gerst, Cirino, Fletcher, & Yoshida, 2017). For example, using a sample of 6-13-year-old school children, Aronen et al. (2005) investigated the association between working memory and children's academic achievement and psychiatric symptoms. Children's working memory was measured through a 0-, 1-, and 2-back audiospatial and visuospatial working memory task. In the visuospatial 0-back task, children were asked to press "match" (i.e., the left button of a mouse) if the visual stimuli (i.e., light gray squares) appeared in a pre-determined location, and to press "no match" (i.e., the right button of a mouse) if any other location. In the visuospatial 1-back and 2-back task condition, children were instructed to respond with "match" and "no match" to the stimulus one trial back (i.e., 1-back) and two trials back (i.e., 2-back), respectively. The audiospatial working memory task followed the same procedure as the visuospatial task, but with auditory stimuli (i.e., tones of 2250 Hz). Children's working memory behavioral performance (e.g., percentage of incorrect responses) at different memory load levels were averaged into one mean score. The authors found that more incorrect responses in the auditory task were significantly linked to poorer academic performance at school. Additionally, poor auditory or visual working memory performance was significantly associated with increased attention problems and internalizing symptoms (e.g., anxiety, depression). This study provides empirical evidence showing that poor working memory is associated with compromises in various youth's outcomes.

Further, multiple studies have shown connections between working memory and substance use risks (Bechara & Martin, 2004; Khurana et al., 2013; Khurana, Romer, Betancourt, & Hurt, 2017). For example, Peeters, Monshouwer, Janssen, Wiers, and Vollebergh (2014) identified poor working memory functioning as a risk factor for youth's alcohol use. In this study, the authors recruited a sample of 8th grade adolescents who exhibited externalizing behavioral problems such as aggression, attention problems, and/or hyperactivity. Youth's working memory was assessed by the self-ordered pointing task (SOPT). In this task, youth were shown pictures of everyday objects presented in a grid and asked to follow two sets of instructions: 1) select a different picture each time and 2) do not select the same location of the picture twice in a row. The mean of the percentages of error scores over all trials was taken as the total SOPT score, such that a higher SOPT score indicated poorer working memory functioning. The results showed that reduced working memory was predictive of adolescents' alcohol use 6 months later.

Working memory has also been linked to children's social functioning (Benavides-Nieto, Romero-López, Quesada-Conde, & Corredor, 2017; Caporaso, Boseovski, & Marcovitch, 2019; McQuade et al., 2013). For instance, using a sample of typically developing elementary school children, McQuade et al. (2013) examined the association between working memory and children's social functioning. Children's verbal and spatial working memory was measured through the backward administration of Digit Span task and Finger Windows, respectively. In the Digit Span backward task, children were asked to repeat a series of orally presented numbers in reverse order. In the Finger Windows backward task, research assistants would touch a pencil through a series of holes in a specific order on an 8-11-inch card and asked the children to reproduce the sequence in reverse order by inserting their fingers through the holes. The results revealed that working memory impairment was linked to increased peer rejection, physical and relational aggression, poor conflict resolution skills, and worse overall social competence.

In addition to the direct association with youth's adjustment, working memory may help promote the development of resilience in situations of adversity such as socioeconomic hardship and trauma exposures (Masten et al., 2012; Wingo, Fani, Bradley, & Ressler, 2010; L. Wu et al., 2021). As a core component of executive function, working memory allows youth to integrate verbal and/or nonverbal information to plan ahead, make informed decisions, solve problems, and regulate emotions, thereby facilitating their positive adaptation to stressful environments (Bemath, Cockcroft, & Theron, 2020; Sara M Levens, Armstrong, Orejuela-Dávila, & Alverio, 2017; Sara M. Levens & Gotlib, 2010). Indeed, multiple investigations have reported the resilience-promoting effect of increased working memory (Bemath et al., 2020; Wingo et al., 2010). Avci et al. (2013) found that better working memory was associated with resilient functioning (e.g., positive attitudes and knowledge about oneself; positive relationship with caregivers) among a sample of youth exposed to poverty, family dysfunction, and traumas. In a recent study, Zhou, Yu, Dong, and Zhang (2022) revealed that increased working memory mitigated the effects of stressful life events (e.g., academic stress, bereavement, interpersonal pressure) on children's socioemotional difficulties. Given the vital role of working memory in promoting youth’s positive adjustment and resilience, there is a need for further understanding individual differences that account for variability in the brain-behavior connections during working memory tasks. This knowledge may help inform intervention programs designed to promote youth development through enhancing their cognitive skills (e.g., working memory).

Neural Underpinnings of Working Memory

Working memory is an essential construct in cognitive neuroscience as it plays a central role in supporting most higher-order complex cognitive functions, such as learning and problem-solving (Moser et al., 2018). As such, multiple studies have investigated the neural substrates of working memory (Owen et al., 2005; Owens et al., 2018; Rosenberg et al., 2020; Yaple, Stevens, & Arsalidou, 2019). Converging evidence revealed a core network underlying working memory, including the bilateral dorsolateral prefrontal cortex (superior [SFG], middle [MFG], and inferior frontal [IFG] gyri), dorsomedial prefrontal cortex (supplementary motor area of the SFG), inferior (IPL) and superior (SPL) parietal lobule, and insula (Braver et al., 1997; B. Casey et al., 1995; B. J. Casey et al., 2018; J. D. Cohen et al., 1997; Curtis & D'Esposito, 2003; Owen et al., 2005; Owens et al., 2018). In addition to these task-positive regions that evince increased activity during working memory challenges, there is a network of brain regions that display task-induced deactivations relative to baseline (i.e., task-negative regions; Anticevic, Repovs, Shulman, & Barch, 2010; Sweet et al., 2008). These relative deactivations correspond closely to the more widely known default mode network, which includes the bilateral medial prefrontal, posterior cingulate, and inferior parietal cortices (Buckner, Andrews-Hanna, & Schacter, 2008). The default mode network is most active at rest and least active when external cognitive demands are present (Buckner, Andrews‐Hanna, & Schacter, 2008).

Task-positive Regions associated with Working Memory.

Superior Frontal Gyrus. The superior frontal gyrus (SFG) is a large region situated in the prefrontal cortex. It covers about 1/3 of the human frontal lobe (Nissim et al., 2017). The SFG is thought to contribute to higher cognitive functions, such as proactive control of impulsive response, and in particular, working memory (Boisgueheneuc et al., 2006; S. Hu, Ide, Zhang, & Li, 2016). In a study of patients with a left SFG lesion, Boisgueheneuc et al. (2006) found that those patients exhibited significant deficits in working memory compared to the control groups, and these deficits were magnified with the increases in task complexity. Alagapan, Lustenberger, Hadar, Shin, and Fröhlich (2019) also demonstrated that low-frequency direct cortical stimulation of the superior frontal gyrus enhanced study working memory performance.

Supplementary Motor Area. The supplementary motor area (SMA), located in the medial and superior part of the SFG, has been consistently implicated in cognitive processes, including working memory (Cañas, Juncadella, Lau, Gabarrós, & Hernández, 2018). For instance, Cañas et al. (2018) found that patients with lesions involving the SMA exhibited worse working memory performance than healthy controls. Neurons in the SMA respond to external stimuli and mediate planning and initiation of motor movements (Kaas & Stepniewska, 2002). During fMRI visuospatial working memory tasks, study participants are usually asked to make button presses corresponding to “match” or “no match”. As such, the neural activity observed in the SMA might reflect their preparation and execution of purposeful movements in response to cognitive stimuli (B. Casey et al., 1998).

Dorsolateral Prefrontal Cortex. The prefrontal cortex, which lies anterior to the precentral gyrus, has been implicated in subserving complex cognitive behaviors (Friedman & Robbins, 2022). The dorsal lateral prefrontal cortex (dlPFC) centered on the middle frontal gyrus of the human prefrontal cortex is specifically linked to executive functions such as working memory, selective attention, maintaining abstract rules, and inhibiting inappropriate responses (Curtis & D'Esposito, 2003; Kobayashi, 2009). The role of the dlPFC in manipulating and maintaining information in memory (i.e., working memory) has been particularly well-documented (B. J. Casey et al., 2018; G. Zhang, Yao, Zhang, Long, & Zhao, 2013). In a study conducted among a group of brain-injured and neurologically healthy veterans, Barbey, Koenigs, and Grafman (2013) found that damage observed in the dlPFC was associated with deficits in manipulating information in working memory. Tsuchida and Fellows (2009) also found that lesions within the dlPFC were related to poor working memory task performance.

Inferior Frontal Gyrus (IFG). The pars opercularis, a sub-region of the inferior frontal gyrus (IFG), is also often found to be actively engaged during working memory tasks (Owens et al., 2018). The IFG is suggested to play a significant role in inhibitory control, defined as the ability to respond appropriately while suppressing inappropriate responses (Aron, Robbins, & Poldrack, 2004). In a meta-analysis using functional neuroimaging data, Neumann, Lohmann, Derrfuss, and Von Cramon (2005) found consistent involvement of IFG during inhibitory control. This is essential during working memory, as it is needed to inhibit the retrieval of, and responses to irrelevant stimuli that would otherwise decrease performance (Nissim et al., 2017).

Inferior and Superior Parietal Lobule. The inferior parietal lobule (IPL) is a core neural substrate that underpins diverse cognitive processes (Caspers et al., 2013). Situated at the convergence zone of visual, auditory, and somatosensory cortices, the IPL is implicated in visuospatial attention and sensorimotor integration (Caspers et al., 2013; Johns, 2014). The IPL is also found to be involved in motor planning and preparation, which is a subordinate cognitive and behavioral function essential to working memory tasks (Caspers et al., 2013; Caspers, Zilles, Laird, & Eickhoff, 2010). In a recent meta-analysis investigating the executive processes of working memory, Nee et al. (2013) also suggested the prominent role of the IPL in shifting and giving elaborative details about the focus of attention in working memory. This process is important when individuals need to keep mental representations of multiple items active. The superior parietal lobule (SPL), another subdivision situated at the top of the parietal lobule, is also found to be extensively involved in visuospatial perception and attention, processes that are integral to performing working memory tasks (Johns, 2014).

Insula. In addition to the frontal-parietal regions that support working memory, neural activity in the insula has been linked to working memory (Owens et al., 2018). The insula is a part of the cerebral cortex located deeply within the lateral fissure separating the frontal and parietal lobes from the temporal lobe (Cechetto & Topolovec, 2002; Uddin, Nomi, Hébert-Seropian, Ghaziri, & Boucher, 2017). The insula is thought to be involved in diverse functions such as interoception (i.e., perception of body's inner sensations), self-awareness, salience detection, emotion, and cognition (Uddin, Kinnison, Pessoa, & Anderson, 2014). The insula is also a key node of a salience brain network, which supports complex cognitive functions through connections with other networks to integrate relevant sensory, emotional, and cognitive information (Menon, 2015; Menon & Uddin, 2010). Yaple et al. (2019) suggested that the insula plays a role during working memory tasks as it enables individuals to filter various incoming sensory stimuli and stay focused on task-relevant stimuli.

Task-negative Regions associated with Working Memory.

Default Mode Network. Besides brain regions that are typically activated during working memory tasks, a group of brain regions such as the bilateral medial prefrontal cortex, posterior cingulate cortex, and inferior parietal lobe near the temporoparietal junction have been shown to decrease levels of baseline activity during working memory tasks (Owens et al., 2018). These task-negative brain regions overlap substantially with the Default Mode Network (DMN), which is more active when the brain is at rest and less active when there are external cognitive demands (Buckner et al., 2008). DMN activity has been specifically linked to internally directed or self-generated thoughts, such as mind-wandering, remembering the past, imaging the future, and thinking about oneself (Andrews-Hanna, Smallwood, & Spreng, 2014). The suppression of DMN during working memory tasks might reflect individuals' ability to reduce goal-irrelevant cognitive processes (e.g., mind-wandering) in support of goal-directed cognition and behaviors (Anticevic et al., 2012).

Individual Differences in the Brain-Behavior Relations: Neural Efficiency

Extant functional neuroimaging studies have revealed a consistent pattern of neural activity that supports working memory (Braver et al., 1997; J. D. Cohen et al., 1997; Owens et al., 2018; Rosenberg et al., 2020). Greater neural activity in task-positive regions has been generally associated with enhanced working memory performance (Chein, Moore, & Conway, 2011; Nyberg, Dahlin, Stigsdotter Neely, & Bäckman, 2009; Osaka et al., 2003; Ullman, Almeida, & Klingberg, 2014). Similarly, greater deactivation relative to baseline in task-negative regions have been linked to better working memory performance (Anticevic et al., 2010; Sweet et al., 2008). Despite the established links between working memory related neural response and behavioral performance, less is known on the environmental conditions that generate individual differences in the strength of this link. Given that adverse rearing environments has been associated with compromised neurocognitive development, ELS might be a context from which substantial individual differences in brain-behavior relation emerge. Such heterogeneity in the brain-behavior relation might be explained by individual disparities in neural efficiency as a result of exposure to ELS (Karlsgodt, 2015).

In general, neural efficiency is defined as the degree to which neural responses are elicited to effectively perform a task (Barulli & Stern, 2013). In the present study, neural efficiency describes the strength of relation between brain function and behavioral performance during a cognitive (i.e., working memory) task. In this regard, higher neural efficiency suggests a stronger relation between neural response and behavioral performance. On the other hand, functional over-recruitment of neural resources in task-positive regions or excessive relative deactivation in task-negative regions are regarded as markers of lower neural efficiency (Barulli & Stern, 2013; Qiu et al., 2019). In other words, lower neural efficiency is characterized by a weaker association (e.g., more disassociation) between brain response and behavioral performance. Hence, increases in neural response among people with low neural efficiency do not result in as much improvement in behavioral performance as individuals with high neural efficiency.

The concept of neural efficiency has been extensively applied to study and explain individual or group differences in the link between neural response and behavioral output among older adults (Grady, 2012; Poldrack, 2015). However, scarce research has investigated whether ELS affects neural efficiency among youth. In the aging literature, neural efficiency has been used to characterize individual differences in brain-behavior relations attributable to advancing age (Grady, 2012). Extant research shows that the aging brain undergoes a series of structural and functional changes (Farokhian, Yang, Beheshti, Matsuda, & Wu, 2017; Persson et al., 2005). Scholars have proposed that these neural changes accompanying aging might induce a loss of neural efficiency and make the brain work harder to meet external cognitive demands (Grady, 2012; Reuter-Lorenz & Cappell, 2008). These changes may include reductions in gray and white matter structures, loss of synaptic connections, loss of white matter integrity, and weaker neural network structural and functional connectivity (Carp, Gmeindl, & Reuter-Lorenz, 2010; Geerligs, Renken, Saliasi, Maurits, & Lorist, 2014; Kaup, Mirzakhanian, Jeste, & Eyler, 2011; Stern, 2009; Varangis, Habeck, Razlighi, & Stern, 2019).

For example, some studies have revealed that increased activity in task-relevant brain regions among older study participants does not always result in better behavioral performance, which reflects age-related declines in neural efficiency (Colcombe et al., 2005; Morcom & Henson, 2018). In a neuroimaging study conducted by Colcombe, Kramer, Erickson, & Scalf (2005), the authors found that a subgroup of older adults exhibited increased cortical activation during an inhibitory control task but did not show increases in task performance. Similarly, in an fMRI study using a large sample of adults on a wide age spectrum, Morcom and Henson (2018) showed that older adults showed increased prefrontal activity during a memory task, but this additional neural recruitment did not result in significantly better task performance. These results suggest that neural resources were not used efficiently among older adults; greater neural responses did not translate into increases in behavioral performance (i.e., low neural efficiency).

Individual variations in the link between neural responses and behavioral output have also been reflected in aging literature, in which researchers investigated neurocompensatory effects in task-positive and task-negative brain regions (Duda et al., 2019; Grady, 2012). Neural compensatory activation is defined as the recruitment of greater neural resources in task-relevant brain regions or in additional brain regions that are typically not activated to maintain cognitive functioning (Cabeza, 2002; Cabeza, Anderson, Locantore, & McIntosh, 2002). Similarly, neural compensatory deactivation refers to greater suppression of task-unrelated activity to support cognitive performance (Duda et al., 2019). Within this body of literature, investigators typically examine age-related differences in neural responses when older adults demonstrated comparable behavioral performance as younger adults (Cabeza et al., 2004; Duda et al., 2019; Mattay et al., 2006). For example, Mattay et al. (2006) found that senior study participants had equivalent working memory performance as younger participants, but exhibited greater prefrontal cortical activity. Likewise, Cabeza et al. (2004) showed that older and younger adults in the study had similar behavioral accuracy during a working memory task, but older adults displayed greater activation responses in the prefrontal cortex. In addition, Duda et al. (2019) revealed that older adults who performed well on a working memory task elicited more deactivation relative to baseline in the default mode network. Such over-recruitment of task-positive neural resources or greater deactivation of task-negative regions to support successful cognitive performance have often been referred to as (successful) neural compensation (Duda et al., 2019; Grady, 2012). These neural compensatory processes appear to subserve the maintenance of cognitive functioning among older adults, but also may reflect their declining efficiency in performing cognitive tasks.

It is well established in the literature that ELS, including psychosocial deprivation, can negatively affect neurocognitive development (Ansell, Rando, Tuit, Guarnaccia, & Sinha, 2012; De Bellis et al., 2002; Hanson et al., 2013; Hanson et al., 2012; Tomoda et al., 2009). Despite the existing empirical evidence supporting individual differences in neural efficiency, scarce research has investigated if exposure to ELS can contribute to this effect. It is hypothesized that children in more deprived environment may not be able to use neural resources as efficiently as children in more enriching and stimulating environment. For example, as neural activation increases, children from deprived environments might not be able to exhibit the same level of increase in behavioral performance as those in less deprived environment. The current study proposes that ELS, in particular, psychosocial deprivation, influences youth’s neural efficiency during a working memory task.

Considering Development in Environmental Context

Contemporary research on human development across the life span suggests that individuals’ development and functioning cannot be isolated from their embedding environmental contexts (Bronfenbrenner & Morris, 2007; Magnusson & Stattin, 2006). In particular, developmental ecological frameworks suggest that a holistic insight of developmental phenomena would necessitate consideration of the complex interplay of individual and contextual factors. For example, the bioecological theory of human development from Bronfenbrenner and Morris (2007) centered on the role of environment in shaping development. This theory highlights the powerful influence of people (e.g., caregivers, peers, teachers) and interpersonal relationships (e.g., family relationships) within a child’s rearing environment on development. Similarly, the person-context interaction theory from Magnusson and Stattin (2006) views that an individual is part of an integrated and dynamic person-environment system. As such, the individual’s ongoing functioning cannot be fully understood without knowledge of their surrounding environment. The ecological models on human development have guided decades of research in delineating how proximal, and distal ecological contexts shape developmental trajectories (F. R. Chen & Raine, 2018; Cummings & Schatz, 2012; Luengo Kanacri et al., 2017).

With neuroscience being increasingly integrated into research on child development, researchers have advocated for an ecological approach to examine the developing brain (Hyde et al., 2020). This ecological neuroscience approach places the developing brain within multiple ecological contexts and seeks to elucidate how environmental inputs impact brain structures and functions (Hyde et al., 2020). Accordingly, integrating the ecological approach with developmental cognitive neuroscience is vital to having a fuller understanding of children's neurocognitive development and functioning. Hence, the study of individual differences in the brain-behavior relations needs to account for a child's early rearing environment.

Theoretical Perspectives and Models Informing Research on Early Life Stress

Developmental cognitive neuroscience has contributed significantly to our understanding of the impact of ELS, including psychosocial deprivation on neurocognitive development (Goodman, Freeman, & Chalmers, 2019). A substantial amount of work from animal and human research shows that a deprived rearing environment can lead to a number of changes in neural architectures and function, such as decreases in brain volume, synaptic connections, and cortical thickness, as well as functional connectivity (McLaughlin, Weissman, & Bitrán, 2019). These structural and functional alterations may subsequently lead to a loss of neural efficiency, meaning that it is possible that neural activity may not be as efficient in producing behavioral outcomes among children raised in adverse rearing contexts. In the following section, I will introduce psychosocial deprivation as a dimension of ELS, by briefly reviewing the three prevailing approaches in conceptualizing ELS: cumulative risk, specificity, and dimensional approaches to ELS. In addition, I will provide rationale for the potential role of psychosocial deprivation in moderating the brain-behavior relation specific to working memory.

Cumulative Risk

Studies that adopt a cumulative risk approach measure the number of various types of adversities experienced as a composite score and use this score to predict developmental outcomes (Oshri, Hallowell, et al., 2019; Treat, Sheffield Morris, Williamson, Hays-Grudo, & Laurin, 2019). This approach considers that adversities do not happen in isolation, and has provided a wealth of empirical evidence on the negative association between ELS and youths' adjustment (Lima, Caughy, Nettles, & O'Campo, 2010). For instance, exposure to multiple adverse experiences are more robustly linked to children's adjustment than are single exposures (Appleyard, Egeland, van Dulmen, & Alan Sroufe, 2005; Jaffee, Caspi, Moffitt, Polo-Tomas, & Taylor, 2007). Models of cumulative adversity, however, fail to identify distinct forms of ELS and their disparate developmental and neurobiological consequences (McLaughlin, Sheridan, & Lambert, 2014).

Specificity Approach to Risk

Research predicated on the specificity approach focuses on specific types of adverse life experiences, such as socioeconomic hardship (Ming, Zhang, Jiang, Ren, & Huang, 2021) and child maltreatment types (Mezzacappa, Kindlon, & Earls, 2001). This approach has also contributed significant knowledge to the link between ELS and youths' adjustment (D. J. Jones et al., 2013). For example, prospective studies have documented a consistent association between poverty and impaired working memory among children and adults (Evans & Schamberg, 2009; Kokosi, Flouri, & Midouhas, 2021). Similarly, experiences of child maltreatment have been linked to poor executive function (Fay-Stammbach, Hawes, & Meredith, 2017; Mothes et al., 2015; Nikulina & Widom, 2013). However, this approach has major limitations (McLaughlin, Sheridan, & Lambert, 2014). First, this approach fails to account for the co-occurrence among different forms of ELS. Second, the discrete stressor model assumes that distinct mechanisms are underlying the associations between different types of adversity and adjustment outcomes. This assumption has been challenged by a dimensional approach to ELS (Sheridan & McLaughlin, 2014).

Dimensional Approach – Threat/Deprivation, and Harshness/Unpredictability

More recent theoretical frameworks suggest that ELS is a multidimensional construct

(McLaughlin et al., 2021; McLaughlin, Sheridan, & Lambert, 2014). Accordingly, scholars have proposed two dimensional models. The first dimensional model proposed by McLaughlin, Sheridan, and Lambert (2014) distinguishes between experiences of threat and deprivation. Threat refers to those adverse experiences that pose harm or potential harm to a child's physical integrity (e.g., child abuse). On the other hand, deprivation refers to an absence of expected intellectual, cognitive, and social stimulation essential to healthy development (e.g., institutional rearing, child neglect). Guided by life history theory from an evolutionary developmental perspective, the second dimensional model posits harshness and unpredictability as two core dimensions of environmental adversity (Belsky, Schlomer, & Ellis, 2012; Ellis et al., 2009). Harshness refers to external causes of morbidity and mortality (e.g., exposure to family and community violence), while unpredictability encompasses spatial and temporal variation in environmental harshness (Ellis et al., 2009; McLaughlin et al., 2021). The dimensional approach to conceptualizing ELS accounts for the fact that different types of adversity are likely to co-occur. Additionally, it acknowledges core features underlying various adverse experiences with the goal of advancing research that tries to uncover unique and distinct neural pathways linking ELS to later developmental outcomes.

The threat-deprivation model

Drawing evidence from animal models and emerging human studies, the threat and deprivation model of ELS hypothesizes that threat- and deprivation-based adversities exert adverse effects on youths' adjustment through at least partially distinct neural pathways (McLaughlin, Sheridan, & Lambert, 2014). Studies suggest that early threat exposure is associated with changes in neural circuits that subserve emotion learning, in particular, fear learning. These neural circuits include brain regions such as the hippocampus, amygdala, and the ventral prefrontal cortex (vmPFC) (McLaughlin, Sheridan, & Lambert, 2014). Emerging evidence shows that experiences of threat were associated with blunted stress reactivity, poor emotion regulation, and atypical patterns of fear learning reflected in children's reduced ability to distinguish threat and safety cues (Lambert et al., 2017; McLaughlin et al., 2016).

On the other hand, experiences of deprivation are hypothesized to be linked to structural changes (e.g., reductions in cortical thickness) in brain regions that support complex processing of social and cognitive information, including the prefrontal cortex (PFC), superior and inferior parietal cortex, and superior temporal cortex (McLaughlin, Sheridan, & Lambert, 2014). This hypothesis is supported by evidence emerging from research on institutionalized children, who showed overall decreases in gray matter volume and thickness in brain regions subserving the development of higher-level cognitive processes, compared to never-institutionalized children (McLaughlin, Sheridan, Winter, et al., 2014; Sheridan, Fox, Zeanah, McLaughlin, & Nelson, 2012). Moreover, recent studies have shown that compared to threat, experiences of deprivation have a stronger relation with youths' performances on tasks requiring executive functioning (D. Johnson et al., 2021; Lambert et al., 2017; Machlin, Miller, Snyder, McLaughlin, & Sheridan, 2019; Vogel, Perry, Brandes-Aitken, Braren, & Blair, 2021). Informed by this dimensional approach and its supporting empirical evidence, the present study focuses on experience of deprivation, particularly psychosocial deprivation, as it is expected to be strongly associated with the development of executive function among youth. In other words, psychosocial deprivation would be the most salient context to investigate executive function-specific brain-behavior relation.

The harshness-unpredictability model

The harshness-unpredictability model is guided by the life history (LH) theory (Ellis et al., 2009). LH theory is a theoretical framework for investigating and understanding diversity and variations in the ways in which organisms (e.g., humans) allocate resources to different life goals to optimize their evolutionary fitness (e.g., chances of survival and reproduction; Belsky et al., 2012; Ellis et al., 2009; Griskevicius, Tybur, Delton, & Robertson, 2011; Kim & Hillard, 1999; Stearns, 1992). This theory proposes that individuals' LH traits, such as timing of puberty, parental investment, and reproduction timing and rates, lies on a continuum from slow to fast (Del Giudice, 2020; Nettle, 2010). Variations in the LH traits depend on individuals' adaptive trade-offs in allocating limited energy and resources between different life tasks, such as the trade-offs between survival and reproduction, maintenance and growth, and offspring quality and quantity (Belsky et al., 2012; Brumbach, Figueredo, & Ellis, 2009; Roff, Mostowy, & Fairbairn, 2002). These trade-offs reply on environmental cues to promote behavioral strategies that can maximize evolutionary fitness and optimize survival and reproduction chances (Belsky et al., 2012; Brumbach et al., 2009). When children grow up in a safe and predictable environment, they are more likely to develop slower life history strategies such as prolonged maturation and later reproduction (Hawkes, 2006). However, if the early rearing environment is harsh and unpredictable, individuals are more likely to adopt faster life strategies, including prioritizing immediate rewards, quicker maturation, and earlier reproduction (Brumbach et al., 2009).

Informed by Ellis et al. (2009), investigators have focused empirical attention on evaluating unpredictability as a core dimension underlying various adverse experiences (Liu & Fisher, 2022; McLaughlin et al., 2021). Behavioral research has documented the negative impact of environmental unpredictability on various child outcomes (Evans, Gonnella, Marcynyszyn, Gentile, & Salpekar, 2005; Glynn et al., 2018; Howland et al., 2021). For example, a chaotic family environment (e.g., lack of routine and structure) is linked to increased socioemotional maladjustment among children (Evans et al., 2005; Raver, Blair, Garrett-Peters, & Investigators, 2015). Studies have also found a link between economic instability and food insecurity with poor health and education outcomes among children (Elliott, 2013; Wolf & Morrissey, 2017).

In addition to the negative effects of unpredictability on children's socioemotional and behavioral adjustment, emerging evidence shows that unpredictability might also affect children's neural development (Liu & Fisher, 2022). In particular, the corticolimbic circuitry has been proposed as an underlying neural mechanism through which unpredictability confers risk on development (Gee, 2021; Gee & Cohodes, 2021). In studies of rodents, exposure to unpredictable maternal signals has been linked to greater amygdalar activity as well as resting-state functional connectivity between the amygdala and medial prefrontal cortex (M. M. Cohen et al., 2013; Guadagno et al., 2018). In humans, a recent longitudinal study by Granger et al. (2021) showed that greater unpredictability of maternal sensory signals during infancy was associated with greater structural integrity of the uncinate fasciculus, but not hippocampal cingulum in children 9-11 years old. This resulting imbalance in maturation of corticolimbic circuits was linked to poor episodic memory. Despite the increasing scholarly interests, research on unpredictability as a dimension of ELS remains scarce (Liu & Fisher, 2022). Further research is needed to understand its neurobiological consequences.

Biological Embedding of Early Life Stress in Executive Functions

The biological embedding of ELS describes processes by which adverse early life experiences get "beneath the skin" and affect various neurobiological systems, leading to adverse developmental outcomes (e.g., cognitive functioning; Berens et al., 2017). Exposure to psychosocial deprivation, in particular, is posited to affect youth's neural development essential to executive functioning through global stress mechanisms and experience-driven brain development (Goetschius, 2021; McLaughlin et al., 2021). In the paragraphs below, I will present theoretical and empirical support for how psychosocial deprivation may alter neural structures and functions that subserve youth's development of executive functioning, and thus constitutes a critical context that affects youth's neural efficiency.

Psychosocial deprivation, Dysregulated Stress Response, and Executive Function

One theory that depicts how stress "gets under the skin" is the allostatic load model introduced by McEwen and Stellar (1993). The allostatic load refers to the "wear and tear" on the body's multiple biological systems, resulting from exposure to repeated and chronic challenges in the environment (Guidi, Lucente, Sonino, & Fava, 2021). The hypothalamic-pituitary-adrenal (HPA) axis and the sympathetic-adrenomedullary (SAM) system are the body's two primary interrelated biological systems responsible for responding to and coping with environmental stress (Gunnar & Quevedo, 2007). When confronted by stress that threatens or undermines their socioemotional or physical well-being, the body triggers a series of physiological and psychological responses in order to adequately cope with the stressors, aiming to regain homeostasis (Kloet, Joel, & Holsboer, 2005). The hormonal cascades set off by the activations of the HPA axis (e.g., production of cortisol) and SAM mobilize the body's resources to cope with external stress, which allows for healthy day-to-day functioning (Hostinar 2014; Godoy, et al., 2018). However, repeated and/or extended activations of the body's stress response system can lead to allostatic overload, which in turn, leads to dysregulated physiological responses to future stress (Juster, McEwn, and Lupien, 2010). Dysregulated stress responses (i.e., hyper- or hypo-response) or allostatic load resulted from repeated exposure to stress have been shown to induce neurocognitive vulnerabilities (Booth et al., 2015).

Altered stress physiology, such as hyper-responsivity in the HPA axis, has been purported as a primary embedding mechanism that relates ELS to deficits in executive function. Specifically, heightened stress reactivity from exposure to ELS can confer cognitive risks through altering neural structures and functions in key brain regions supporting neurocognitive development (Evans & Schamberg, 2009; Hostinar, Stellern, Schaefer, Carlson, & Gunnar, 2012; Metz et al., 2018). For example, the prefrontal cortex (PFC), which plays a prominent role in development of complex executive functions, has dense concentrations of glucocorticoid receptors that are main actors of the stress-response systems (Lupien, McEwen, Gunnar, & Heim, 2009). Therefore, increased secretion of cortisol resulted from a hyper-responsive stress response might be detrimental to the PFC, and undermine cognitive development (Blair & Raver, 2012; Raymond, Marin, Majeur, & Lupien, 2018).

In addition to a hyperactive HPA axis, blunted stress response has also been associated with deficits in cognitive functioning (Wesarg, Van Den Akker, Oei, Hoeve, & Wiers, 2020). Suor, Sturge-Apple, Davies, Cicchetti, and Manning (2015) indicated that children who exhibited low cortisol patterns in response to environmental stress might not be able to efficiently mobilize metabolic resources necessary for learning and memory consolidation. In addition, low levels of cortisol secretion may hamper synaptic potentiation in the prefrontal cortex and hippocampus, thus leading to a negative impact on the development of executive function (Lupien, Maheu, Tu, Fiocco, & Schramek, 2007).

Psychosocial Deprivation, Experience-driven Brain Development, and Executive Function

In addition to exposure to chronic stress in rearing environments that leads to enduring alterations of neurodevelopmental trajectories, a deprived environment characterized by an absence of cognitive and positive social stimulation can also compromise neurocognitive development (Nelson III et al., 2019). The anatomical changes crucial to brain maturation, such as synaptic pruning and myelination, form the fundamental processes that subserve the development of higher cognitive functioning (e.g., working memory; Arain et al., 2013; Tierney & Nelson, 2009). These processes are largely modulated by experiences that continue through adolescence and into young adulthood (Luna & Sweeney, 2001; Paus, 2005; Spear, 2013; Tierney & Nelson, 2009). Children reared in deprived environments are often subject to a lack of intellectual and psychosocial stimulation essential for this experience-driven brain development, and therefore vulnerable to poor cognitive development (McLaughlin, Sheridan, & Lambert, 2014).

Indeed, extant research shows that experiences of deprivation are linked to changes in brain morphology, such as widespread decreases in cortical thickness, and reductions in both gray and white matter volumes, a possible mediating mechanism leading to compromises in neurocognitive development (Eluvathingal et al., 2006; Humphreys & Zeanah, 2015; McLaughlin, Sheridan, Winter, et al., 2014; Mehta et al., 2009; Sheridan et al., 2012). For instance, Edmiston et al. (2011) found that emotional neglect was associated with decreased gray matter volume in the dorsolateral prefrontal cortex among adolescents without psychiatric diagnoses. Among youth adopted internationally, Herzberg and Gunnar (2020) showed that post-institutionalized youth had smaller prefrontal volume and anterior cingulate surface area compared to youth in a control group. Similarly, among a sample of 110 post institutionalized children, structural neuroimaging detected significant reductions in prefrontal cortex volume (Hodel et al., 2015). This body of literature suggests that exposure to psychosocial deprivation may exert harmful impacts on brain regions essential to executive functioning.

Psychosocial Deprivation and Working Memory

In the section below, I review current literature on psychosocial deprivation and working memory. Both behavioral and neuroimaging research will be reviewed. Because there is scant literature investigating the effects of psychosocial deprivation on working memory utilizing fMRI methods, I will also review fMRI literature that studies different types of ELS and types of executive function in addition to working memory.

Behavioral Research on Psychosocial Deprivation and Working Memory

Extant literature has consistently documented a link between psychosocial deprivation and children's poor executive function (Bos et al., 2009; Loman et al., 2013; Emily C. Merz & McCall, 2011). Research on children raised in institutions has provided empirical support for the negative association between psychosocial deprivation and working memory (Bos et al., 2009; Pollak et al., 2010; Tibu et al., 2016). For example, Bos et al. (2009) found that early institutional care was significantly associated with poor visuospatial working memory. Tibu and colleagues (2016) showed that disruptions of working memory performance significantly mediated the association between exposure to institutionalization and symptoms of attention deficit hyperactivity disorder (i.e., ADHD). Similarly, Pollak et al. (2010) revealed that children adopted from institutions exhibited greater visuospatial working memory deficits than those who were adopted from foster care.

Beyond institutional rearing, child neglect, a form of psychosocial deprivation, has been significantly linked to deficits in working memory (Demeusy, Handley, Rogosch, Cicchetti, & Toth, 2018; Tran, Van Berkel, van Ijzendoorn, & Alink, 2017). For instance, using a longitudinal study of 89 infants, Demeusy et al. (2018) showed that early neglect, assessed by review of Child Protective Service records, was predictive of poorer visuospatial working memory performance, which in turn led to higher rates of aggression. Tran et al. (2017) found that lifetime experience of neglect was linked to poorer working memory performance among a sample of Vietnamese adolescents. Similar findings have also been reported in longitudinal studies that incorporated a dimensional model to ELS. Vogel et al. (2021) found that deprivation as indicated by learning materials available in the home, sensitive parenting, and consistent caregiver partnerships , was significantly and inversely related to working memory performance two years later. Additionally, Schäfer et al. (2022) reported that exposure to deprivation (e.g., measured using indicators such as neglect and parental absence, etc.), but not threat, was associated with worse performance on tasks that assessed executive function, including working memory, cross-sectionally and longitudinally.

Despite the above evidence, research that examines psychosocial deprivation as an environmental correlate of working memory among community samples of children and adolescents remains scarce. In addition, children exposed to psychosocial deprivation live in an environment characterized by more than a lack of consistent and responsive caregiving. They are also likely to suffer from a lack of opportunities for positive interactions with peers and other adults in the family and school contexts, as well as varying and enriching daily activities and experiences (McLaughlin, Sheridan, & Lambert, 2014). Nevertheless, few studies to date conceptualize psychosocial deprivation as a multilayered construct that spans multiple ecological contexts that extend beyond the immediate caregiving environment. Furthermore, research that investigates both behavioral and neural correlates of working memory following exposure to psychosocial deprivation is limited.

Functional Neuroimaging Research on Psychosocial Deprivation and Working Memory

To date, there is scant research that focuses on examining psychosocial deprivation and working memory-related functional neural correlates using fMRI. Therefore, in the review below, I will also include research literature on different types of ELS and studies that have examined other types of executive functions in addition to working memory. The study by Sheridan and colleagues (2017) and Oshri, Hallowell, et al. (2019) are two of the few studies that examined associations between deprivation and fMRI correlates of working memory. In the Sheridan et al. (2017) study, the researchers found that parent education level (as a measure of deprivation) was positively associated with children's performance on a working memory task. In addition, the authors found parental education level was negatively associated with neural activations in MFG, and SPL during the task. Therefore, investigators concluded that children whose parents had less education exhibited a less efficient neural recruitment pattern in support of high working memory loads. More specifically, the authors stated that children who had parents with low education levels showed greater intensity of activation responses in the task-relevant regions, but performed worse on the task, which suggests weaker neural efficiency.

However, the Sheridan et al. (2017) study has noteworthy limitations. First, investigators used one indicator, parental education, as an implicit measure of deprivation. Second, there is a possibility that among children who had parents with low education levels, increased neural recruitment could result in comparable behavioral performance to those who had parents with higher education levels. Probing this hypothesis would necessitate testing how the relation between working memory related neural activity and actual performance changes at different levels of parental education.

In the Oshri, Hallowell, et al. (2019) study, the researchers measured deprivation through chronic socioeconomic hardship (measured over three years). The findings revealed that socioeconomic hardship severity was linked to reduced responses in the middle frontal gyrus and inferior parietal lobule during a working memory task, which was, in turn, associated with reduced working memory performance. Although this result provided valuable insights into neural mechanisms underlying the effect of ELS (i.e., deprivation) on working memory, it has some limitations as well. First, socioeconomic hardship, typically indexed by factors such as level of parental education or poverty status, is used by many investigators as an implicit measure of deprivation (Lambert et al., 2017; Machlin et al., 2019). However, it does not directly assess the level of social and cognitive stimulation in the rearing environment (Vogel et al., 2021). In addition, the study tested working memory-related neural activity as an intermediary between socioeconomic hardship and behavioral performance. This statistical test assumes a monotonic relation between working memory-related neural activity and behavioral performance, which might mask more nuanced individual variability in the brain-behavior relation.

In another fMRI study of young adults, Raine et al. (2001) found that non-violent participants with a history of child physical abuse showed lower left, but higher right hemisphere activation of the superior temporal gyrus during a visuospatial-verbal working memory challenge. Additionally, they exhibited a strong deficit in task behavioral performance. In a study of 27 adults, Philip et al. (2016) revealed that compared to controls, participants with a history of child maltreatment demonstrated greater activation in the expected working memory-related brain regions (e.g., inferior parietal lobule), but showed worse working memory task performance. In an earlier study by the same group, greater relative deactivation in the default mode network appeared to reflect compensatory effects (i.e., greater deactivation to support working memory performance), as participants had maintained expected working memory performance levels (Philip, Sweet, Tyrka, Price, Carpenter, et al., 2013). This body of literature suggests variations in neural efficiency as a result of exposure to ELS. However, these studies have mostly relied on small sample sizes and were conducted retrospectively with adult populations.

Neuroimaging studies on brain response and behavioral performance patterns during other executive function tasks (e.g., response inhibition) following ELS have revealed varying patterns of the brain-behavior relation. For example, among a sample of young adults, Lim et al. (2015) found that greater recruitment of dlPFC during a stop-signal task was linked to unsuccessful inhibition among abused participants. Another study by Mueller et al. (2010) investigated the association between ELS and cognitive control assessed through a stop signal task among a sample of adolescents using fMRI. Adolescents recruited in the ELS group had a history of child maltreatment or had multiple foster care placements before getting adopted. The behavioral analysis showed that youth in the ELS group had the same level of behavioral performance accuracy as youth in the control group during correct inhibition trials. However, youth in the ELS group exhibited greater recruitment of the inferior prefrontal cortex.

These varying findings may be explained by different types of ELS exposure, characteristics of study samples, or the different task paradigms used. However, they may also suggest significant heterogeneity in brain-behavior relations, and that neural responses need to be investigated along with behaviors to fully understand the influence of adversity on neurocognitive development. For example, greater activation might suggest successful compensation in the aftermath of adversity if it is associated with uncompromised behavioral performance during cognitive tasks. Furthermore, these findings converge to highlight the importance of providing developmental context to the executive function specific brain-behavior relation (e.g., children exposed to ELS elicit more neural activity during cognitive tasks). Given that a cognitively and socially stimulating environment is essential to youth’s development of executive function, more research is needed to elucidate how psychosocial deprivation affects neural efficiency.

Aims and Hypotheses

The primary aim of the present study is to investigate whether psychosocial deprivation is a source of individual difference that affects the linkages between neural responses and behavioral performance (i.e., neural efficiency) during an fMRI paradigm that challenges working memory. Specifically, I aim to test the moderating role of psychosocial deprivation on the association between working memory-related neural responses and behavioral performance accuracy. I hypothesize that 1) psychosocial deprivation will attenuate the relation between brain activation (i.e., BOLD signal) in task-positive regions and behavioral performance accuracy during a working memory task; 2) psychosocial deprivation will also weaken the relation between relative deactivation in task-negative regions and behavioral performance accuracy.

CHAPTER 3

METHODS

In the present study, I used data from the Adolescent Brain Cognitive Development (ABCD) Study, which were collected from 21 sites across the United States with diverse socioeconomic, racial-ethnic, and biobehavioral health backgrounds.

Participants and Procedures

Sample

All study hypotheses were tested with data from the ABCD study. The ABCD study is an ongoing, multi-site longitudinal study that was designed to facilitate investigations of socio-emotional, behavioral, cognitive, and neurobiological development from pre-adolescent to young adulthood (Garavan et al., 2018). A baseline cohort of children aged nine and ten years old (N = 11, 878) and their primary caregivers/guardians were recruited from 21 data acquisition sites across the United States between 2016 and 2018 and will be followed for ten years (Garavan et al., 2018).

Participants were recruited utilizing multi-stage probability sampling to ensure that they were representative, as closely as possible, of the sociodemographic characteristics (e.g., age, gender, race-ethnicity, socioeconomic status, urbanicity) in the US population (Garavan et al., 2018; Heeringa, West, & Berglund, 2017). The sociodemographic factors under consideration included age, gender, race and ethnicity, socio-economic status (SES), and urbanicity. Participants were excluded from being recruited into the ABCD study if a) the child was not fluent in English, or the child had a parent not fluent in English or Spanish, b) the child had major medical or neurological conditions, including a history of traumatic brain injury, and current diagnoses of schizophrenia, autism spectrum disorder, intellectual disability, or substance use disorder, c) the child was born prematurely (i.e., gestational age under 28 weeks) or had a birthweight under 1200g, or d) the child had MRI contradictions, such as having metal implants (Karcher, O'Brien, Kandala, & Barch, 2019; Thompson et al., 2019). Data were accessed from the National Institute of Mental Health (NIMH) Data Archive, which included baseline data (Wave 1; N_{W1} = 11, 878, 47.8% female, M_{age} = 9.48). The sample's racial-ethnic composition was as follows: 52.3% White, 15.0% Black, 20.3% Hispanic/Latino(a), 2.1% Asian, 10.5% Other. Detailed sample demographic characteristics are listed in Figure 2.

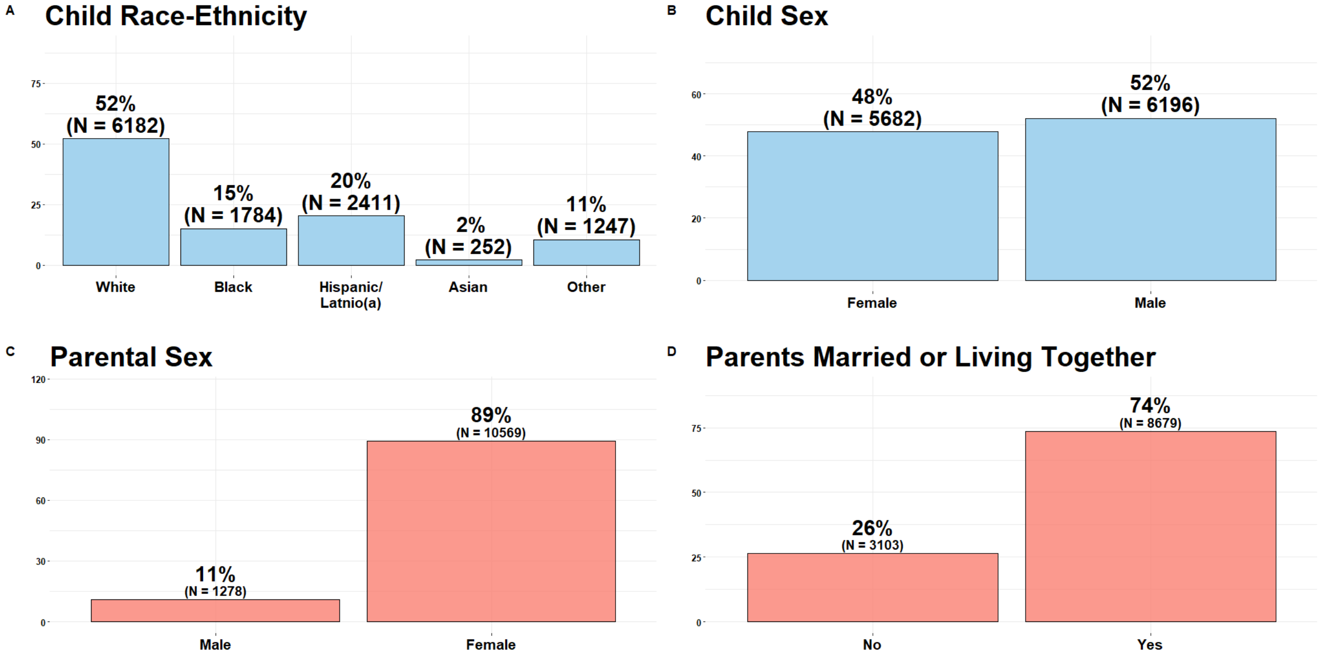


Figure 2. Demographic characteristics of the ABCD study sample (N = 11,878).

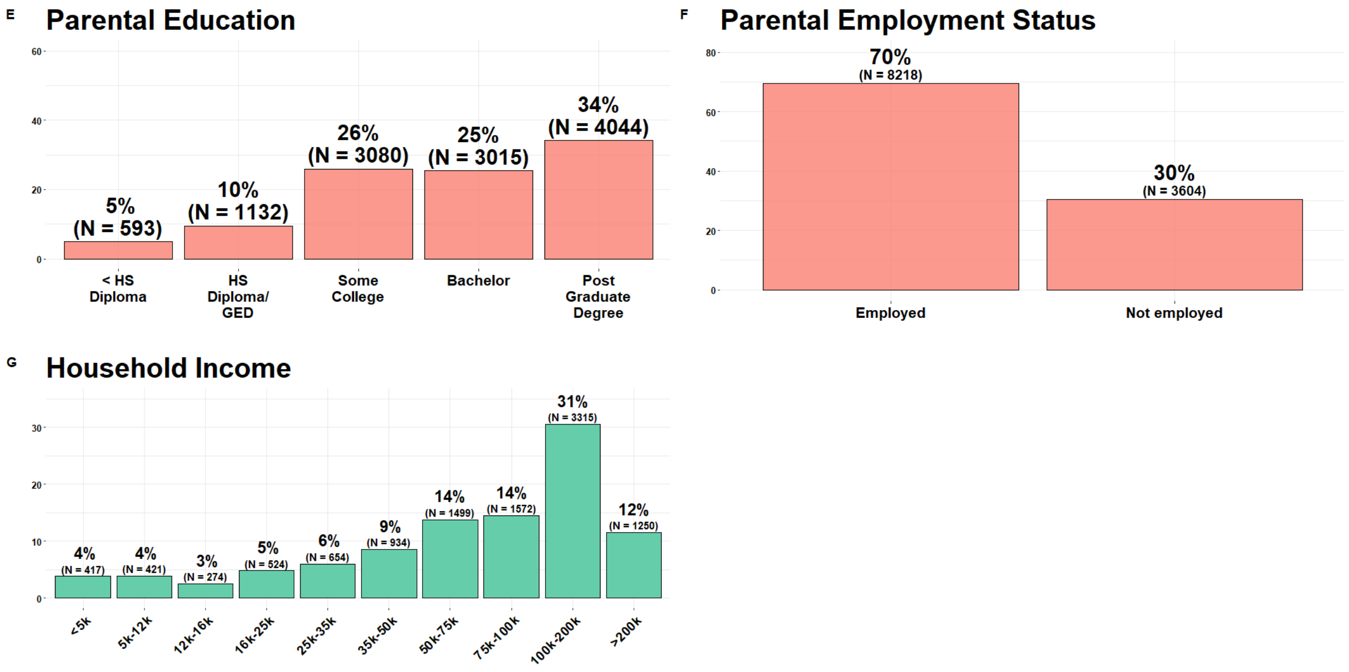


Figure 2. (continued)

Procedures

All ABCD's study protocols were approved by the Institutional Review Board of the University of California, San Diego (#160091). In addition, the Institutional Review Boards across the 21 data collection sites approved the study (Duncan B Clark et al., 2018; Owens et al., 2021). Primary caregivers provided consent after the study procedures had been fully explained and children provided assent to participate in the study (Duncan B Clark et al., 2018). In-person lab-based assessments, which include self-report survey data collection are conducted annually (Karcher et al., 2019). The self-report surveys assess aspects of a child's rearing contexts including parenting behaviors, family, and school environment. Magnetic Resonance Imaging (MRI) is conducted every two years (Garavan et al., 2018). Data presented in this study include baseline (Wave 1) task-based functional MRI (fMRI) and questionnaire self-report data.

Neuroimaging Acquisition, Processing, and Quality Control

MRI Acquisition

The ABCD study used three 3T scanner platforms, including Siemens Prisma, General Electric (GE) 750, and Philips. The neuroimaging protocol was harmonized across all 21 sites (See Table 1 for harmonized imaging parameters). Standard adult-size and multi-channel head coils capable of multiband echo planar imaging (EPI) acquisitions were used. All ABCD fMRI tasks are programmed in E-Prime Professional 2.0 version 2.0.10.356 or later (Psychology Software Tools, Pittsburgh, PA) that works reliably for PC Windows 8.1 or earlier. Children viewed the tasks through rear projection or goggles and responded to tasks using a Current Design 2-button box placed at their dominant hand. The response collection box is harmonized across all tasks and all sites, however, the equipment used for visual display and auditory delivery varies by sites to accommodate variations in scanner and control room set-up among sites. Structural images are obtained for anatomical reference using 3D T1-weighted magnetization-prepared rapid acquisition gradient echo scan. Functional scans are acquired using high spatial and temporal resolution simultaneous multi-slice (SMS)/multiband EPI with fast integrated distortion correction. Real-time motion detection and correction for structural scans are implemented using prospective motion correction (PROMO) on the GE, Volumetric Navigators (vNav) for prospective motion correction and selective reacquisition on the Siemens and Philips platform (when available).

Table 1. ABCD Harmonized Imaging Scanning Parameters

Scanner	**Siemens**			**Philips**			**GE**		
	T1	**T2**	**fMRI**	**T1**	**T2**	**fMRI**	**T1**	**T2**	**fMRI**
Matrix	256 x 256	256 x 256	90 x 90	256 x 256	256 x 256	90 x 89	256 x 256	256 x 256	90 x 89
Slices	176	176	60	225	256	60	208	208	60
FOV	256 x 256	256 x 256	216 x 216	256 x 240	256 x 256	216 x 216	256 x 240	256 x 256	216 x 216
%FOV phase	100%	100%	100%	93.75%	100%	100%	100%	100%	100%
Resolution (mm)	1.0 ^3	1.0 ^3	2.4 ^3	1.0 ^3	1.0 ^3	2.4 ^3	1.0 ^3	1.0 ^3	2.4 ^3
TR (ms)	2500	3200	800	6.31	2500	800	2500	3200	800
TE (ms)	2.88	565	30	2.9	251.6	30	2	60	30
TI (ms)	1060	N/A	N/A	1060	N/A	N/A	1060	N/A	N/A
Flip Angle (deg)	8	Variable	52	8	90	52	8	Variable	52
Parallel Imaging	2x	2x	Off	1.5 x 2.2	1.5 x 2.0	Off	2x	2x	Off

MultiBand Acceleration	Off	Off	6	Off	Off	6	Off	Off	6
Phase partial Fourier	Off	Off	Off	N/A	N/A	N/A	Off	Off	Off
Half Scan Factor	N/A	N/A	N/A	Off	Off	0.9	N/A	N/A	N/A
Acquisition Time	7:12	6:35	--	5:38	2:53	--	6:09	5:50	--

Notes. This information was obtained from Hagler Jr et al. (2019) and B. J. Casey et al. (2018). FOV = Field-of-view, TR = Repetition time, TE = Echo time, TI = Inversion time, Multiband Acc. = Multiband acceleration.

Imaging Processing

The neuroimaging data processing was conducted using a series of publicly available neuroimaging software packages, including FreeSurfer (Fischl, 2012), Analysis of Functional NeuroImages (AFNI; Cox, 1996), and FMRIB Software Library (FSL; Jenkinson, Beckmann, Behrens, Woolrich, & Smith, 2012; Smith et al., 2004). Automated registration between the spin-echo B0 calibration scans and T1w structural scans was performed based on within-modality registration to atlas brains using mutual information (Wells III, Viola, Atsumi, Nakajima, & Kikinis, 1996). Initial volumes (8 TRs for Siemens and Philips scanner, 5 TRs for GE DV25, 16 TRs for GE DV26 [DV25 and 26 are scanner operating system versions]) were removed. AFNI’s 3dvolreg command was used to correct head motion by registering each frame to the first. This was done after removing the first several TRs of the run (see above). This process provided estimates of head motion time courses that were further incorporated into task-fMRI analyses. B0 distortions were corrected using the reversing polarity method (Holland, Kuperman, & Dale, 2010). The displacement field was estimated from separate spin-echo calibration scans, then adjusted for estimated between-scan head motion, and lastly applied to the series of gradient-echo images. Images were corrected for distortions due to gradient nonlinearities (Jovicich et al., 2006). Between-scan motion was corrected by resampling each scan with cubic interpolation into alignment with a reference scan (nearest to the middle of the fMRI scans for any given participant). In terms of brain segmentation, cortical surface reconstruction and subcortical segmentation were performed using FreeSurfer v5.3. Cortical regions were parceled and labeled according to the standard Desikan atlas-based classification (Desikan et al., 2006).

A voxelwise General Linear Model (GLM) procedure was conducted to quantify the task-specific neural activity at the individual level using AFNI's 3dDeconvolve command (Cox, 1996). Motion estimates and their derivatives, baseline and quadratic trends in the time-series fMRI data were included as regressors (Power et al., 2014). Time points with framewise displacement (FD) greater than 0.9mm were censored (Siegel et al., 2014). The time course of each type of stimulus in each of the n-back conditions (i.e., 0-back and 2-back) was introduced into the GLM as predictors, and the 0-back stimuli were modeled as the linear contrast baseline. The blood-oxygen-level-dependent (BOLD) signals over time were modeled as the dependent variable in the GLM. A linear contrast of 2-back versus 0-back reflected neural response during working memory challenge. For each ROI, average GLM beta coefficients across voxels were computed for each run, and then averaged across two runs, weighted by nominal degrees of freedom. Based on prior fMRI literature on working memory (Owen et al., 2005; Owens et al., 2018; Yaple et al., 2019), working memory related neural responses for 11 bilateral ROIs were extracted for final analyses (See Figure 3.1 and 3.2).

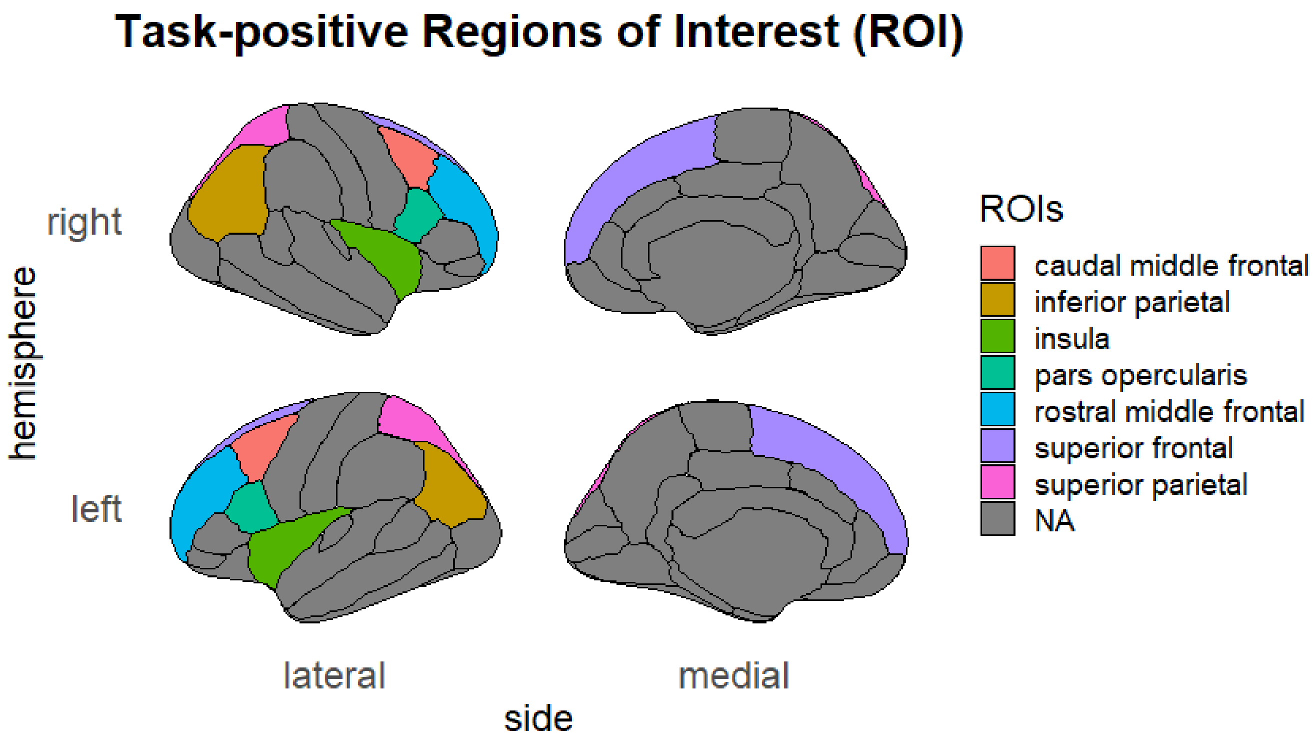


Figure 3.1. Task-positive regions of interest.

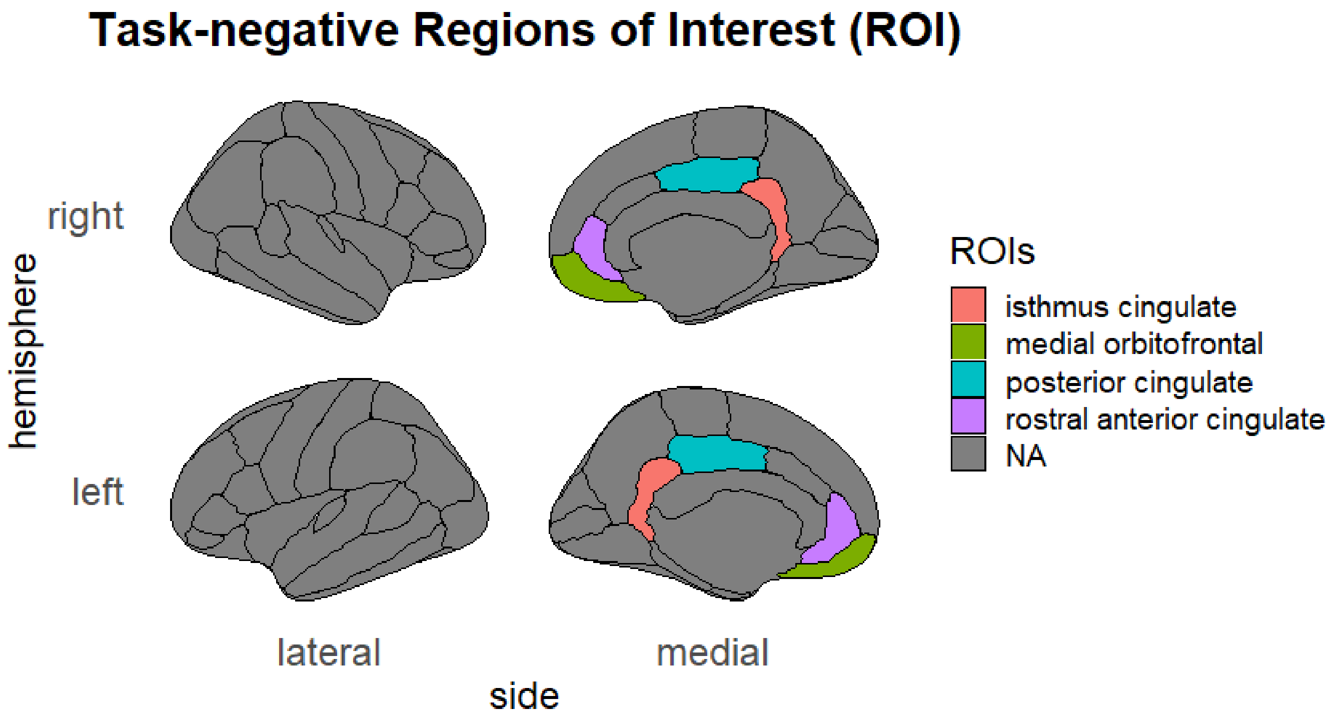


Figure 3.2. Task-negative regions of interest.

Imaging Quality Control

The quality control process followed the recommended inclusion criteria for fMRI data generated by the ABCD study (B. J. Casey et al., 2018). After data collection, datasets were reviewed and checked for problems, including incorrect acquisition parameters, imaging artifacts, corrupted data files, incomplete imaging series, etc (Hagler Jr et al., 2019). Tabulated fMRI data from the EN-back task from 79.96% (N = 9,498) of the baseline sample remained after initial quality control and protocol compliance check. To be included in future analysis, additional quality control was applied. The participants needed to meet the following extra quality control criteria: (1) Data presented no serious incidental radiological findings (e.g., unexpected findings of tumor, hydrocephalus, etc.) by a Board Certified Neuroradiologist during the manual review process (3.17%, N = 377 participants excluded); (2) EN-back average beta weights degree of freedom (i.e., number of frames remaining after excessive motion censoring minus number of model parameters) > 200 (0.44%, N = 42); (3) EN-back imaging and E-prime behavioral data matched or the mismatch does not significantly affect the validity of the data (no participant excluded); (4) fMRI data available for B0 unwarp (0.09%, N = 9 participants excluded); (5) Data passed the FreeSurfer quality control manual review, during which trained technicians reviewed artifacts and irregularities (3.28%, N = 312 participants excluded); (6) fMRI data passed post-processing quality control manual review (1.83%, N = 174 participants excluded); (7) the normalized score indicating the displacement and rotation of fMRI fieldmap relative to the T1w volume was smaller than 19 (no participant excluded); (8) the fMRI maximum dorsal and ventral field of views (FOV) cutoff scores (i.e., clipping of the dorsal or ventral aspect of the cortex) were smaller than 65 and 60, respectively (0.19%; N = 18 participants excluded; 0.23%; N = 22 participants excluded); (9) behavioral performance were acceptable on the EN-back task (i.e., 0-back and 2-back performance accuracy ≥ 60%; 13.75%, N = 1306 participants excluded); (10) per ABCD data use recommendations, the top and bottom .25% of ROI neural activity data were winsorized. This means that imaging data of ROI neural activity within the top and bottom .25% were set to be equal to the values at the 97.75th percentile and .25th percentile, respectively. Therefore, an EN-back fMRI dataset of 7481 (62.98%) were included in the final analyses.

Functional Magnetic Resonance Imaging (fMRI) Task Paradigm and Processing

Emotional N-back (EN-back) Paradigm

The EN-back is a block-design task that engages youths' working memory and evokes emotional regulation and reactivity processes. Youth engaged in two imaging runs totaling 160 trials (10 [trials/block]*8 [blocks]*2 [runs]). Each imaging run has 8 blocked-series of 10 trials (2.5s each) and 4 fixation blocks (15s each). On each trial, youth are instructed to respond as to whether the current picture is a "Match" or "No Match." Within each run, there are 4 blocks of 0-back conditions and 4 blocks of 2-back conditions alternating with each other. For the 0-back condition, youth are instructed to respond "Match" when the current stimulus is the same as a target presented at the beginning of the block. For the 2-back condition, youth are asked to respond "Match" when the current stimulus is the same as the one shown two trials back. At the beginning of each block, a 2.5s cue (i.e., instruction) is presented on the screen to indicate whether the task type is 0-back (shown on the screen as "target = a photo of the target stimuli" or 2-back (shown on the screen as "2-back"). Further, a 0.5s colored fixation cross will appear right before each block's instruction to alert the child of a switch in the task type. Each trial was consisted of a stimulus (i.e., a picture) presented for a duration of 2s, followed immediately by a 0.5s fixation cross (i.e., interstimulus interval). The emotional component of the EN-back task contains 4 emotional stimulus types, including happy, fearful, and neutral facial expressions as well as one landscape control stimulus (i.e., pictures of places) (Casey et al., 2018; Tottenham et al., 2009). There is a total of 160 trials across 4 different stimulus types presented in separate blocks in each run, with each block containing only one type of image (i.e., stimulus). To assess neural responses evoked by the working memory component, which is the focus of the study, the main contrast is the block design analyses contrasting the 2-back and 0-back conditions (8 blocks each).

Emotional N-back (EN-back) Behavioral Assessment

Children's behavioral performance measures on average reaction time for all correct responses, number of correct responses, the rate of correct responses, and the standard deviation of the reaction time for all correct responses are calculated. These behavioral performance measures are calculated by each stimulus type (e.g., positive faces, negative faces), working memory condition (e.g., 0-back, 2-back), and combinations of the two (e.g., 0-back positive faces, 2-back negative faces). In the present study, the rates of correct trials (i.e., behavioral accuracy) for the two memory conditions (i.e., 0-back and 2-back) are used as primary behavioral measures, which are obtained by calculating the percentage of correct trials (i.e., correct positive and correct negatives) for the 0-back low memory load and the 2-back high memory load condition, respectively. Poor performance is indicated if the overall response accuracy for the 0-back or 2-back blocks is less than 60%. The comparison of the 0-back and 2-back memory conditions allows for the assessment of neural activations associated with working memory as opposed to cognitive function more generally. Behaviorally, a higher 2-back behavioral performance indicates better working memory.

Measures

Psychosocial Deprivation

In the present study, environmental psychosocial deprivation was conceptualized as a lack of (a) consistent and responsive caregiving, (b) a positive family environment, and (c) a supportive school environment characterized by rich opportunities for cognitive stimulation and building positive social relationships.

Lack of Parental Acceptance

Parental acceptance was assessed using the Child Report of Parental Behavior Inventory (CRPBI; Mann & Sanders, 1994). The 5-item acceptance subscale measures parents’ expression of affection of warmth. Children responded to all questions on a three-point Likert scale (1 = "*not like him/her*" to 3 = "*a lot like him/her*"). A sample item is “*Makes me feel better after talking over my worries with him/her*”. All items were reversed coded. A higher average score indicates lower levels of parental acceptance (α = .70).

Lack of Parental Monitoring

A 5-item self-report questionnaire was used to assess parental knowledge of children’s whereabouts and who children are spending time with, how often parents and children sit together for family dinner, how often the children know how to get in touch with parents if they are not at home, and how often children communicate with parents about their upcoming plans and activities (Karoly, Callahan, Schmiege, & Feldstein Ewing, 2016). Children rated each question on a five-point Likert scale (1 = "*never*" to 5 = "*always*"). A sample item is “*How often do you talk to your mom/dad or guardian about your plans for the coming day, such as your plans about what will happen at school or what you are going to do with friends?*”. All items were reversed coded. A higher mean score suggested lower parenting monitoring (α = .43). Although the reliability of the parental monitoring scale is low, it has been shown to reliably differentiate youth of high risk (for future substance use) from those of low risk (Gonzalez et al., 2021). This evidence supports the parental monitoring scale as an acceptable measure for assessing environmental risk.

Lack of Family Cohesion

Family context was measured through the youth-reported family conflict subscale of the ABCD Family Environment Scale (Moos, 1990). Children responded to all questions on a binary scale (1 = "*true*" and 0 = "*false*"). A sample question is "*Family members often criticize each other.*" Two items that are indicative of physical violence ("*Family members sometimes get so angry they throw things.*" and "*Family members sometimes hit each other.*") were removed. The remaining seven items were averaged to create a mean score. A higher score indicates less positive and warm family environment (α = .61).

Lack of Supportive and Enriching School Environment

School environment was measured via the ABCD School Risk and Protective Factors Survey. Seven questions that assess the availability of extracurricular activities, opportunities to help decide class activities and rules, children's positive relationship with teachers, and if children get praise if they do a good job. Children responded to each question on a 4-point Likert scale (1 = "*NO!*" to 4 = "*YES!*"). A sample question is "*There are lots of chances for students in my school to get involved in sports, clubs, or other school activities outside of class.*" All items were reverse coded. A higher average score indicated less supportive and enriching school environment (α = .66).

Control variables

Family Socioeconomic Status (SES)

Family's socioeconomic status (SES) was conceptualized as a multidimensional construct composed of income-to-poverty ratio, parental education level, marital status, and employment status (Brody et al., 2013).

Income-to-poverty Ratio. Income-to-poverty ratio (IPR) were calculated by first taking the average of each income bracket reported by the family (<$5000, $5,000 - $11,999, $12,000 - $15,999, $16,000 - $24,999, $25,000 - $34,999, $35,000 - $49,999, $50,000 - $74,999, $75,000 - $99,999, $100000 - $199999, >=$200000). Then, the family's income was divided by the federal poverty threshold for the year (i.e., 2016, 2017, 2018) during which the family was interviewed, adjusted for the number of people living in the same household at the time (DeJoseph, Herzberg, Sifre, Berry, & Thomas, 2022).

Parental Education Level. The primary caregiver's highest education (in years) was coded into five categories including *"< High School Diploma"*, *"High School Diploma/GED"*, *"Some College"*, *"Bachelor"*, *"Post Graduate Degree"*.

Marital status. The primary caregiver's marital status (i.e., married or living together) was a dichotomous variable coded 0 = *"no"* and 1 = *"yes"*.

Employment Status. Parental employment status was a dichotomous variable coded as 0 = *"unemployed"* and 1 = *"full-/part-time employed"*.

Additional Demographic Covariates. Children's sex (1 = Female, 2 = Male) and age were included as additional covariates in all analyses.

Data Analysis Plan

Preliminary Analyses

Before testing study hypotheses, descriptive statistics and zero-order bivariate correlations among all study variables were examined. Additionally, rates of missing data, data non-normality including skewness and kurtosis were inspected. Missing data were evaluated to determine if the pattern of missingness was completely at random (MCAR), at random (MAR), or not at random (MNAR). Little’s MCAR test was conducted to investigate if the pattern of missing data was MCAR.

Hypothesis Testing

Measurement and multivariate models were tested in Mplus 7.4 (Muthén & Muthén, 1998-2010) under a structural equation modeling framework (SEM) using maximum likelihood estimation with robust standard errors (Yuan & Bentler, 2000). A measurement model of a psychosocial deprivation latent variable was tested with confirmatory factor analysis (CFA). In addition, CFA was used to build latent factors of neural responses in ROIs within the frontoparietal network and the default mode network. To test individual differences in neural efficiency, a series of SEM models were built to test the moderating effect of psychosocial deprivation on the association between neural response within the frontoparietal network, the default mode network, the insula (independent variable) and working memory behavioral performance (i.e., 2-back behavioral accuracy, dependent variable). Significant moderating effects were probed using the Johnson-Neyman technique (P. O. Johnson & Neyman, 1936) and simple slope method (Aiken, West, & Reno, 1991; Dawson, 2014).

All SEM models were evaluated based on several fit indices, including root mean squared residual (SRMR), root mean square error of approximation (RMSEA), and Comparative Fix Index (CFI; L. t. Hu & Bentler, 1999). Model fit was determined to be adequate if RMSEA is at most .08 or below, CFI at least .90 or above, and SRMR is at most .08 or below. Two-level complex survey data was used to account for clustering effects of participants within families and sites (Muthén & Muthén, 1998-2010). In addition, sample propensity scores were used to mitigate potential selection bias in the ABCD sampling and recruitment process (Heeringa & Berglund, 2020).

Power analysis

Post hoc power analyses were conducted using Monte Carlo simulations with 500 repetitions in MPlus (version 7.4), using the observed sample statistics (Muthén & Muthén, 2010; Thoemmes, MacKinnon, & Reiser, 2010).

CHAPTER 4

RESULTS

In this chapter, I will present my findings in two sections. First, I will review results from descriptive analyses that were conducted to better understand the characteristics of study variables. I will also detail results from my missing data analysis, power analysis, as well as analyses conducted to examine group differences between the sample of participants that were entered into the final analyses and the rest of the sample that was excluded due to missingness or failed quality control on working memory imaging data. Next, I will present findings from SEM models that were used to test study hypotheses. In this section, I will first report results from confirmatory factor analyses that were conducted to build latent factors of psychosocial deprivation and neural responses associated with working memory within the frontoparietal network and the default mode network. Following that, I will show results from SEM models that were constructed to test the moderating effect of psychosocial deprivation on the association between working memory related neural response and behavioral accuracy. Lastly, I will present results from follow-up moderation analyses which aimed to probe patterns of neural response at different performance levels across varying degrees of psychosocial deprivation.

Preliminary Analyses

Descriptive Statistics

The mean, standard deviation, minimum, maximum values, skewness, and kurtosis for all study variables are presented in Table 2. The normality of each variable was assessed by examining the skewness and kurtosis statistics and inspecting a histogram with a normal curve. All study variables were determined to follow a normal curve.

Table 2. Descriptive Statistics for Study Variables

Variable	*N*	Mean	SD	Minimum	Maximum	Skewness	Kurtosis
1. Child sex	7481	1.51	.50	1.00	2.00	-.05	-2.00
2. Child age	7474	9.51	.51	8.00	11.00	-.02	-1.80
3. Socioeconomic status	7480	2.31	.95	0.00	6.27	.22	-.48
4. Lack of parental acceptance	7470	1.21	.29	1.00	3.00	1.85	4.21
5. Lack of parental monitoring	7474	1.59	.48	1.00	5.00	1.10	1.55
6. Lack of family cohesion	7473	.23	.23	.001	1.00	.90	.13
7. Lack of supportive sch envir	7472	1.66	.45	1.00	4.00	.88	1.21
8. 0-back accuracy	7481	.86	.10	.60	1.00	-.92	.05
9. 2-back accuracy	7481	.79	.09	.60	1.00	-.08	-.74
10. Bilateral SFG	7481	.01	.21	-1.31	1.09	-.51	7.59
Superior frontal gyrus.lh	7481	.001	.22	-1.44	1.10	-.67	8.96
Superior frontal gyrus.rh	7481	.02	.22	-1.18	1.09	-.30	6.30
11. Bilateral MFG[a]	7481	.10	.28	-1.85	1.59	-.50	5.84
Caudal middle frontal gyrus.lh	7481	.11	.25	-1.18	1.13	-.28	3.43
Caudal middle frontal gyrus.rh	7481	.12	.27	-1.24	1.30	-.18	3.84
Rostral middle frontal gyrus.lh	7481	.07	.39	-2.86	1.89	-1.24	13.24
Rostral middle frontal gyrus.rh	7481	.09	.38	-2.13	2.02	-.40	7.64
12. Bilateral ParsOp	7481	.04	.26	-1.29	1.17	-.22	3.62
Pars opercularis.lh	7481	.03	.26	-1.33	1.08	-.33	3.75
Pars opercularis.rh	7481	.05	.28	-1.25	1.26	-.12	3.57
13. Bilateral Parietal Lobule[b]	7481	.04	.22	-1.18	1.10	-.29	3.83
Inferior parietal lobule.lh	7481	.03	.24	-1.13	1.08	-.13	3.48
Inferior parietal lobule.rh	7481	.06	.25	-1.23	1.11	-.34	4.09
Superior parietal lobule.lh	7481	.03	.23	-1.09	1.08	-.23	3.83
Superior parietal lobule.rh	7481	.03	.24	-1.27	1.13	-.39	4.82
14. Bilateral Insula	7481	-.04	.20	-1.04	.89	-.13	3.37
Insula.lh	7481	-.04	.21	-.95	.80	-.13	3.03
Insula.rh	7481	-.04	.22	-1.14	.99	-.19	4.09
15. Bilateral medPFC[c]	7481	-.10	.52	-4.17	3.15	-.98	14.98
Medial orbitofrontal cortex.lh	7481	-.13	.84	-6.27	4.21	-1.32	15.75
Medial orbitofrontal cortex.rh	7481	-.11	.87	-6.11	5.06	-.83	15.33
Rostral anterior cingulate.lh	7481	-.11	.36	-2.23	1.60	-.53	7.26
Rostral anterior cingulate.rh	7481	-.07	.35	-2.09	1.75	-.31	7.87
16. Bilateral PCC[d]	7481	-.03	.26	-1.24	1.15	-.08	2.55
Posterior cingulate.lh	7481	-.01	.24	-1.07	.96	-.14	2.79
Posterior cingulate.rh	7481	.01	.25	-1.06	1.12	-.02	3.07
Isthmus cingulate.lh	7481	-.08	.32	-1.34	1.24	-.02	2.49
Isthmus cingulate.rh	7481	-.05	.34	-1.48	1.26	-.12	2.51

Notes. Child sex is coded as 1 = female, 2 = male; Socioeconomic status is calculated as mean composite score composed of income to poverty ratio, parental education, parental marital status, and parental employment status. Sch envir = school environment; lh = left hemisphere; rh = right hemisphere. Bilateral = (right hemisphere + left Hemisphere)/2; [a] bilateral MFG (middle frontal gyrus) was calculated as an average of bilateral caudal middle frontal gyrus and bilateral rostral middle frontal gyrus; [b] bilateral parietal lobule was calculated as an average of bilateral inferior parietal lobule and bilateral superior parietal lobule; [c] bilateral medPFC (medial prefrontal cortex) was calculated as an average of bilateral medial orbitofrontal cortex and bilateral rostral anterior cingulate; [d] bilateral PCC (posterior cingulate cortex) was calculated as an average of the posterior cingulate and isthmus cingulate in the original desikan atlas.

Table 3 presents demographic statistics for the full baseline sample (*n* = 11,875), final sample remained for analyses after quality control on imaging data (*n* = 7,481), and the group of participants excluded due to missing and failed quality control on imaging data (*n* = 4397). Chi-square tests and t-tests were performed to examine group differences between the final sample entered for analyses and the excluded sample. The results showed that the final sample and the excluded sample differed significantly on various demographic variables (See Table 4). In terms of child characteristics, the final sample and excluded sample differed significantly by sex (χ^2[1] = 8.44, $p < .01$) and race (χ^2[4] = 307.48, $p < .001$). Children who remained in the final sample were significantly older than children in the excluded sample (*t* [9222.88] = -8.65, $p < .001$).

Regarding caregiver characteristics, parents in the final sample were older than parents in the excluded sample (*t* [8464.02] = -7.12, $p < .001$). In addition, caregivers in the final sample on average had higher levels of education (*t* [8470.71] = -16.87, $p < .001$) and higher annual household income (*t* [6967.59] = -16.53, $p < .001$) than caregivers in the excluded sample. Furthermore, there were significant group differences between the final and excluded sample on caregivers' employment and marital status. Specifically, there was a higher percentage of employment in the final sample than in the excluded sample (χ^2 [1] = 20.91, $p < .001$). There were also more caregivers married or living together in the final sample than in the excluded sample (χ^2 [1] = 144.21, $p < .001$).

Table 3. Demographics of Study Participants

Variables	**Full sample (N = 11, 878)**	**Final sample (N = 7, 481)**	**Excluded sample[a] (N = 4,397)**	χ^2/t
Child characteristics				
Sex, % female	47.80%	48.9%	46.1%	8.44** (χ^2)
Age, mean (SD)	9.48 (.51)	9.51 (.51)	9.43 (.51)	-8.65*** (*t*)
Race, %				307.48*** (χ^2)
White	52.00%	56.9%	43.9%	
Black or African American	15.00%	11.1%	21.7%	
Hispanic/Latino(a)	20.30%	19.4%	21.7%	
Asian	2.10%	2.2%	2.0%	
Other	10.50%	10.4%	10.6%	

Caregiver characteristics				
Sex, % female	89.00%	88.9%	89.1%	10.98 (χ^2)
Age, mean (SD)	39.96 (6.84)	40.32 (6.58)	39.37 (7.22)	-7.12*** (t)
Education, %				
< High School (HS) Diploma	5.00%	3.6%	7.3%	
HS Diploma/GED	9.50%	7.4%	13.2%	
Some College	25.90%	24.2%	29.0%	
Bachelor	25.40%	26.8%	23.0%	
Post Graduate Degree	34.00%	37.9%	27.4%	
Mean (SD)	3.74 (1.17)	3.88 (1.11)	3.5 (1.23)	-16.87*** (t)
Annual household income				
< $5k	3.50%	2.1%	5.9%	
$5k ~ $12k	3.50%	2.7%	5.0%	
$12k ~ $16k	2.30%	2.0%	2.8%	
$16k ~ $25k	4.40%	3.8%	5.4%	
$25k ~ $35k	5.50%	5.0%	6.4%	
$35k ~ $50k	7.90%	7.3%	8.8%	
$50k ~ $75k	12.60%	12.7%	12.4%	
$75k ~ $100k	13.20%	14.5%	11.1%	
$100k ~ $200k	27.90%	30.8%	23.0%	
> $200k	10.50%	11.8%	8.3%	
Mean (SD)	7.22 (2.42)	7.52 (2.22)	6.69 (.47)	-16.53*** (t)
Employment status				20.91***(χ^2)
% employed (full/part-time)	69.20%	70.7%	66.6%	
Marital status				144.21***(χ^2)
% married/living together	73.10%	77.4%	66.6%	

Notes. [a] Sample of children excluded due to missing and failed quality control on imaging data. SD = standard deviation.

Power Analysis

Monte Carlo simulations were used to obtain post-hoc power estimates for 1) SEM models that examined the direct associations between neural responses during working memory challenge and attendant behavioral accuracy; 2) SEM models that investigated the moderating effect of psychosocial deprivation on the associations between neural responses during working memory and attendant behavioral accuracy.

The most complex model in the direct effect SEM models was the one that investigated the direct link between working memory-associated neural responses within the frontoparietal network and attendant behavioral accuracy. This SEM model has 18 parameters. The estimated power for the parameter of interest (i.e., frontoparietal neural activation → working memory behavioral accuracy) achieved 100%, higher than the standard 80%. The 95% confidence interval coverage for the parameter of interest was at or above .95. Therefore, the sample size in the present study (N = 7481) was adequately powered for the direct effect SEM models.

The most complex model in the moderation SEM models was the one that tested the moderating effect of psychosocial deprivation on the link between working memory-associated neural responses within the frontoparietal network and attendant behavioral accuracy. This SEM model involves latent interaction and has 48 parameters. Similarly, results revealed excellent power for the significant interaction effect (i.e., frontoparietal neural activation x psychosocial deprivation → working memory behavioral accuracy), which was 93.0%. The 95% confidence interval coverage for the parameter of interest was at or above .95. Thus, the sample size in the present study (N = 7481) was adequately powered (1-beta ≥ .80) to correctly detect significant effect in moderation analyses examined within SEM models.

Missing Data Analysis

The percentage of missing data ranged from zero to .15%. Data missingness was tested using Little's Missing Completely at Random (MCAR) test. The test was not significant (χ^2 [99] = 98.50, p = .50), indicating that the data were MCAR, namely, participants' missing data were not related to their data on other study variables. A full information maximum likelihood (FIML) estimation was deemed appropriate to estimate missing data under MCAR condition as it produces more accurate parameters estimates than methods such as listwise or pairwise deletion (Enders & Bandalos, 2001).

Bivariate Correlations

Pearson's correlations among all study variables were computed among all study variables and visualized using the *corrplot* package in RStudio version 1.4.1717 (Wei, Simko, & Levy, 2021). Correlation coefficients in colored cells were all significant at $p < .05$. Blank cells indicated that the correlation coefficients were non-significant (See Figure 4).

Bivariate correlations were inspected between family socioeconomic status (SES) and variables that were used to model psychosocial deprivation. SES was significantly and negatively associated with lack of parental acceptance ($r = -.07$, $p < .05$, 95% CI [-.09, -.04]), lack of parental monitoring ($r = -.13$, $p < .05$, 95% CI [-.16, -.11]), and a lack of family cohesion ($r = -.14$, $p < .05$, 95% CI [-.17, -.12]). SES was not significantly associated with a lack of positive school environment. SES was positively linked to children's working memory behavioral accuracy (2-back accuracy; $r = .22$, $p < .05$, 95% CI [.20, .24]). Furthermore, SES was positively linked to neural response in various brain regions, including the middle frontal gyrus ($r = .05$, $p < .05$, 95% CI [.03, .07]), parietal lobule ($r = .03$, $p < .05$, 95% CI [.01, .05]), insula ($r = -.03$, $p < .05$, 95% CI [-.05, -.01]), medial prefrontal cortex ($r = -.03$, $p < .05$, 95% CI [-.05, -.01]), and posterior cingulate cortex ($r = -.03$, $p < .05$, 95% CI [-.049, -.003]).

Children's experience of a lack of parental acceptance ($r = -.03$, $p < .05$, 95% CI [-.05, -.01]), a lack of parental monitoring ($r = -.07$, $p < .05$, 95% CI [-.09, -.05]), and a lack of family cohesion ($r = -.06$, $p <. 05$, 95% CI [-.08, -.03]) was negatively linked to their 2-back working memory behavioral performance. Experience of a lack of positive school environment was not linked to children's 2-back working memory behavioral accuracy. Variables used to model psychosocial deprivation were not significantly associated with any of the neuroimaging data. Child sex and age were positively associated with 2-back accuracy, such that boys tended to perform better than girls during working memory ($r = .13$, $p < .05$, 95% CI [.11, .16]). In addition, children who were older tended to have higher accuracy scores than younger children (*r*

= .16, *p* < .05, 95% CI [.14, .18]). Lastly, as expected, children's 2-back working memory accuracy scores were significantly (positively or negatively) associated with neural responses in almost all ROIs, except for posterior cingulate cortex (See Figure 4).

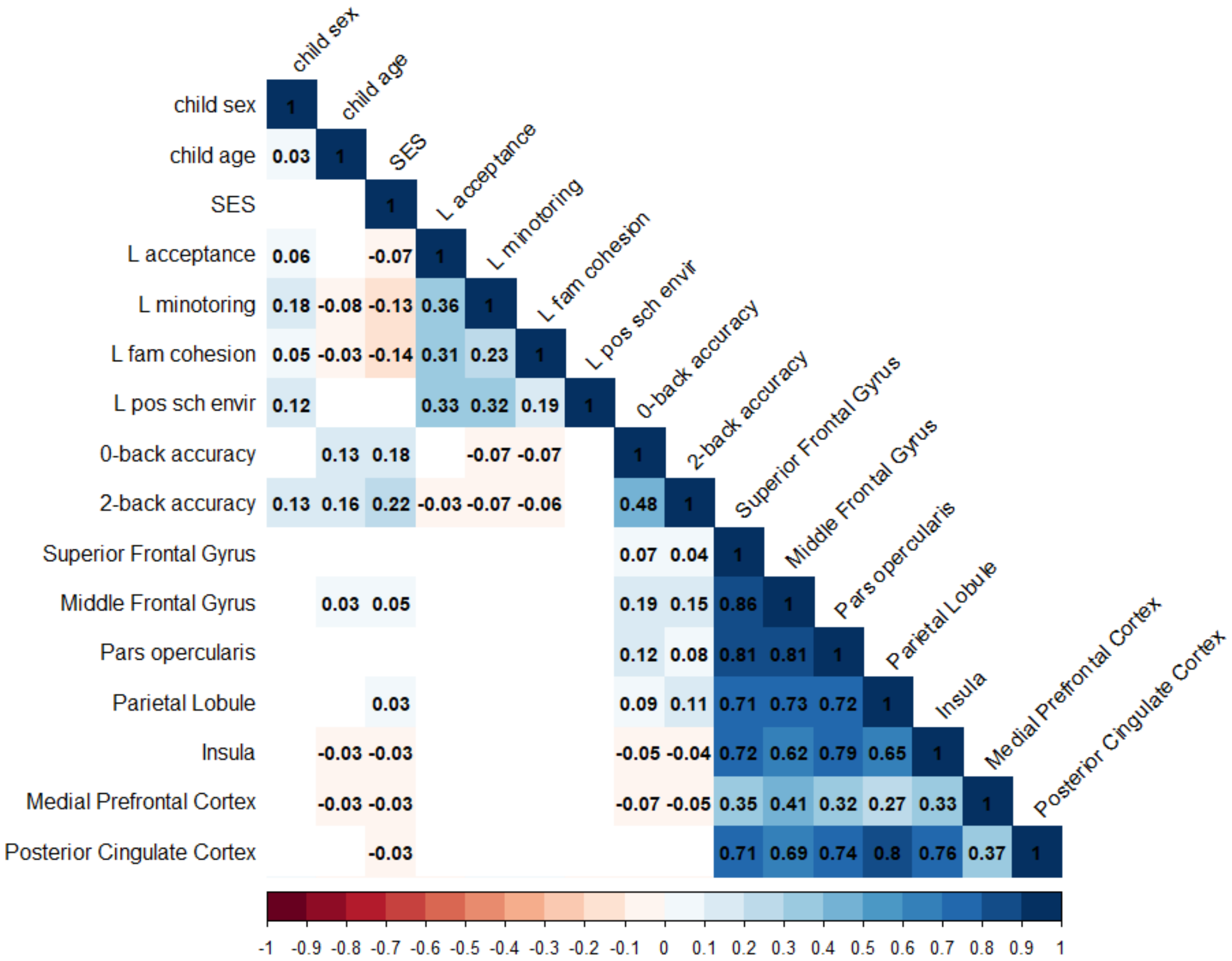


Figure 4. Bivariate correlations among study variables.

Notes. SES = socioeconomic status; L acceptance = lack of parental acceptance; L monitoring = lack of parental monitoring; L fam cohesion = lack of family cohesion; L pos sch envir = lack of positive school environment; Correlation coefficients in colored cells were all significant at *p* < .05; correlation coefficients in blank cells were non-significant.

Hypothesis Testing

Measurement Models

Confirmatory Factor Analysis (CFA) was used to construct a latent factor of psychosocial deprivation. Additionally, CFA was used to build latent factors of neural responses in ROIs within the frontoparietal network and the default mode network.

Psychosocial Deprivation

The latent factor of psychosocial deprivation was comprised of four indicators: lack of parental acceptance, lack of parental monitoring, lack of family cohesion, and lack of positive school environment. The measurement model had excellent model fit: $\chi^2[2] = 32.26$, $p < .001$, CFI = .98, RMSEA = .05, 90%CI [.03, .06], SRMR = .02. All factor loadings were above .43 and significant ($p < .001$; See Table 4).

Task-positive Network of ROIs within the Frontoparietal Regions (FPN)

A latent factor of the frontoparietal network was constructed using four task-positive ROIs, including the bilateral superior frontal gyrus, middle frontal gyrus, pars opercularis of the inferior frontal gyrus, and parietal lobule. This measurement model had great fit: $\chi^2[2] = 17.35$, $p < .001$, CFI = .99, RMSEA = .03, 90%CI [.02, .05], SRMR = .01. All standardized factor loadings were above .78 and significant ($p < .001$; See Table 4).

Task-negative Network of ROIs within the Default Mode Network (DMN)

A latent factor of the default mode network was composed of two core nodes of the default mode network, which included the medial prefrontal cortex and the posterior cingulate cortex. Because a latent factor of two indicators was locally under-identified, therefore, certain scaling constraints were imposed to obtain a just-identified model. These constraints include: 1) setting the variance of the latent factor to 1; 2) assuming the two indicators were an equivalent reflection of the latent construct (Brown, 2015; Little, 2013). The resultant model was saturated, and standardized factor loadings were above .44 and significant ($p < .001$).

Table 4. Measurement models of psychosocial deprivation and neural responses in targeted brain regions during working memory challenge.

Measurement model	**λ**	**(*SE*)**	**R^2**	**95% CI of λ**	***p***
Psychosocial Deprivation[a]					
Lack of parental acceptance	.68	.02	.46	[.64, .71]***	< .001
Lack of parental monitoring	.56	.02	.32	[.53, .60]***	< .001
Lack of family cohesion	.43	.02	.18	[.40, .46]***	< .001
Lack of positive school environment	.50	.02	.25	[.47, .54]***	< .001
Frontoparietal Network[b]					
Superior frontal gyrus	.92	.01	.85	[.90, .94]***	< .001
Middle frontal gyrus	.93	.01	.86	[.92, .94]***	< .001
Pars opercularis	.88	.01	.77	[.86, .89]***	< .001
Parietal lobule	.78	.01	.61	[.76, .80]***	< .001
Default Mode Network[c]					
Medial prefrontal cortex	.44	.02	.19	[.41, .47]***	< .001
Posterior cingulate cortex	.86	.03	.73	[.81, .90]***	< .001

Notes. λ = standardized factor loadings. [a] $\chi^2[2] = 32.24$, $p < .001$, CFI = .98, RMSEA = .05, 90%CI [.03, .06], SRMR = .02; [b] $\chi^2[2] = 17.35$, $p < .001$, CFI = .99, RMSEA = .03, 90%CI [.02, .05], SRMR = .01; [c] the model was saturated. Middle frontal gyrus = (caudal middle frontal gyrus + rostral middle frontal gyrus)/2; parietal lobule = (inferior parietal lobule + superior parietal lobule)/2; medial prefrontal cortex = (medial orbitofrontal cortex + rostral anterior cingulate)/2; posterior cingulate cortex = (desikan atlas based posterior cingulate + isthmus cingulate)/2.

Direct Effect Models

Several SEM models were first constructed to examine associations between neural responses in targeted brain regions associated with working memory and 2-back working memory behavioral performance. Child sex, age, and family SES were entered in all models as covariates. Latent factors of ROIs within the frontoparietal network and within the default mode network, and an observed variable of neural response within the insula were tested one by one. All models exhibited great model fit (See Table 5 for detailed information on model parameters and model fit).

As expected, children's neural responses within the frontoparietal network during working memory challenge were positively and significantly associated their working memory behavioral performance. Specifically, increased neural responses in brain regions within the frontoparietal network (B = .05, *β* = .10, $p < .001$, 95% CI of B [.03, .06] were linked to better 2-back behavioral performance. Insula, on the other hand, was negatively and significantly associated 2-back behavioral accuracy (B = -.01, *β* = -.03, $p < .05$, 95% CI of B [-.022, -.001]), contrary to expectations. Lastly, neural responses in brain regions within the default mode network were negatively and significantly linked to 2-back accuracy, such that increased deactivations within the default mode network were associated with better working memory behavioral performance (B = -.01, *β* = -.04, $p < .01$, 95% CI of B [-.010, -.002]).

Table 5. Parameters of SEM models that investigate the direct associations between working memory associated neural responses in targeted brain regions and attendant behavioral accuracy.

SEM	**B**	**(*SE*)**	**β**	**95% CI of B**	***p***
Model 1[a]					
Frontoparietal network → 2-back accuracy	.05	.01	.10	[.03, .06]	< .001
Sex → 2-back accuracy	.03	.002	.14	[.02, .03]	< .001
Age → 2-back accuracy	.03	.002	.15	[.02, .03]	< .001
Family SES → 2-back accuracy	.02	.001	.22	[.019, .023]	< .001
Model 2[b]					
Insula → 2-back accuracy	-.01	.01	-.03	[-.022, -.001]	< .05
Sex → 2-back accuracy	.03	.002	.14	[.02, .03]	< .001
Age → 2-back accuracy	.03	.002	.15	[.02, .03]	< .001
Family SES → 2-back accuracy	.02	.001	.22	[.019, .023]	< .001
Model 3[c]					
Default mode network → 2-back accuracy	-.01	.002	-.04	[-.010, -.002]	< .01
Sex → 2-back accuracy	.03	.002	.14	[.02, .03]	< .001
Age → 2-back accuracy	.03	.002	.15	[.02, .03]	< .001
Family SES → 2-back accuracy	.02	.001	.22	[.019, .024]	< .001

Notes. SES = socioeconomic status. [a] $\chi^2[17] = 264.78$, $p < .001$, CFI = .97, RMSEA = .04, 90%CI [.04, .05], SRMR = .02; [b] $\chi^2[3] = 5.78$, $p = .12$, CFI = 1.00, RMSEA = .01, 90%CI [.001, .025], SRMR = .01; [c] $\chi^2[7] = 13.60$, $p = .06$, CFI = .99, RMSEA = .01, 90%CI [.001, .020], SRMR = .01.

Moderation Models: The Moderating Role of Psychosocial Deprivation on the Association between Working Memory Related Neural Response and Behavioral Accuracy

A series of SEM models were created to test the moderating role of psychosocial deprivation on the associations between neural responses during working memory challenge and working memory behavioral performance. Child sex, age, and family SES were controlled for in all models as covariates. Latent factors of ROIs within the frontoparietal network and within the default mode network, and an observed variable of neural response within the insula were tested one by one. All models exhibited adequate model fit (See Table 6 for detailed information on model parameters and model fit; See Figure 5, 6, and 7 for graphic presentations). Significant moderating effects were probed using the Johnson-Neyman technique (P. O. Johnson & Neyman, 1936) and simple slopes analysis (Aiken et al., 1991; Dawson, 2014).

Table 6. Parameters of SEM models that investigate the moderating role of psychosocial deprivation on the associations between working memory associated neural responses in targeted brain regions and attendant behavioral accuracy.

SEM Models	**B**	**(*SE*)**	**β**	**95% CI of B**	***p***
Model 1[a]					
FPN → WM accuracy	.05	.01	.11	[.04, .06]	< .001
Psychosocial deprivation → WM accuracy	-.03	.01	-.06	[-.04, -.01]	< .001
Interaction effect → WM accuracy	-.11	.04	-.05	[-.18, -.04]	< .01
Sex → WM accuracy	.03	.002	.15	[.02, .03]	< .001
Age → WM accuracy	.03	.002	.15	[.02, .03]	< .001
Family SES → WM accuracy	.02	.001	.21	[.018, .022]	< .001
Model 2[b]					
Insula → WM accuracy	-.01	.01	-.03	[-.02, .001]	.06
Psychosocial deprivation → WM accuracy	-.03	.01	-.06	[-.04, -.01]	< .001
Interaction effect → WM accuracy	-.03	.04	-.01	[-.10, .05]	.47
Sex → WM accuracy	.03	.002	.15	[.02, .03]	< .001
Age → WM accuracy	.03	.002	.15	[.02, .03]	< .001
Family SES → WM accuracy	.02	.001	.21	[.018, .023]	< .001
Model 3[c]					
DMN → WM accuracy	-.01	.004	-.04	[-.02, -.002]	< .05
Psychosocial deprivation → WM accuracy	-.03	.01	-.05	[-.04, -.01]	< .01
Interaction effect → WM accuracy	-.05	.02	-.05	[-.09, -.002]	< .05
Sex → WM accuracy	.03	.002	.15	[.02, .03]	< .001
Age → WM accuracy	.03	.002	.15	[.02, .03]	< .001
Family SES → WM accuracy	.02	.001	.21	[.018, .023]	< .001

Notes. FPN = frontoparietal network; DMN = default mode network; WM = working memory;

SES = socioeconomic status. [a] $\chi^2[43] = 560.42$, $p < .001$, CFI = .96, RMSEA = .04, 90%CI [.037, .043], SRMR = .02; [b] $\chi^2[17] = 261.40$, $p < .001$, CFI = .93, RMSEA = .04, 90%CI [.04, .05], SRMR = .04; [c] $\chi^2[24] = 278.97$, $p < .001$, CFI = .93, RMSEA = .04, 90%CI [.03, .04], SRMR = .02.

Model 1

Model 1 tested the moderating effect of psychosocial deprivation on the link between neural response within the frontoparietal network during working memory challenge and attendant behavioral accuracy. This model displayed great model fit: $\chi^2[43] = 560.42$, $p < .001$, CFI = .96, RMSEA = .04, 90%CI [.037, .043], SRMR = .02. The results revealed that psychosocial deprivation significantly attenuated the association between neural activations within the frontoparietal network during working memory challenge and attendant behavioral accuracy (B = -.11, $\beta = -.05$, $p < .01$, 95% CI of B [-.18, -.04]; Table 6 Model 1 and Figure 5). Probing of the moderation effects showed that as psychosocial deprivation increased from 1.42SD below the mean to 1.37SD above the mean (-1.42SD ~ +1.37SD), the positive effect of working memory-related neural activations within the frontoparietal network on behavioral accuracy decreased (94.0% of participants [N = 7032] fell in the region of significance; Figure 8).

Model 2

Model 2 tested the moderating effect of psychosocial deprivation on the link between neural response within the insula during working memory challenge and attendant behavioral accuracy. This model displayed adequate model fit: $\chi^2[17] = 261.40$, $p < .001$, CFI = .93, RMSEA = .04, 90%CI [.04, .05], SRMR = .04. Psychosocial deprivation did not significantly moderate the association between neural response within the insula during working memory challenge and attendant behavioral accuracy (B = -.03, β = -.01, p = .47, 95% CI of B [-.10, .05]; Table 6 Model 2 and Figure 6).

Model 3

Model 3 investigated the moderating effect of psychosocial deprivation on the link between neural response within the default mode network during working memory challenge and attendant behavioral accuracy. This model displayed adequate model fit: $\chi^2[24] = 278.97$, $p < .001$, CFI = .93, RMSEA = .04, 90%CI [.03, .04], SRMR = .02. The results showed that psychosocial deprivation significantly intensified the association between neural deactivations within the default mode network during working memory challenge and attendant behavioral accuracy (B = -.05, β = -.05, $p < .05$, 95% CI of B [-.09, -.002]; Table 6 Model 3 and Figure 7). Probing of the moderation effects showed that as psychosocial deprivation increased from .01SD below the mean to 5.95SD above the mean (-.01SD ~ +5.95SD), the inverse association between working memory-related neural deactivations within the frontoparietal network and behavioral accuracy increased (43.90% of participants [N = 3284] fell in the region of significance; Figure 9).

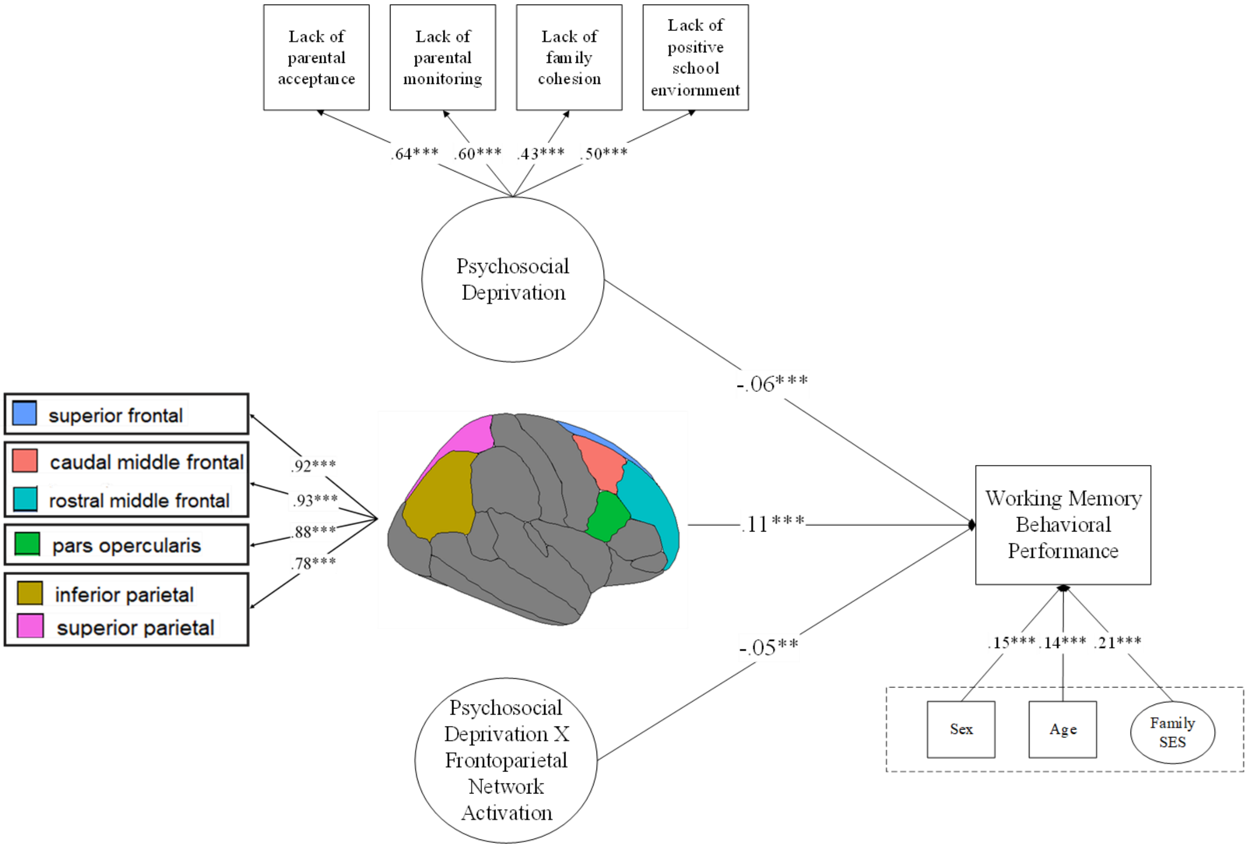


Figure 5. The moderating role of psychosocial deprivation on the association between working memory related neural response within the frontoparietal network and behavioral accuracy.

Notes. χ^2[43] = 560.42, $p < .001$, CFI = .96, RMSEA = .04, 90%CI [.037, .043], SRMR = .02. Standardized parameters are presented. Covariates including child sex, age, and family socioeconomic status (SES) were included.

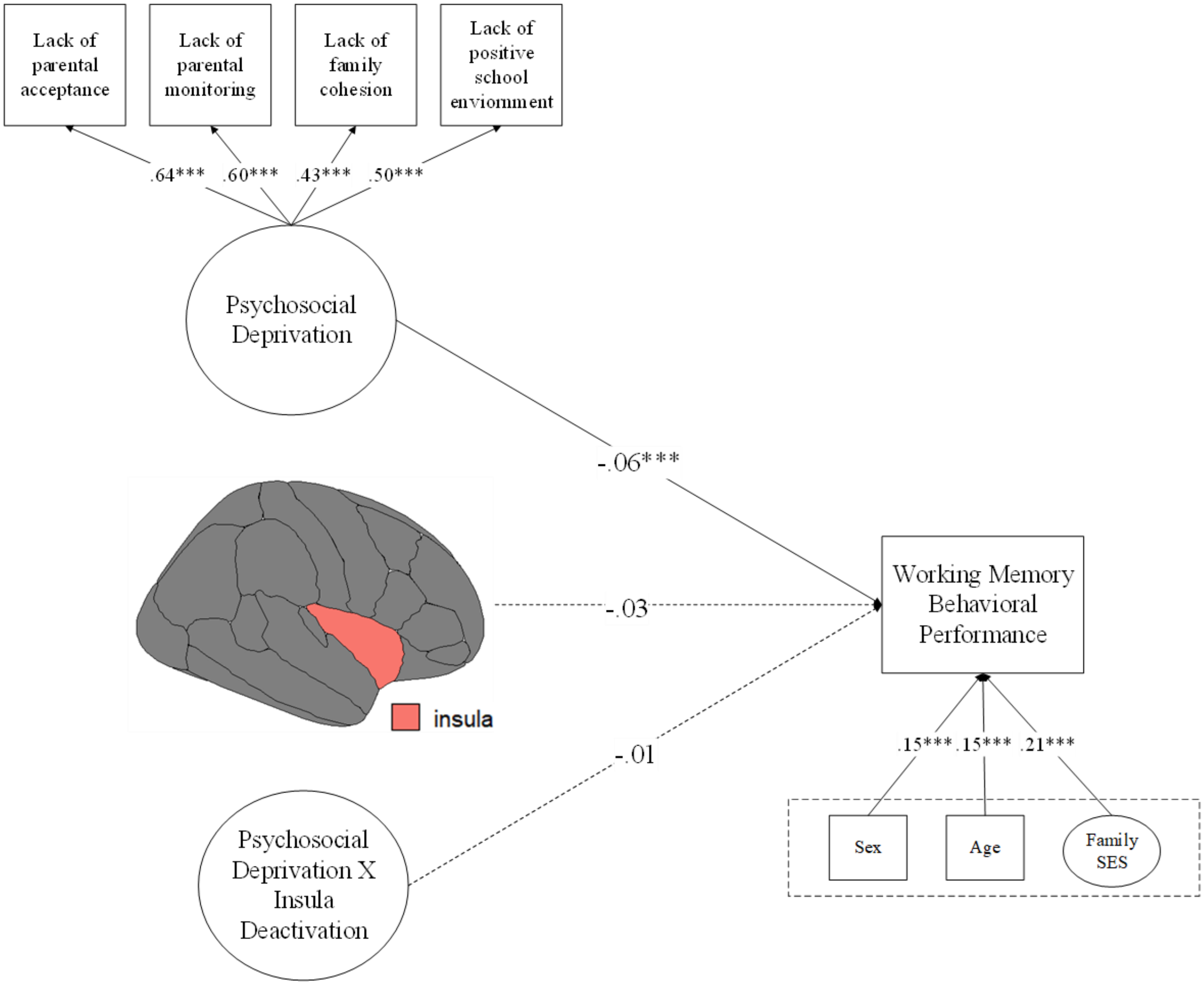


Figure 6. The moderating role of psychosocial deprivation on the association between working memory related neural response within the insula and behavioral accuracy.

Notes. χ^2[17] = 261.40, *p* < .001, CFI = .93, RMSEA = .04, 90%CI [.04, .05], SRMR = .04. Standardized parameters are presented. Covariates including child sex, age, and family socioeconomic status (SES) were included.

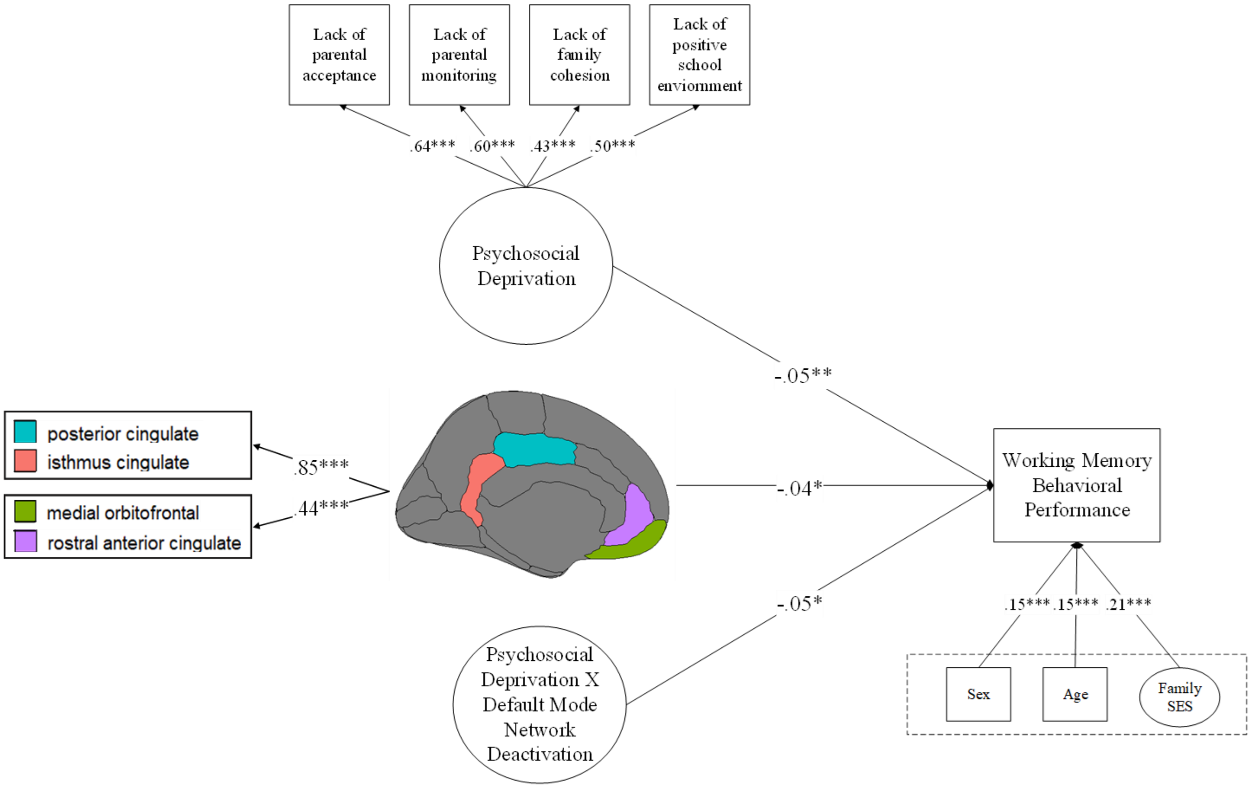
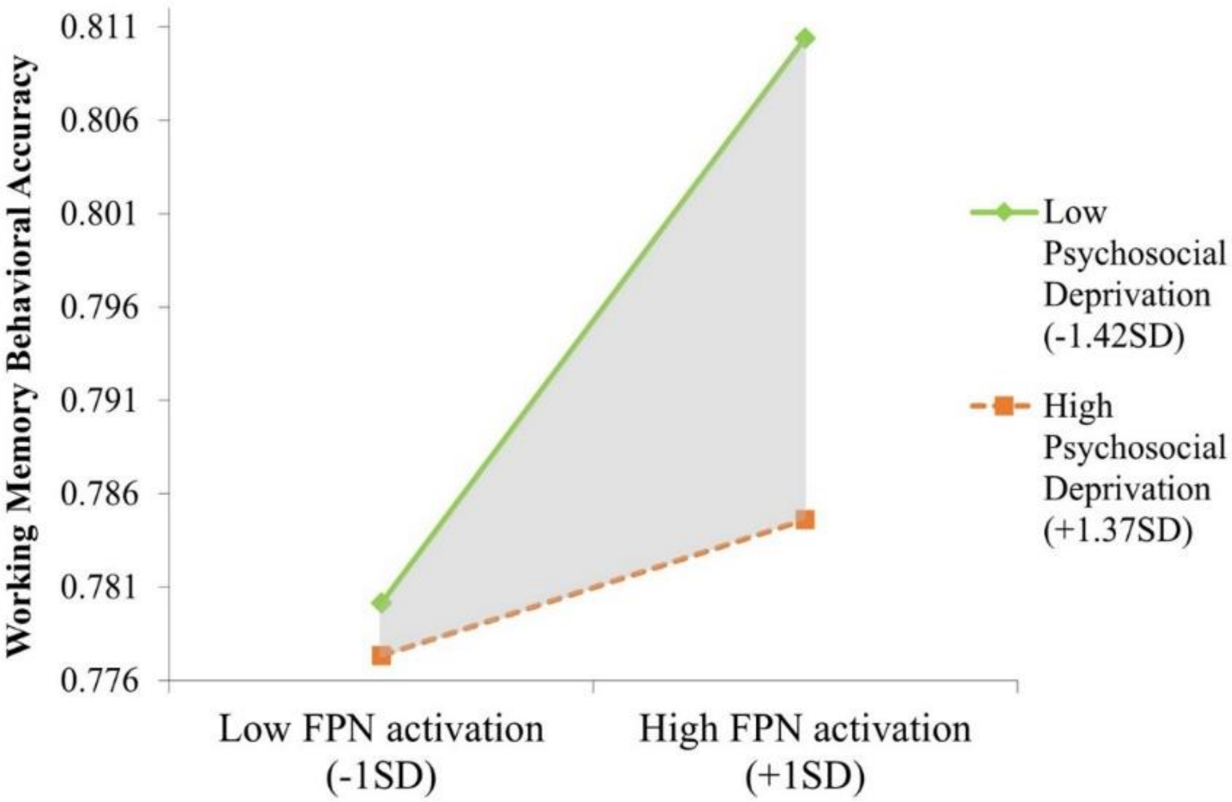


Figure 7. The moderating role of psychosocial deprivation on the association between working memory related neural response within the default mode network and behavioral accuracy.

Notes. $\chi^2[24] = 278.97$, $p < .001$, CFI = .93, RMSEA = .04, 90%CI [.03, .04], SRMR = .02. Standardized parameters are presented. Covariates including child sex, age, and family socioeconomic status (SES) were included.


Working Memory Behavioral Accuracy
0.811
0.806
0.801
0.796
0.791
0.786
0.781
0.776
Low FPN activation (-1SD)
High FPN activation (+1SD)
Low Psychosocial Deprivation (-1.42SD)
High Psychosocial Deprivation (+1.37SD)

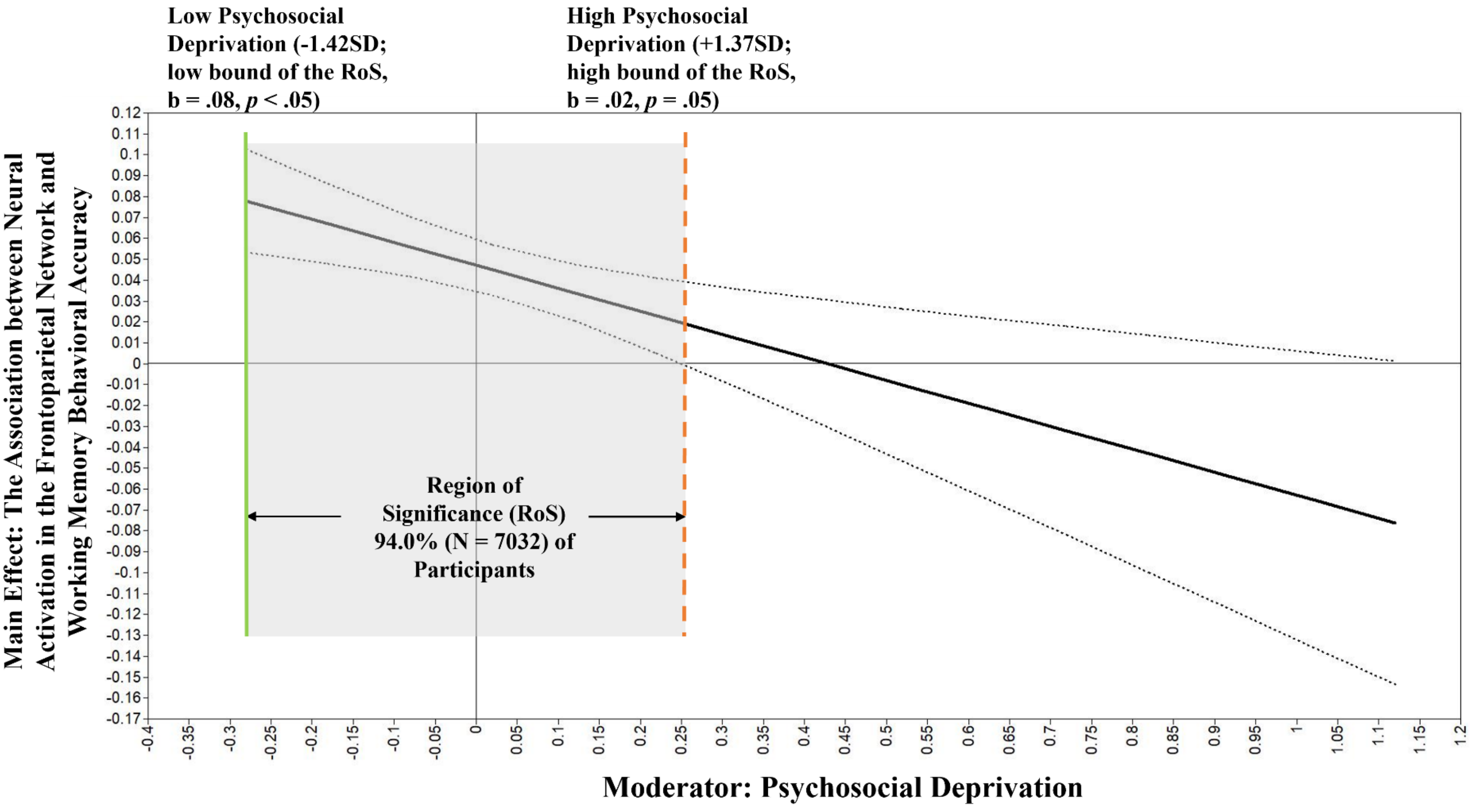
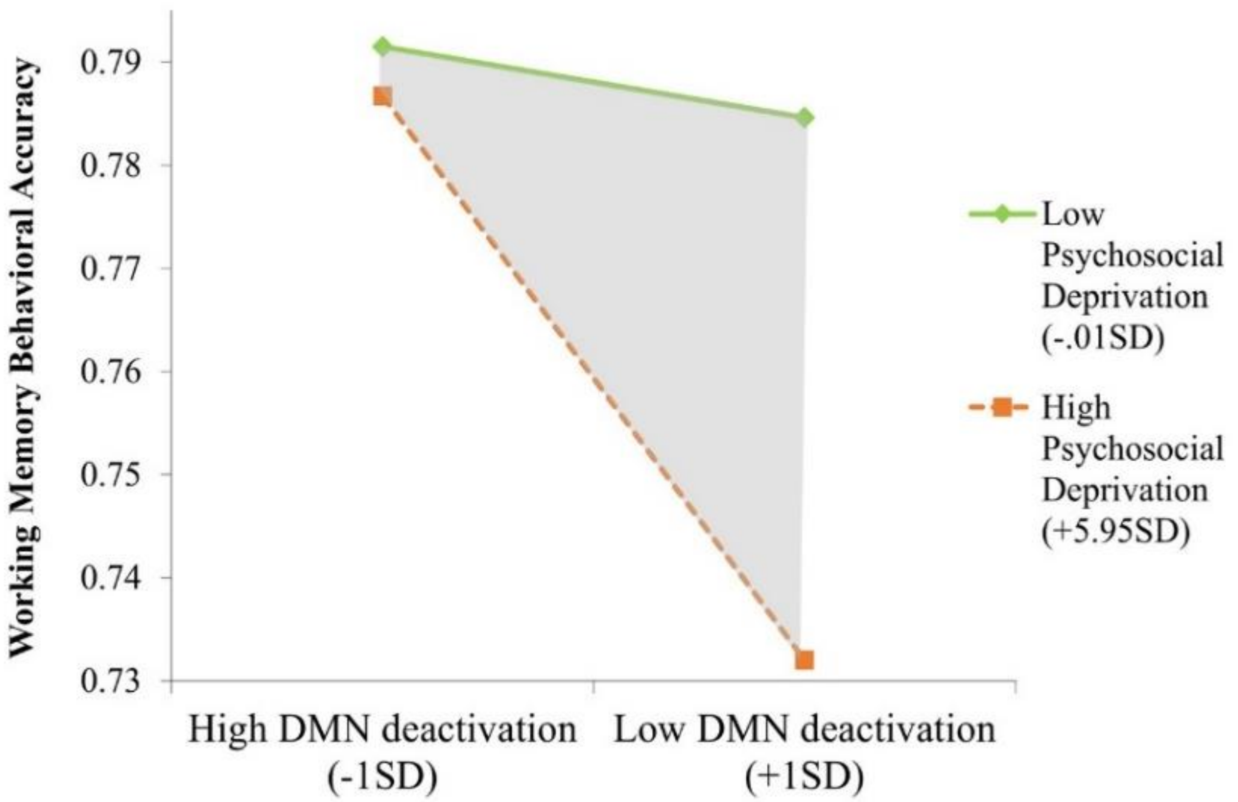

Low Psychosocial Deprivation (-1.42SD; low bound of the RoS, b = .08, p < .05)
High Psychosocial Deprivation (+1.37SD; high bound of the RoS, b = .02, p = .05)
Main Effect: The Association between Neural Activation in the Frontoparietal Network and Working Memory Behavioral Accuracy
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
-0.1
-0.11
-0.12
-0.13
-0.14
-0.15
-0.16
-0.17
Region of Significance (RoS) 94.0% (N = 7032) of Participants
-0.4
-0.35
-0.3
-0.25
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0.55
0.6
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1
1.05
1.1
1.15
1.2
Moderator: Psychosocial Deprivation

Figure 8. Dawson plot and Johnson Neyman plot of the moderation effect of psychosocial deprivation on the association between neural activation within the frontoparietal network during working memory challenge and attendant behavioral accuracy.

Notes. FPN = frontoparietal network; RoS (shaded area) = region of significance. The x-axis represents the factor scores of the latent variable psychosocial deprivation. The y-axis represents the unstandardized coefficient b of the main effect of neural activation within the frontoparietal network during working memory challenge on attendant behavioral accuracy. The solid line represents the main effect of neural activation within the frontoparietal network during working memory challenge on attendant behavioral accuracy corresponding to the values of psychosocial deprivation. The dotted lines represent 95% confidence interval around this main effect.


Working Memory Behavioral Accuracy
0.79
0.78
0.77
0.76
0.75
0.74
0.73
High DMN deactivation (-1SD)
Low DMN deactivation (+1SD)
Low Psychosocial Deprivation (-.01SD)
High Psychosocial Deprivation (+5.95SD)

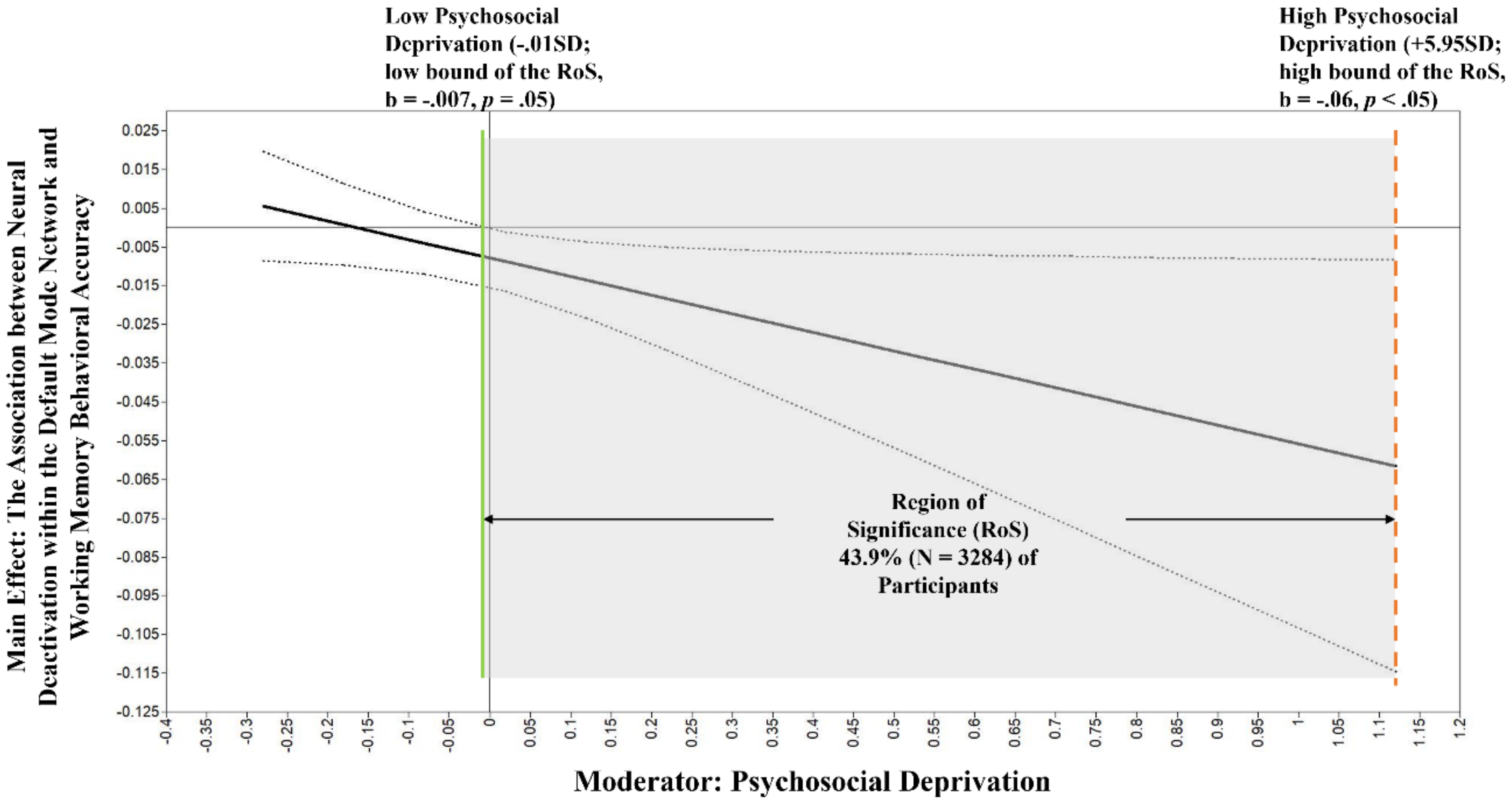

Low Psychosocial Deprivation (-.01SD; low bound of the RoS, b = -.007, p = .05)
High Psychosocial Deprivation (+5.95SD; high bound of the RoS, b = -.06, p < .05)
Main Effect: The Association between Neural Deactivation within the Default Mode Network and Working Memory Behavioral Accuracy
0.025
0.015
0.005
-0.005
-0.015
-0.025
-0.035
-0.045
-0.055
-0.065
-0.075
-0.085
-0.095
-0.105
-0.115
-0.125
Region of Significance (RoS) 43.9% (N = 3284) of Participants
-0.4
-0.35
-0.3
-0.25
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0.55
0.6
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1
1.05
1.1
1.15
1.2
Moderator: Psychosocial Deprivation

Figure 9. Dawson plot and Johnson Neyman plot of the moderation effect of psychosocial deprivation on the association between neural deactivation within the default mode network during working memory challenge and attendant behavioral accuracy.

Notes. DMN = default mode network; RoS (shaded area) = region of significance. The x-axis represents the factor scores of the latent variable psychosocial deprivation. The y-axis represents the unstandardized coefficient b of the main effect of neural deactivation within the default mode network during working memory challenge on attendant behavioral accuracy. The solid line represents the main effect of neural deactivation within the default mode network during working memory challenge on attendant behavioral accuracy corresponding to the values of psychosocial deprivation. The dotted lines represent 95% confidence interval around this main effect.

Follow-up Moderation Analyses: Probing Patterns of Working Memory Related Neural Response at Different Levels of Behavioral Performance across Varying Degrees of Psychosocial Deprivation

A series of SEM models were created to probe patterns of working memory-related neural response at different levels of behavioral accuracy moderated by psychosocial deprivation. Similarly, child sex, age, and family SES were controlled for in all analyses as covariates. Latent factors of ROIs within the frontoparietal network and within the default mode network, and an observed variable of neural response within the insula were tested one by one. All models exhibited adequate model fit (See Table 7 for detailed information on model parameters and model fit). Significant moderating effects were probed using the Johnson-Neyman technique (P. O. Johnson & Neyman, 1936) and simple slopes analysis (Aiken et al., 1991; Dawson, 2014).

Table 7. Parameters of SEM models that probed patterns of working memory-related neural response at different levels of behavioral accuracy across varying levels of psychosocial deprivation

SEM	B	(*SE*)	β	95% CI of B	*p*
Model 1^a					
WM accuracy ~ FPN	.34	.05	.11	[.25, .43]	< .001
Psychosocial deprivation ~ FPN	.51	.25	.37	[.01, 1.00]	< .05
Interaction effect ~ FPN	-.60	.31	-.04	[-1.204, -.003]	< .05
Sex ~ FPN	-.10	.01	-.02	[-.026, .003]	.11
Age ~ FPN	.003	.01	.01	[-.01, .02]	.66
Family SES ~ FPN	.001	.004	.004	[-.01, .01]	.79
Model 2^b					
WM accuracy ~ Insula	-.07	.03	-.03	[-.133, -.001]	< .05
Psychosocial deprivation ~ Insula	.18	.19	.16	[-.20, .55]	.36
Interaction effect ~ Insula	-.20	.24	-.02	[-.67, .26]	.39
Sex ~ Insula	.001	.01	.001	[-.01, .01]	.97
Age ~ Insula	-.01	.01	-.02	[-.018, .003]	.16
Family SES ~ Insula	-.01	.003	-.02	[-.011, .001]	.06
Model 3^c					
WM accuracy ~ DMN	-.23	.09	-.05	[-.40, -.06]	< .01
Psychosocial deprivation ~ DMN	.94	.45	.43	[.06, 1.82]	< .05
Interaction effect ~ DMN	-1.18	.55	-.05	[-2.26, -.09]	< .05
Sex ~ DMN	.003	.01	.003	[-.02, .03]	.85
Age ~ DMN	-.02	.01	-.03	[-.046, .004]	.10

Family SES ~ DMN	-.02	.01	-.03	[-.03, -.001]	< .05

Notes. FPN = Frontoparietal network; DMN = default mode network; WM = working memory; SES = socioeconomic status. [a] χ^2[43] = 560.42, $p < .001$, CFI = .96, RMSEA = .05, 90%CI [.037, .043], SRMR = .02; [b] χ^2[17] = 261.40, $p < .001$, CFI = .91, RMSEA = .04, 90%CI [.04, .05], SRMR = .02; [c] χ^2[24] = 278.97, $p < .001$, CFI = .92, RMSEA = .04, 90%CI [.03, .04], SRMR = .02.

Model 1

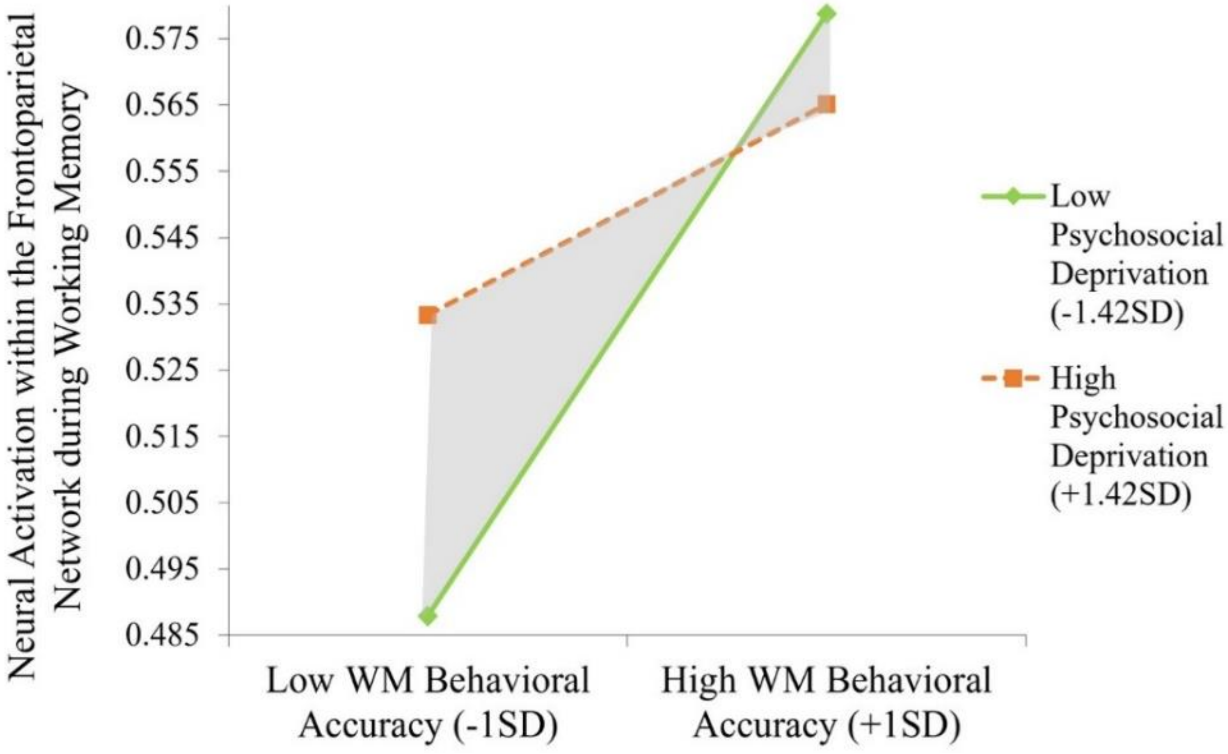
Model 1 tested neural response patterns within the frontoparietal network during working memory challenge at different levels of behavioral accuracy moderated by psychosocial deprivation. This model displayed great model fit: χ^2[43] = 560.42, $p < .001$, CFI = .96, RMSEA = .05, 90%CI [.037, .043], SRMR = .02. The results revealed a significant moderation effect (B = -.60, β = -.04, $p < .05$, 95% CI of B [-1.204, -.003]; Table 7 Model 1). Probing of the moderation effect showed that as psychosocial deprivation increased from 1.42SD below the mean to 1.42SD above the mean (-1.42SD ~ +1.42SD), the positive association between behavioral accuracy and neural activation within the frontoparietal network during working memory challenge decreased (94.5% of participants [N = 7070] fell in the region of significance; Figure 10). Interestingly, children in more psychosocially deprived environment tended to exhibit more neural activation within the frontoparietal network than children in more enriching environment at low levels of behavioral performance (e.g., -1SD below the mean). However, to increasingly reach high levels of behavioral accuracy, children in more enriched environments seemed to have higher levels of neural activations within the frontoparietal network than children in more deprived environment.

Model 2

Model 2 tested the pattern of neural response within the insula during working memory challenge at different levels of behavioral accuracy moderated by psychosocial deprivation. This model displayed adequate model fit: $\chi^2[17] = 261.40$, $p < .001$, CFI = .91, RMSEA = .04, 90%CI [.04, .05], SRMR = .02. The result showed no significant interaction effect (B = -.20, β = -.02, $p = .39$, 95% CI of B [-.67, .26]; Table 7 Model 2).

Model 3

Model 3 tested patterns of neural response within the default mode network during working memory challenge at different levels of behavioral accuracy moderated by psychosocial deprivation. This model displayed great adequate fit: $\chi^2[24] = 278.97$, $p < .001$, CFI = .92, RMSEA = .04, 90%CI [.03, .04], SRMR = .02. The result revealed a significant moderation effect (B = -1.18, β = -.05, $p < .05$, 95% CI of B [-2.26, -.09]; Table 7 Model 3). Probing of the moderation effect showed that as psychosocial deprivation increased from .16SD below the mean to 5.95SD above the mean (-.16SD ~ +5.95SD), the inverse association between behavioral accuracy and neural deactivation within the default mode network during working memory challenge increased (52.0% of participants [N = 3890] fell in the region of significance; Figure 11). Specifically, children in more psychosocially deprived environment exhibited insufficient suppression of the default mode network compared to children in more enriched environments at low levels of behavioral performance (e.g., -1SD below the mean). However, to increasingly reach high levels of behavioral accuracy, children in more deprived environment exhibited more deactivation within the default mode network than children from more enriched environments.


Neural Activation within the Frontoparietal Network during Working Memory
0.575
0.565
0.555
0.545
0.535
0.525
0.515
0.505
0.495
0.485
Low WM Behavioral Accuracy (-1SD)
High WM Behavioral Accuracy (+1SD)
Low Psychosocial Deprivation (-1.42SD)
High Psychosocial Deprivation (+1.42SD)

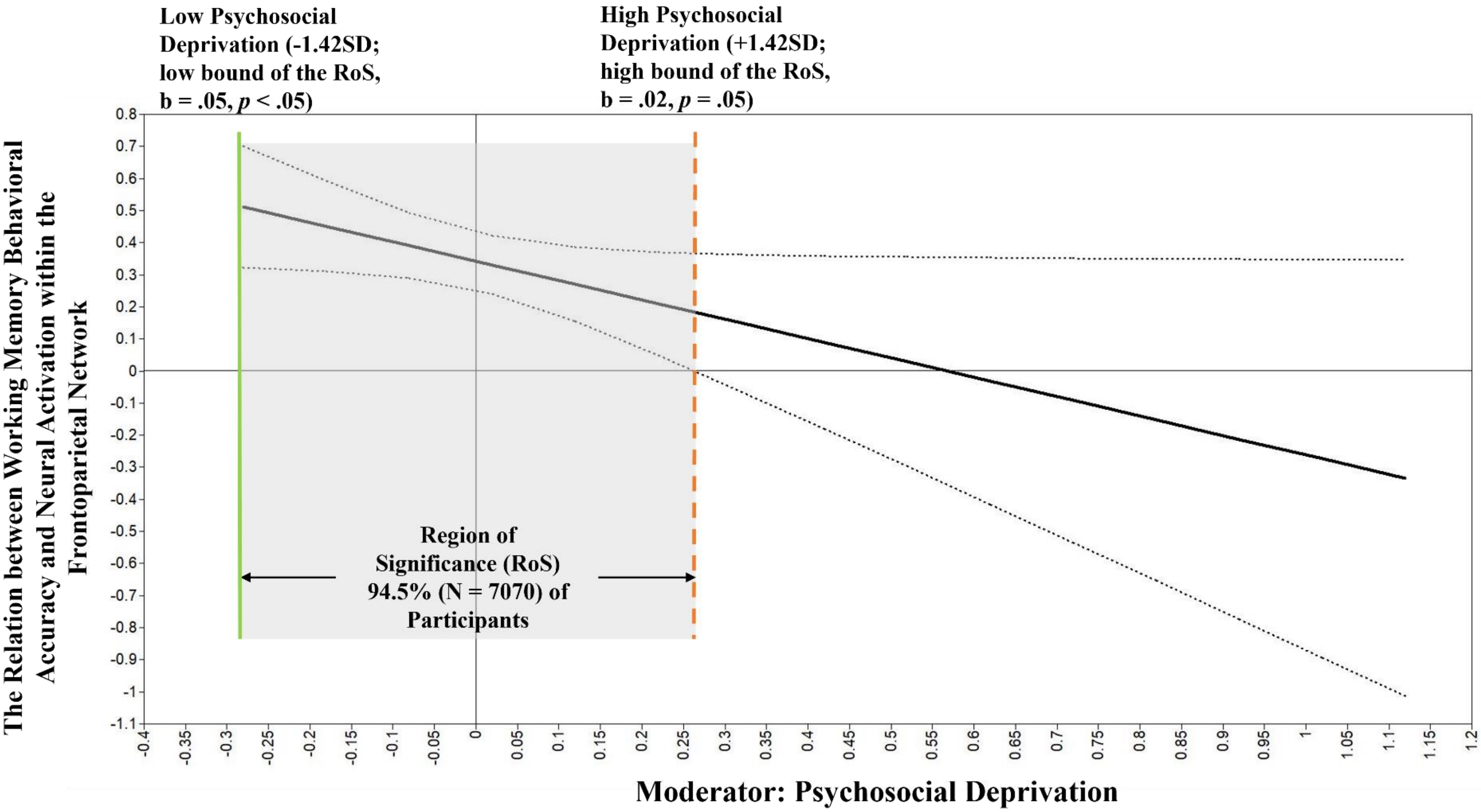
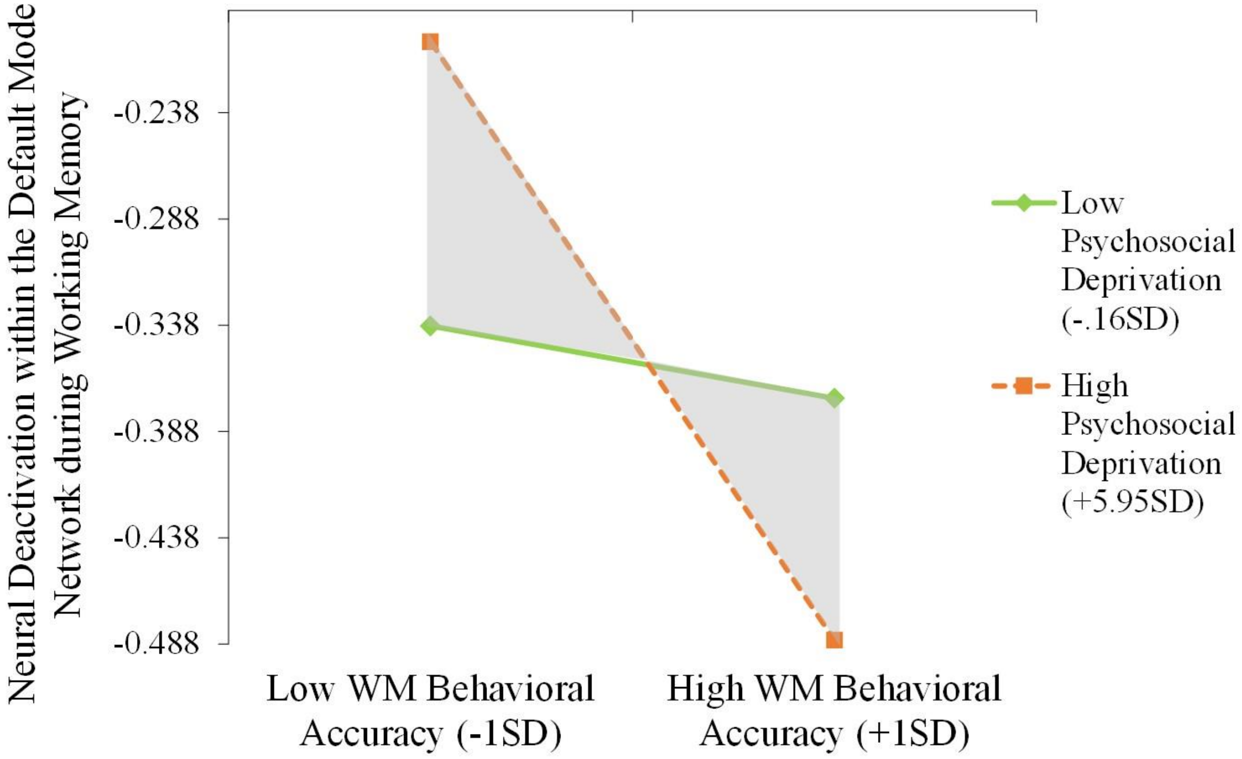

Low Psychosocial Deprivation (-1.42SD; low bound of the RoS, b = .05, p < .05)
High Psychosocial Deprivation (+1.42SD; high bound of the RoS, b = .02, p = .05)
The Relation between Working Memory Behavioral Accuracy and Neural Activation within the Frontoparietal Network
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1
-1.1
Region of Significance (RoS) 94.5% (N = 7070) of Participants
-0.4
-0.35
-0.3
-0.25
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0.55
0.6
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1
1.05
1.1
1.15
1.2
Moderator: Psychosocial Deprivation

Figure 10. Dawson plot and Johnson Neyman plot of the moderation effect of psychosocial deprivation on the relation between behavioral accuracy and neural activation within the frontoparietal network during working memory challenge.

Notes. FPN = frontoparietal network; RoS (shaded area) = region of significance. The x-axis represents the factor scores of the latent variable psychosocial deprivation. The y-axis represents the unstandardized coefficient b of the relation between behavioral accuracy and neural activation within the frontoparietal network during working memory challenge. The solid line represents the relation between behavioral accuracy and neural activation within the frontoparietal network during working memory challenge corresponding to the values of psychosocial deprivation. The dotted lines represent 95% confidence interval around this association.


Neural Deactivation within the Default Mode Network during Working Memory
-0.238
-0.288
-0.338
-0.388
-0.438
-0.488
Low WM Behavioral Accuracy (-1SD)
High WM Behavioral Accuracy (+1SD)
Low Psychosocial Deprivation (-.16SD)
High Psychosocial Deprivation (+5.95SD)

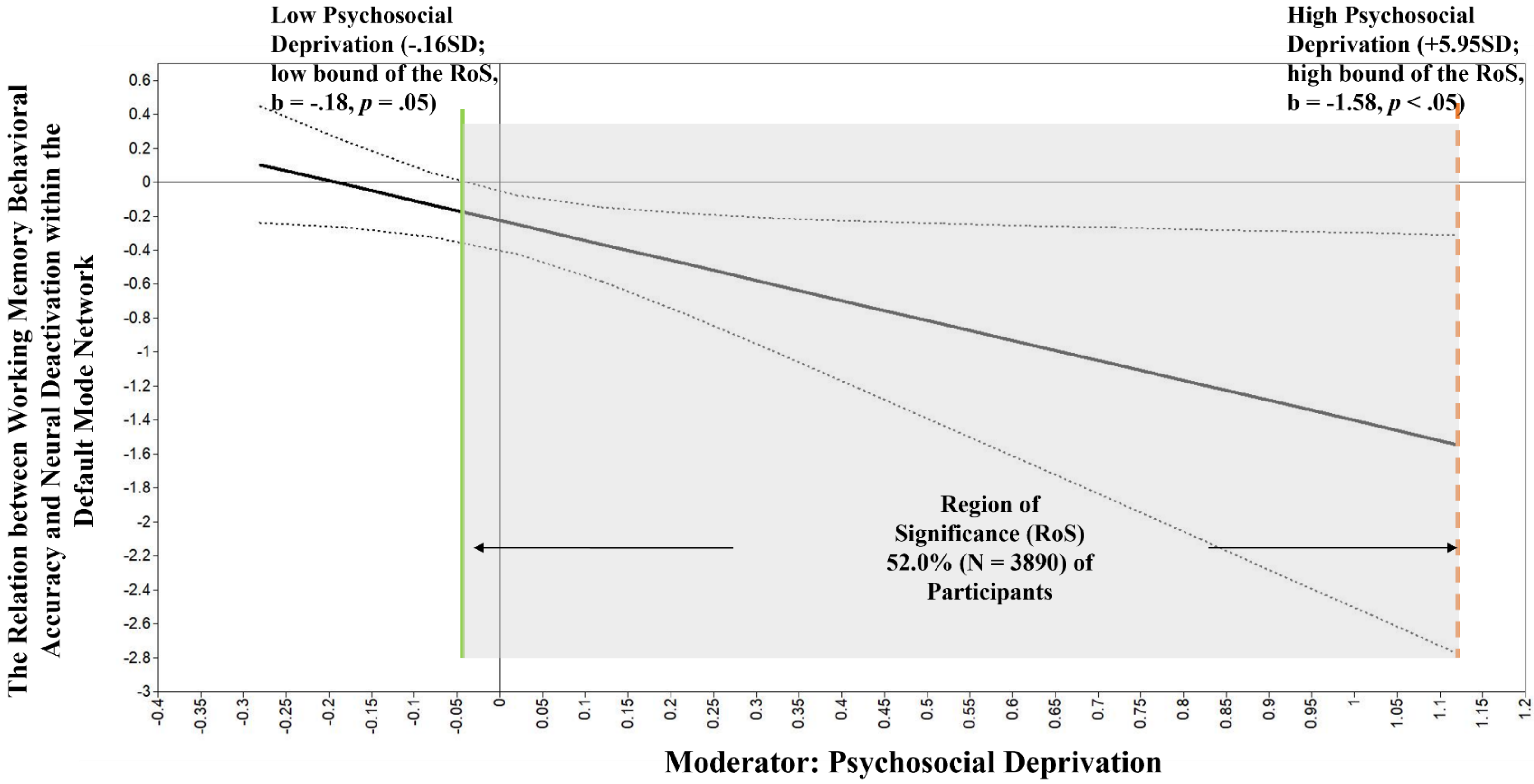

Low Psychosocial Deprivation (-.16SD; low bound of the RoS, b = -.18, p = .05)
High Psychosocial Deprivation (+5.95SD; high bound of the RoS, b = -1.58, p < .05)
Region of Significance (RoS) 52.0% (N = 3890) of Participants
The Relation between Working Memory Behavioral Accuracy and Neural Deactivation within the Default Mode Network
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
-2
-2.2
-2.4
-2.6
-2.8
-3
-0.4
-0.35
-0.3
-0.25
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0.55
0.6
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1
1.05
1.1
1.15
1.2
Moderator: Psychosocial Deprivation

Figure 11. Dawson plot and Johnson Neyman plot of the moderation effect of psychosocial deprivation on the relation between behavioral accuracy and neural deactivation within the default mode network during working memory challenge.

Notes. DMN = default mode network; RoS (shaded area) = region of significance. The x-axis represents the factor scores of the latent variable psychosocial deprivation. The y-axis represents the unstandardized coefficient b of the relation between behavioral accuracy and neural deactivation within the default mode network during working memory challenge. The solid line represents the relation between behavioral accuracy and neural deactivation within the default mode network during working memory challenge corresponding to the values of psychosocial deprivation. The dotted lines represent 95% confidence interval around this association.

CHAPTER 5

DISCUSSION

Developmental cognitive neuroscience is an evolving interdisciplinary field seeking to illuminate the neural basis of cognitive development. With the advent of neuroimaging methods such as fMRI, researchers have made much progress in advancing our understanding of the links between brain cognitive functions and behaviors as children grow up. Nevertheless, current investigations of the brain-behavior relations are often devoid of environmental contexts in which children are embedded, leaving out knowledge on substantial individual differences. Informed by ecological models in developmental research and the accumulation of empirical evidence suggesting the neural embedding of ecological contexts, an integration of ecological approach and developmental cognitive neuroscience is crucial to a fuller understanding of children's neural functioning in relation to behaviors. Hence, the current study aimed to address the extant research gap by investigating the influence of psychosocial deprivation on the brain-behavior relation during a working memory challenge.

Working memory, the ability to retain and manipulate small amounts of information over a short period of time, is a foundational executive function linked to various aspects of youth development. Converging evidence from neuroimaging studies have revealed a consistent network of task-positive and task-negative neural substrates underlying working memory (Owen et al., 2005; Owens et al., 2018; Yaple et al., 2019). Despite the knowledge gained on the links between brain functions and behaviors associated with working memory, less is known on how exposure to adverse rearing environmental contexts may account for individual variability in the brain-behavior relation. This heterogeneity in the brain-behavior relation might be attributable to individual differences in neural efficiency. Psychosocial deprivation, a dimension of ELS, has been shown to exert profound harmful effects on children's neurocognitive development (Bos et al., 2009; D. Johnson et al., 2021). As a result, the present study investigated whether psychosocial deprivation is a salient environmental context that may modulate the link between neural activity and behavior associated with working memory (i.e., neural efficiency).

In summary, the findings partially supported my hypotheses, and contribute to our understanding of individual differences in brain-behavior relations, and the psychosocial context from which this heterogeneity emerges. Results from the present study suggested that psychosocial deprivation significantly moderated the associations between neural responses during a working memory challenge and attendant behavioral performance. Specifically, psychosocial deprivation significantly attenuated the positive association between neural activation in task-positive neural substrates within the frontoparietal network and behavioral performance. Additionally, psychosocial deprivation intensified the negative association between neural deactivation in task-negative neural substrates within the default mode network and behavioral performance. There was no significant result regarding the moderating role of psychosocial deprivation on the link between neural response in the insula and behavioral performance during the working memory task. Overall, the results of the present study show that exposure to psychosocial deprivation can significantly alter working memory-related brain-behavior relations.

Direct Associations between Neural Responses and Behavioral Performance during a Working Memory Challenge

Frontoparietal Network

Study findings from testing the direct associations between working memory-related neural response in task-positive ROIs and behavioral performance are mostly consistent with prior working memory fMRI literature (Oshri, Hallowell, et al., 2019; Owen et al., 2005; Owens et al., 2018; Sweet et al., 2008; Sweet et al., 2006; Yaple et al., 2019). Specifically, I identified a latent factor that was composed of a network of task-positive neural activity elicited during working memory challenge. This network includes neural activation in the bilateral superior, middle, and inferior frontal gyrus, as well as inferior and superior parietal lobe, which putatively comprise nodes of the frontoparietal network. The frontoparietal network serves as a central hub that supports diverse cognitive functions and has been consistently shown to be activated in response to working memory challenges (Leung & Alain, 2011; Owens et al., 2018; Sweet et al., 2006). As expected, increased activation in ROIs within the frontoparietal network in the current study was significantly and positively associated with superior working memory behavioral performance.

Insula

Contrary to the expectation of insula as a task-positive ROI, neural response in the insula showed deactivation at the mean level during the working memory task in the present study. Furthermore, the result showed that neural response in the insula was significantly and inversely related to working memory behavioral performance, such that greater activation in the insula led to worse behavioral performance. This result is in contrast with findings on neural response in the insula in previous fMRI studies on working memory (Oshri, Hallowell, et al., 2019; Owens et al., 2018; Yaple & Arsalidou, 2018). For example, Oshri, Gray, et al. (2019) reported a positive relation between insula activation and working memory behavioral performance. In a meta-analysis of 17 fMRI studies on working memory among children and adolescents, the authors reported an active involvement of the insula during working memory tasks (Yaple & Arsalidou, 2018). Previous findings on insula activation during working memory tasks are consistent with the role of insula in high-level cognitive processes, such as attention and cognitive control (Uddin et al., 2014; Uddin et al., 2017). In addition, as a core node of the salience network, the insula is hypothesized to mediate cognitive processes through integrating bottom-up attention to detect salient stimuli in the environment and top-down control to focus on task-relevant stimuli (Menon & Uddin, 2010; Yaple et al., 2019). This dynamic process may play a great part during working memory tasks.

However, it is worth noting that the working memory tasks in the majority of the prior studies use stimuli such as numbers, letters, and words, which are usually without emotional content (Owen et al., 2005; Yaple et al., 2019). Hence, the average deactivation in the insula and its negative association with working memory behavioral performance in the present study might be attributable to the emotional component of the N-back task. In addition to its involvement in working memory, the insula is thought to play a role in other various affective and cognitive processes including interoception, perception, and emotion (Duerden, Arsalidou, Lee, & Taylor, 2013; Kirsch et al., 2020; Uddin et al., 2014). For example, a meta-analysis by Duerden et al. (2013) provided evidence for activation of bilateral insula in response to both perception of emotions in others and experience of emotions. In another fMRI study that investigated the role of the insula in interoceptive attention among a sample of healthy young adults, Wang et al. (2019) observed increased activation in the anterior insula during a task where participants were instructed to direct attention toward their physiological signals arising from within the body during their own breathing.

Evidence from the above-mentioned studies may suggest that increased activation in the insula during the emotional N-back task is linked to greater attention to the emotional aspect of the stimuli or sensory signals and emotional states from within the body among children. These processes might interfere with working memory task performance. In this sense, children with greater deactivation in the insula would have better working memory behavioral performance, as they were probably more able to suspend their attention to the irrelevant or distracting processes during the task (Sweet et al., 2008). Additionally, researchers have suggested that during emotional working memory tasks, the bottom-up attention recruited by salient differences in the emotional aspect of the stimuli might conflict with top-down cognitive control used to stay focused on the goal of the working memory task (i.e., looking for similarity to match stimuli; Hur, Iordan, Dolcos, & Berenbaum, 2017). This conflict may also impair working memory behavioral performance. As the insula plays a critical role in mediating this dynamic interaction between bottom-up and top-down attention processes, its activation might imply increased conflict between these two competing processes (Luo et al., 2014). Nevertheless, given the insula's diverse functions, more research is needed to understand its role in emotional working memory processing. Additionally, the activations findings of the insula in prior working memory fMRI literature are usually specific to the anterior insula. However, the ROI (i.e., insula) specified using the Desikan atlas in the present study is very big, which includes the entire insula. Therefore, it is necessary to further conduct an empirical ROIs analysis to more accurately understand the role of insula during a emotional working memory paradigm.

Default Mode Network

As anticipated, the results showed that a latent network of neural response associated with working memory in the task-negative ROIs within the default mode network was negatively linked to behavioral performance. This finding is consistent with empirical observations of the default mode network as a brain system repeatedly shown to be more active during resting state and less active when individuals focus on the external environment (Buckner et al., 2008; Raichle, 2015). The medial prefrontal and posterior cingulate cortex that comprise core regions within the default mode network have been shown to reduce activity during working memory tasks in previous fMRI literature (Owens et al., 2018; Piccoli et al., 2015; Sweet et al., 2008). For example, using a verbal working memory paradigm among a sample of healthy youth and adults, Sweet et al. (2008) found decreased activity during the 2-back relative to the 0-back control condition in bilateral medial frontal cortices and posterior cingulate. Further, the researchers observed inverse relations between brain activity in the medial prefrontal cortices and posterior cingulate and 2-back accuracy scores. Similarly, in another study using a sample of healthy young adults, Piccoli et al. (2015) reported deactivations in default mode network regions including the medial prefrontal cortex and posterior cingulate cortex during a spatial working memory paradigm.

Neural activity within the default mode network has been specifically linked to internally directed or self-generated thoughts, such as mind-wandering, remembering the past, imaging the future, and thinking about ones’ own personality, preferences, or attitudes (Andrews-Hanna et al., 2014; Davey, Pujol, & Harrison, 2016; Mason et al., 2007; Schneider et al., 2008). Such introspective and self-referencing processing might interfere with task performance when individuals need to focus on external cognitive stimuli. Therefore, in the current study, children who were better able to suspend attentional focus on internal-directed cognitive processing irrelevant to the working memory task were shown to achieve higher accuracy scores. The suppression of default mode network served to support external goal-directed cognitive functioning.

The Moderating Effect of Psychosocial Deprivation on the Associations between Neural Response and Behavioral Performance during Working Memory Challenge

Frontoparietal Network

Findings from the current study showed that psychosocial deprivation significantly attenuated the positive association between working memory-related neural activation within the frontoparietal network and behavioral accuracy. This result supported my first hypothesis and is consistent with findings from emerging fMRI studies that investigated neural functioning during working memory tasks among children and adults exposed to adverse childhood experiences. Among a sample of adolescents, Sheridan et al. (2017) found that youth who had parents with low education levels showed stronger brain activation in the inferior and middle frontal gyrus and the superior parietal lobule, but performed less well (i.e., low accuracy scores) during a visuospatial working memory task. Similarly, Philip et al. (2016) showed that adults exposed to ELS (i.e., child maltreatment) exhibited greater activation in brain regions including the inferior frontal gyrus and inferior parietal lobule during a working memory challenge, but had lower behavioral performance. These studies suggest a loss of neural efficiency among individuals exposed to ELS, namely, a weaker association between brain function and behavioral performance. Likewise, findings in the current study suggest that exposure to psychosocial deprivation may reduce neural efficiency within the frontoparietal network that supports working memory.

The finding that psychosocial deprivation negatively affected children’s neural efficiency in brain regions involved in complex cognitive functions (e.g., working memory) is in line with theory and empirical research on the biological embedding of ELS (Berens et al., 2017; McCrory, De Brito, & Viding, 2011; McEwen, 2012). Models of biological embedding of ELS describe processes by which a child’s early adverse rearing environment gets “under the skin” through affecting the body’s neurobiological systems (Berens et al., 2017; McEwen, 2012). The neurobiological consequences as a result of exposure to ELS may result in functional differences in neural structures supporting executive function, and thus contribute to individual differences in neural efficiency. Psychosocial deprivation, in particular, may compromise the development and functions of neural substrates within the frontoparietal network by altering stress physiology and hampering experience-driven brain development.

One of the potential ways in which psychosocial deprivation becomes biologically embedded to impact neural efficiency is by shaping the development of one of the body’s key stress response systems, the hypothalamic-pituitary-adrenal (HPA) axis. Children living in a psychosocially deprived environment are often subject to lack of responsive and warm caregiving as well as positive and supportive social environment (e.g., family and school). Exposures to such environments may evoke strong stress responses, and chronic exposures can lead to dysregulated HPA functioning, as shown by profiles of hyper- or hypo- stress reactivity (Blaisdell, Imhof, & Fisher, 2019; Reilly & Gunnar, 2019). Indeed, among studies that focus on children exposed to child neglect and those growing up in institutions who experience severe psychosocial deprivation, atypical stress responses have been observed (McLaughlin et al., 2015; Quevedo, Johnson, Loman, LaFavor, & Gunnar, 2012; Reilly & Gunnar, 2019). Using data from the Fragile and Child Wellbeing Study (FFCWS), Doom et al. (2022) found that deprivation measured as degree of parental disengagement was associated with lower cortisol output. Koss, Mliner, Donzella, and Gunnar (2016) also found that internationally adopted children exhibited blunted cortisol reactivity to laboratory stressors, and this hypo-reactivity was linked to increased attention and externalizing problems. Conversely, Fries, Shirtcliff, and Pollak (2008) revealed that more severe early neglect was linked to the highest basal cortisol levels among a group of post-institutionalized children.

The observed HPA dysregulation (i.e., hyper- and hypo- reactivity) among children exposed to early psychosocial deprivation may subsequently lead to reductions in neural efficiency through impairing the development and function of brain regions critical for higher cognition. Specifically, HPA axis hyper-reactivity triggers increased secretion of cortisol, which can be detrimental to the prefrontal cortex that has dense concentrations of glucocorticoid receptors (Lupien et al., 2009). This is consistent with the neurotoxicity hypothesis, which posits that elevation of stress mediators such as the glucocorticoids due to prolonged stress exposures can lead to death or impeded growth of neurons in stress-sensitive brain regions, such as the prefrontal cortex (Berens et al., 2017; Uno et al., 1994). On the other hand, HPA axis hypo-reactivity has also been suggested to be problematic for healthy neurocognitive development through hampering synaptic potentiation in the prefrontal cortex (Suor et al., 2015; Wesarg et al., 2020). The impact of dysregulated stress response on cognitive functioning have been documented in multiple behavioral studies (Blair, Granger, & Peters Razza, 2005; Sturge-Apple, Davies, Cicchetti, Hentges, & Coe, 2017; Wu, Wang, Cao, & He, 2021). Empirical evidence from these studies further suggests that dysregulated stress response might be a potential embedding mechanism through which psychosocial deprivation influences efficiency in neural substrates key to executive function.

The second embedding mechanism by which psychosocial deprivation may lead to decreased neural efficiency is through undermining experience-dependent brain development. Brain maturation is a continuous and dynamic process not only determined by genetic influences but also heavily guided by environmental input (Gluckman, Hanson, Cooper, & Thornburg, 2008; Levitt, 2003). The structural changes crucial to brain development and concurrent growth in complex cognitive abilities, include processes such as synaptic pruning and myelination, and axonal and dendritic growth (Levitt, 2003; Sedmak et al., 2018). These processes are substantially modulated by and particularly sensitive to environmental stimulation during early childhood (Gluckman et al., 2008; Luna & Sweeney, 2001; Tierney & Nelson, 2009). Experience-induced synaptic pruning in cognitively and socially stimulating environment, for example, is key to developing an efficient brain; however, absence of cognitive and psychosocial stimuli may promote accelerated and excessive elimination of synapses, leading to inefficient processing (McLaughlin, Sheridan, & Nelson, 2017).

Indeed, researchers purported that among children, reduced cognitive and psychosocial stimulation could lead to reductions in thickness and volumes of cortices engaged in processing complex cognitive and social input, including the prefrontal and parietal cortex (McLaughlin, Sheridan, & Lambert, 2014; Sheridan & McLaughlin, 2014). This prediction has been supported by empirical studies on the impact of deprivation on brain morphology. Researchers have shown that children exposed to child neglect and institutionalization exhibited decreased cortical thickness, as well as reduced prefrontal and parietal cortex gray matter and white matter volumes (Edmiston et al., 2011; Herzberg et al., 2018; Hodel et al., 2015; McLaughlin, Sheridan, Winter, et al., 2014). For instance, Edmiston et al. (2011) showed that emotional neglect was linked to decreased gray matter volume in the dorsolateral prefrontal cortex among adolescents without psychiatric diagnoses. A structural neuroimaging study also detected significant reductions in prefrontal cortex volume among a sample of post institutionalized children (Hodel et al., 2015). Similarly, in a recent study by Mackes et al. (2020), researchers found that young adults exposed to severe early deprivation in Romanian orphanages (i.e., deprived adoptees) had significantly smaller total brain volumes than a control group of nondeprived adoptees (i.e., placed for adoption before 6 months). In addition, global reductions in total brain volumes significantly mediated the association between institutionalization and attention deficit/hyperactivity disorder symptoms. This body of empirical work supports the contention that deprivation-related structural alterations in neural substrates essential to complex cognitive processing may lead to diminished processing capacity and efficiency.

The reduced neural efficiency within the frontoparietal network associated with exposure to psychosocial deprivation might also be attributable to weakened structural and functional brain network connectivity. Among a group of post-institutionalized children, Govindan, Behen, Helder, Makki, and Chugani (2010) noted decreased white matter integrity in the superior longitudinal fasciculus, a reciprocal association pathway connecting multiple cortices, including the parietal cortex and the frontal lobe. Studies have also started to reveal links between ELS and alterations in brain network functional connectivity (J. Zhang et al., 2022; Zhao et al., 2021). For example, in an adult sample, Zhao et al. (2021) found decreased functional connectivity within the frontoparietal network among those with a history of childhood trauma (i.e., maltreatment) compared to healthy controls. Since efficient higher-order cognitive processing might not only rely on functions of separate brain regions, decreased intrinsic connectivity within the frontoparietal network might be contributing to its reduced neural efficiency among children exposed to psychosocial deprivation.

Probing patterns of neural activation in task-positive ROIs at different performance levels across varying degrees of psychosocial deprivation also supported the link between psychosocial deprivation and reduced neural efficiency within the frontoparietal network. For example, at low behavioral performance levels (e.g., -1SD below the mean), children living in more psychosocially deprived environments appeared to activate more neural resources within the frontoparietal network. This increased level of activation in task-relevant brain regions may indicate a compensatory mechanism utilized by children in deprived environment to maintain working memory performance by making up for a loss of neural efficiency. Interestingly, as children's working memory performance started to approach a high level (e.g., +1SD above the mean), neural resources recruited by those who were in less deprived environment converged with and then surpassed the level of resources recruited by those exposed to more deprivation. This might be because children in more deprived environment exhausted neural resources or processing capacity within the frontoparietal network. It is possible that continued improvement in behavioral performance would necessitate the use of neural resources in additional brain regions that are not typically activated during working memory tasks (Grady, 2012).

Default Mode Network

Study findings showed that psychosocial deprivation significantly intensified the negative association between neural deactivation within the default mode network and behavioral performance during working memory. Although the direction of the interaction effect was the opposite than what was hypothesized, the revealed empirical pattern corroborated my prediction that psychosocial deprivation was linked to reduced neural efficiency within the default mode network. Interestingly, higher neural efficiency within the task-positive frontoparietal network was shown as greater association between neural response and behavioral performance. On the contrary, higher neural efficiency within the default mode network was shown by decreased association between neural deactivation and behavioral performance during working memory. This empirical pattern might be driven by the fact that at low level of default mode network deactivation (e.g., +1SD above the mean), children in less psychosocially deprived environment were already able to reach a higher level of behavioral performance than children in more deprived environment. This pattern is consistent with prior literature suggesting that individuals with a highly efficient default mode network might have less need to suppress baseline task-unrelated processing (Duda et al., 2019; Philip, Sweet, Tyrka, Price, Carpenter, et al., 2013; Qiu et al., 2019). It is also possible that children in more enriched environment have higher neural efficiency within the task-positive frontoparietal network, and thus, rely less on deactivating the default mode work in support of goal-directed cognition.

The decreased neural efficiency within the default mode network among children exposed to more psychosocial deprivation, on the other hand, may be a consequence of its altered functional connectivity. Although research exclusively focusing on psychosocial deprivation is scarce, many studies have investigated the influence of ELS on default mode network connectivity (Philip, Sweet, Tyrka, Price, Bloom, et al., 2013; Sripada, Swain, Evans, Welsh, & Liberzon, 2014; Zeev-Wolf, Levy, Goldstein, Zagoory-Sharon, & Feldman, 2019). For instance, Zeev-Wolf et al. (2019) found that exposure to early life trauma was associated with reduced functional connectivity within the default mode network among a sample of preadolescents. Similarly, using a sample of medication-free healthy adults, Philip, Sweet, Tyrka, Price, Bloom, et al. (2013) reported that participants with a history of ELS exposure (i.e., child maltreatment) demonstrated decreased functional connectivity within the default mode network. Therefore, it is plausible that exposure to ELS, such as psychosocial deprivation, may affect intrinsic default mode network connectivity, leading to its functional inefficiency. However, the link between ELS and default mode network connectivity have been predominantly investigated during resting state. Hence, more research is needed on task-induced functional connectivity within the default mode network to make better inferences about its neural efficiency in response to external cognitive demands among children exposed to psychosocial deprivation.

Probing of neural deactivation in task-negative ROIs at different levels of behavioral accuracy across varying degrees of psychosocial deprivation also supported reduced neural efficiency within the default mode network associated with psychosocial deprivation. As working memory behavioral accuracy increased, deactivations within the default mode work showed more pronounced increase among children in more deprived environments than those in less deprived environments. In particular, children in more deprived environments tended to exhibit stronger deactivation within the default mode network as they continued to reach better working memory behavioral accuracy (e.g., +1SD above the mean). This pattern corroborates prior research on neural compensatory effects within the default node network. For example, among a sample of healthy adults, Philip, Sweet, Tyrka, Price, Carpenter, et al. (2013) showed that adults exposed to substantial ELS (e.g., child maltreatment, divorce, etc.) performed behaviorally as well as those in the non-ELS control group, but displayed greater deactivation within the default mode network. The observed greater deactivation can be interpreted as a successful compensatory mechanism and an adaptive neural response among children exposed to increased psychosocial deprivation. Nevertheless, the over-deactivation still indicated default mode network neural inefficiency, as the brain needed to work harder among children in deprived environment than those in more enriched environment to achieve equivalent behavioral performance.

Furthermore, more deactivation within the default mode network needed to achieve high working memory behavioral performance may also reflect the greater need of children in deprived environment to suspend distracting or task-irrelevant processes (Sweet et al., 2008).

First, the scanning experience might be an inherent stressful experience for children, and thus can trigger a certain level of anxiety. The resultant stress could be emotionally overwhelming or hard to manage among children living in psychosocially deprived environment as they might lack efficient cognitive and emotion regulation skills. As such, it would probably require more effort on their part to minimize the interference of internal thoughts and emotions in order to stay focused on the working memory task. Second, extant research shows that children exposed to psychosocial deprivation not only show deficits in working memory, but also in executive functions, such as attention control (Kreppner, O'Connor, & Rutter, 2001; Emily C Merz, McCall, & Wright, 2013). The tendency to lose attention during the working memory challenge may also lead to increased interference of internal generated and task-unrelated thoughts, such as mind wandering. Thus, among children exposed to more psychosocial deprivation, greater deactivation within the default mode network maybe needed to suspend distracting thoughts in order to achieve high performance levels.

Insula

There was no evidence found in the present study for the moderating role of psychosocial deprivation on the link between neural response within the insula and behavioral performance during the working memory challenge. The insignificant link between psychosocial deprivation and insula neural efficiency may be due to its diverse functional roles and marked individual differences in how it is engaged in cognitive tasks. As delineated above in the discussion, extant research has revealed inconsistent findings regarding the involvement of the insula during working memory. Whereas many studies have shown insula activation during working memory, its deactivation has been reported as well (Owens et al., 2018; Sweet et al., 2008; Sweet et al., 2006; Yaple et al., 2019). On one hand, investigators have argued the insula’s active role in exerting top-down control of attention on salient task-relevant stimuli (Yaple et al., 2019). On the other hand, the insula's deactivation during cognitive tasks has been hypothesized to play a role in suspending the monitoring of one's internal emotional state (Hester et al., 2004). Although a mean level insula deactivation was found in the present study, the existing mixed findings and multiple interpretations regarding the diverse functions of the insula indicate that the mechanisms underlying insula involvement in support of working memory performance may significantly vary across individuals (e.g., activation or deactivation). For example, in the current EN-back design, some children may rely on insula deactivation to suspend attention to their own emotional state, while others might exhibit increased insula activity in response to the emotional faces as a salient aspect of the stimuli to guide their attention (Mohanty & Sussman, 2013). As a result, the heterogeneity in the link between insula function and working memory behavioral performance may not be appropriately captured by exposure to psychosocial deprivation.

Implications

Findings from this dissertation have several implications. First, the moderating role of psychosocial deprivation on the link between working memory neural response and behavioral performance highlights the need to situate the brain-behavior relation in context. Developmental cognitive neuroscience is a growing interdisciplinary field devoted to understanding the neurological bases of cognitive processing and development as children grow up. Ecological models of human development have advocated for the incorporation of contexts in behavioral and psychological science (Bronfenbrenner & Morris, 2007; Magnusson & Stattin, 2006). With neuroscience being increasingly conceptualized as one of several levels of analysis in research on child development, an ecological developmental cognitive neuroscience approach to understanding the developing brain and attendant neurocognitive development is needed

(Bronfenbrenner, 1977; Bronfenbrenner & Morris, 2007; Hyde et al., 2020; Sameroff, 2009). Growing theoretical and empirical work has begun to link a child's early rearing environments to individual differences in neural structures and functions that underlie trajectories of cognitive development (McLaughlin, Sheridan, & Lambert, 2014; McLaughlin, Sheridan, Winter, et al., 2014; McLaughlin et al., 2019; Sheridan et al., 2017). This body of research acknowledges the developing brain as a complex system embedded in multi-level ecological contexts and motivates the integration of ecological models to developmental cognitive neuroscience. As such, there is a need for emphasizing the consideration of environmental contexts when investigating brain-behavior relations associated with children's cognitive functions. By incorporating both neuroimaging (i.e., neural response) and behavioral measures (i.e., accuracy scores), findings from the present study suggest that psychosocial deprivation is a context that may alter brain-behavior relations. Specifically, the findings implicate that a certain level of neural response (i.e., activation or deactivation) during cognitive tasks can mean different levels of behavioral performance among children growing up in varying contexts.

Although moderation analyses in the current study demonstrated a loss of neural efficiency among children in deprived environments, they also suggested potential compensatory neural mechanisms that support the maintenance of working memory performance. The results suggest that some children exposed to more psychosocial deprivation were able to increase the recruitment of neural resources or further abandon task-irrelevant processing to achieve equivalent performance as those in more enriched environments. The observed increase in neural activation or deactivation in response to external cognitive demands implies neural adaptation in deprived rearing environments, and may reflect a neural correlate of resilience (Philip, Sweet, Tyrka, Price, Carpenter, et al., 2013). Yet, these neural patterns might also mean that the brains of many children in deprived environments were working harder (i.e., increased activation or deactivation) during the working memory challenge trying to achieve good task performance. In daily life outside of the context of a research study, children often might have to engage in demanding tasks that require working memory (especially in school). For example, in classroom settings, many learning activities such as those related to reading and mathematics often require children to hold multiple pieces of information while carrying out behaviors to complete tasks (e.g., solving math word problems). These activities could impose considerable burden on children's working memory. Consequently, it is possible that a loss of neural efficiency may lead to frequent working memory overload for children in more deprived environments.

Furthermore, for those children living in deprived environment who constantly need to over-activate or over-deactivate their brains to maintain cognitive function, the manifestation of resilience may implicate underlying neurobiological costs. The biological costs of working hard to succeed has been depicted in the folklore of an African American railroad worker, John Henry. The story goes that John Henry won a race against a steam-powered machine, but eventually died because of his high effort (Hudson, Neighbors, Geronimus, & Jackson, 2016; James, Keenan, Strogatz, Browning, & Garrett, 1992). The concept of John Henryism thus has been used to refer to high-effort coping in the face of environmental stress, which may confer harmful effects on health (Hudson et al., 2016). Relatedly, it is possible that the constant neural compensation among children in psychosocially deprived environments might result in hidden neurobiological costs of resilience.

Findings from the present study also have implications for prevention and intervention for children in adverse rearing environments. The present study provided further evidence that a deprived environment characterized by a lack of cognitive and positive social stimulation can negatively affect children’s working memory-related neural functioning (i.e., reduced efficiency). Therefore, primary prevention and intervention efforts to increase children’s exposure to psychosocially stimulating environment and experiences are crucial. For example, prevention programs can be implemented to promote responsive caregiving and psychosocial stimulation during parent-child interactions that are conducive to children’s cognitive development. In addition, schools can increase enrichment or extra-curricular activities in class or after school to create more opportunities for learning and social interactions among children and between children and adults (e.g., teachers, mentors). Although not directly testing the psychosocial aspect of the school environment, a recent neuroimaging study showed that positive school climate as indicated by academic support was positively associated with children’s global cortical thickness and executive function (Piccolo, Merz, Noble, the Pediatric Imaging, & Study, 2019). This study provides promising evidence supporting the potential neurocognitive benefits associated with improving children’s school environment.

Furthermore, emerging research has shown the effects of working memory training in improving behavioral performance while reducing neural activations and enhancing functional connectivity within and between task-relevant brain networks (Iordan et al., 2020; J. S. Jones, Adlam, Benattayallah, & Milton, 2022; Miró-Padilla et al., 2019). For instance, in a study on the effects of N-back training, Miró-Padilla et al. (2019) found that young adults in the trained group showed improved working memory performance than the control group. Additionally, better behavioral performance in the trained participants was accompanied by decreased activation in brain areas associated with working memory, such as the superior/middle cortex, and the inferior parietal cortex. Among a sample of typically developing children, J. S. Jones et al. (2022) showed that working memory training increased the intrinsic functional connectivity between the bilateral intra-parietal sulci and behavioral performance. These studies suggest that working memory training might be another promising avenue for promoting neural efficiency among children in deprived environments.

Limitations and Directions for Future Research

Findings from the current study should be viewed in light of several limitations. First, the analyses in the study relied on a set of a priori ROIs, which were selected from reviewing prior fMRI working memory literature. However, previous literature has used samples of populations of different demographic backgrounds and different working memory paradigms. In addition, the ABCD tabulated task-based neuroimaging data were calculated based on cortical surface-based ROIs using the Desikan atlas (Hagler Jr et al., 2019). The ROIs specified in this way by the Desikan atlas are relatively larger (e.g., the entire superior frontal gyrus) than those reported in existing neuroimaging working memory literature (Owens et al., 2018). The empirical working memory-related ROIs reported in existing studies usually include a limited number of significantly activated/deactivated voxels (Oshri, Hallowell, et al., 2019; Sweet et al., 2008). This suggests that averaging BOLD signals across the whole region may swamp working memory related signals from a small number of voxels with those from the remaining non-activated/deactivated or not working memory related subregions (Poldrack, 2007). To increase the internal validity of the results, it is necessary to conduct an empirical ROI analysis by constructing a working memory functional map that is internally valid for the sample of children and working memory paradigm used in the current study.

Second, the current study provided evidence for individual differences in neural efficiency associated with exposure to psychosocial deprivation. Nevertheless, future research is needed to understand the mechanisms underlying these individual differences. Extant theoretical and empirical research suggests that deprivation-induced structural changes in brain areas essential for the development of higher cognitive abilities are linked to poor executive function (McLaughlin, Sheridan, & Lambert, 2014; McLaughlin, Sheridan, Winter, et al., 2014; Sheridan et al., 2017). Thus, future research may directly and empirically test if deprivation-related structural changes (e.g., reductions in gray and white matter) in neural substrates subserving working memory underlie the loss of neural efficiency. In addition, recent research reveals links between ELS and brain structural and functional connectivity (Govindan et al., 2010; Philip, Sweet, Tyrka, Price, Bloom, et al., 2013; Zhao et al., 2021). As efficient cognitive processing might not only rely on isolated brain regions, future research may investigate if structural and functional connectivity within and between brain networks can account for individual differences in working memory-related neural efficiency.

Third, analyses conducted in the present study did not include children whose neuroimaging data were missing or excluded during quality control procedures advised by ABCD protocols. Descriptive analyses showed that the sample of children who were entered into the final analyses and those were excluded differed significantly on several demographic variables, such as child age, sex, and family SES. Although the use of propensity weights in the analyses adjusted for sampling biases, it did not consider biases introduced by missing and exclusion of fMRI data (Liu, Oshri, Kogan, Wickrama, & Sweet, 2021).

Fourth, the current study was cross-sectional. The next step will be to investigate if psychosocial deprivation is longitudinally linked to working memory-related neural efficiency. Fifth, the present study used 2-back accuracy score as an indicator of working memory behavioral performance. Future work should also consider using reaction time as a behavioral indicator in the investigation of working memory-related neural efficiency.

Conclusion

The present study aimed to investigate whether psychosocial deprivation moderated the link between neural activity and behavioral performance during a working memory task using a nationally representative sample of pre-adolescent children. Recent theoretical and empirical work on ELS suggests that exposure to psychosocial deprivation negatively influences children's neurocognitive development. In particular, psychosocial deprivation can "get under the skin" and induce structural and functional changes in neural substrates that subserve working memory. Findings of the present study provide further evidence that psychosocial deprivation can compromise children's working memory related neural function through undermining neural efficiency. In addition, results from follow-up moderation analyses shed light on potential neural mechanisms by which children in psychosocially deprived environments preserve working memory performance. Knowledge on the impact of psychosocial deprivation on working memory related neural efficiency can inform prevention and intervention efforts to create an enriched environment with more opportunities for cognitive and social stimulation among children. Additionally, working memory training can be offered to enhance children's neural efficiency. In sum, findings from the current study highlight psychosocial deprivation as a salient context from which individual differences in neural efficiency emerges, and provide practical implications for promoting working memory, an executive function crucial to children's development and learning.

References

Aiken, L. S., West, S. G., & Reno, R. R. (1991). *Multiple regression: Testing and interpreting interactions*: sage.

Alagapan, S., Lustenberger, C., Hadar, E., Shin, H. W., & Fröhlich, F. (2019). Low-frequency direct cortical stimulation of left superior frontal gyrus enhances working memory performance. *NeuroImage, 184*, 697-706. doi:https://doi.org/10.1016/j.neuroimage.2018.09.064

Andersson, U. (2008). Working memory as a predictor of written arithmetical skills in children: The importance of central executive functions. *British Journal of Educational Psychology, 78*(2), 181-203.

Andrews-Hanna, J. R., Smallwood, J., & Spreng, R. N. (2014). The default network and self-generated thought: component processes, dynamic control, and clinical relevance. *Annals of the new York Academy of Sciences, 1316*(1), 29-52. doi:10.1111/nyas.12360

Ansell, E. B., Rando, K., Tuit, K., Guarnaccia, J., & Sinha, R. (2012). Cumulative adversity and smaller gray matter volume in medial prefrontal, anterior cingulate, and insula regions. *Biological psychiatry, 72*(1), 57-64.

Anticevic, A., Cole, M. W., Murray, J. D., Corlett, P. R., Wang, X.-J., & Krystal, J. H. (2012). The role of default network deactivation in cognition and disease. *Trends in Cognitive Sciences, 16*(12), 584-592.

Anticevic, A., Repovs, G., Shulman, G. L., & Barch, D. M. (2010). When less is more: TPJ and default network deactivation during encoding predicts working memory performance. *NeuroImage, 49*(3), 2638-2648.

Arain, M., Haque, M., Johal, L., Mathur, P., Nel, W., Rais, A., . . . Sharma, S. (2013). Maturation of the adolescent brain. *Neuropsychiatric disease and treatment, 9*, 449-461. doi:10.2147/NDT.S39776

Aristizabal, M. J., Anreiter, I., Halldorsdottir, T., Odgers, C. L., McDade, T. W., Goldenberg, A., . . . Sokolowski, M. B. (2020). Biological embedding of experience: A primer on epigenetics. *Proceedings of the National Academy of Sciences, 117*(38), 23261-23269.

Aron, A. R., Robbins, T. W., & Poldrack, R. A. (2004). Inhibition and the right inferior frontal cortex. *Trends in Cognitive Sciences, 8*(4), 170-177.

Aronen, E. T., Vuontela, V., Steenari, M. R., Salmi, J., & Carlson, S. (2005). Working memory, psychiatric symptoms, and academic performance at school. *Neurobiology of Learning and Memory, 83*(1), 33-42. doi:https://doi.org/10.1016/j.nlm.2004.06.010

Avci, G., Hanten, G., Schmidt, A., Li, X., Orsten, K., Faber, J., . . . Newsome, M. R. (2013). Cognitive contributors to resilience in youth from underserved populations: A brief report. *Journal of Public Mental Health*.

Baddeley, A. (1992). Working Memory. *Science, 255*(5044), 556-559. doi:doi:10.1126/science.1736359

Barbey, A. K., Koenigs, M., & Grafman, J. (2013). Dorsolateral prefrontal contributions to human working memory. *cortex, 49*(5), 1195-1205.

Barulli, D., & Stern, Y. (2013). Efficiency, capacity, compensation, maintenance, plasticity: emerging concepts in cognitive reserve. *Trends in Cognitive Sciences, 17*(10), 502-509.

Bechara, A., & Martin, E. M. (2004). Impaired decision making related to working memory deficits in individuals with substance addictions. *Neuropsychology, 18*(1), 152.

Belsky, J., Schlomer, G. L., & Ellis, B. J. (2012). Beyond cumulative risk: distinguishing harshness and unpredictability as determinants of parenting and early life history strategy. *Developmental psychology, 48*(3), 662.

Bemath, N., Cockcroft, K., & Theron, L. (2020). Working memory and psychological resilience in South African emerging adults. *South African Journal of Psychology, 50*(4), 493-506. doi:10.1177/0081246320920868

Benavides-Nieto, A., Romero-López, M., Quesada-Conde, A. B., & Corredor, G. A. (2017). Basic executive functions in early childhood education and their relationship with social competence. *Procedia-Social and Behavioral Sciences, 237*, 471-478.

Berens, A. E., Jensen, S. K., & Nelson, C. A. (2017). Biological embedding of childhood adversity: from physiological mechanisms to clinical implications. *BMC medicine, 15*(1), 1-12.

Bick, J., Fox, N., Zeanah, C., & Nelson, C. A. (2017). Early deprivation, atypical brain development, and internalizing symptoms in late childhood. *Neuroscience, 342*, 140-153.

Blair, C., Granger, D., & Peters Razza, R. (2005). Cortisol reactivity is positively related to executive function in preschool children attending Head Start. *Child development, 76*(3), 554-567.

Blair, C., & Raver, C. C. (2012). Child development in the context of adversity: experiential canalization of brain and behavior. *American psychologist, 67*(4), 309.

Blaisdell, K. N., Imhof, A. M., & Fisher, P. A. (2019). Early adversity, child neglect, and stress neurobiology: From observations of impact to empirical evaluations of mechanisms. *International Journal of Developmental Neuroscience, 78*, 139-146. doi:https://doi.org/10.1016/j.ijdevneu.2019.06.008

Boisgueheneuc, F. d., Levy, R., Volle, E., Seassau, M., Duffau, H., Kinkingnehun, S., . . . Dubois, B. (2006). Functions of the left superior frontal gyrus in humans: a lesion study. *Brain, 129*(12), 3315-3328.

Booth, T., Royle, N. A., Corley, J., Gow, A. J., Hernández, M. d. C. V., Maniega, S. M., . . . Wardlaw, J. M. (2015). Association of allostatic load with brain structure and cognitive ability in later life. *Neurobiology of Aging, 36*(3), 1390-1399.

Bos, K. J., Fox, N., Zeanah, C. H., & Nelson Iii, C. A. (2009). Effects of early psychosocial deprivation on the development of memory and executive function. *Frontiers in behavioral neuroscience, 3*, 16-16. doi:10.3389/neuro.08.016.2009

Braver, T. S., Cohen, J. D., Nystrom, L. E., Jonides, J., Smith, E. E., & Noll, D. C. (1997). A parametric study of prefrontal cortex involvement in human working memory. *NeuroImage, 5*(1), 49-62.

Brody, G. H., Yu, T., Chen, E., Miller, G. E., Kogan, S. M., & Beach, S. R. (2013). Is resilience only skin deep? Rural African Americans' socioeconomic status–related risk and competence in preadolescence and psychological adjustment and allostatic load at age 19. *Psychological science, 24*(7), 1285-1293.

Bronfenbrenner, U. (1977). Toward an experimental ecology of human development. *American* *psychologist, 32*(7), 513.

Bronfenbrenner, U., & Morris, P. A. (2007). The bioecological model of human development. *Handbook of child psychology, 1*.

Brown, T. A. (2015). *Confirmatory factor analysis for applied research*: Guilford publications.

Brumbach, B. H., Figueredo, A. J., & Ellis, B. J. (2009). Effects of harsh and unpredictable environments in adolescence on development of life history strategies. *Human Nature, 20*(1), 25-51.

Buckner, R. L., Andrews ‐ Hanna, J. R., & Schacter, D. L. (2008). The brain's default network: anatomy, function, and relevance to disease. *Annals of the new York Academy of Sciences, 1124*(1), 1-38.

Buxton, R. B. (2013). The physics of functional magnetic resonance imaging (fMRI). *Reports on progress in physics. Physical Society (Great Britain), 76*(9), 096601-096601. doi:10.1088/0034-4885/76/9/096601

Cabeza, R. (2002). Hemispheric asymmetry reduction in older adults: the HAROLD model. *Psychology and Aging, 17*(1), 85.

Cabeza, R., Anderson, N. D., Locantore, J. K., & McIntosh, A. R. (2002). Aging gracefully: compensatory brain activity in high-performing older adults. *NeuroImage, 17*(3), 1394-1402.

Cabeza, R., Daselaar, S. M., Dolcos, F., Prince, S. E., Budde, M., & Nyberg, L. (2004). Task-independent and task-specific age effects on brain activity during working memory, visual attention and episodic retrieval. *Cerebral cortex, 14*(4), 364-375.

Cañas, A., Juncadella, M., Lau, R., Gabarrós, A., & Hernández, M. (2018). Working Memory Deficits After Lesions Involving the Supplementary Motor Area. *Frontiers in Psychology, 9*. doi:10.3389/fpsyg.2018.00765

Caporaso, J. S., Boseovski, J. J., & Marcovitch, S. (2019). The individual contributions of three executive function components to preschool social competence. *Infant and Child Development, 28*(4), e2132.

Carp, J., Gmeindl, L., & Reuter-Lorenz, P. (2010). Age Differences in the Neural Representation of

Working Memory Revealed by Multi-Voxel Pattern Analysis. *Frontiers in Human Neuroscience, 4*. doi:10.3389/fnhum.2010.00217

Casey, B., Cohen, J. D., Jezzard, P., Turner, R., Noll, D. C., Trainor, R. J., . . . Rapoport, J. L. (1995). Activation of prefrontal cortex in children during a nonspatial working memory task with functional MRI. *NeuroImage, 2*(3), 221-229.

Casey, B., Cohen, J. D., O'Craven, K., Davidson, R. J., Irwin, W., Nelson, C. A., . . . Rosen, B. R. (1998). Reproducibility of fMRI results across four institutions using a spatial working memory task. *NeuroImage, 8*(3), 249-261.

Casey, B. J., Cannonier, T., Conley, M. I., Cohen, A. O., Barch, D. M., Heitzeg, M. M., . . . Dale, A. M. (2018). The Adolescent Brain Cognitive Development (ABCD) study: Imaging acquisition across 21 sites. *Developmental Cognitive Neuroscience, 32*, 43-54. doi:https://doi.org/10.1016/j.dcn.2018.03.001

Caspers, S., Schleicher, A., Bacha-Trams, M., Palomero-Gallagher, N., Amunts, K., & Zilles, K. (2013). Organization of the human inferior parietal lobule based on receptor architectonics. *Cerebral cortex (New York, N.Y. : 1991), 23*(3), 615-628. doi:10.1093/cercor/bhs048

Caspers, S., Zilles, K., Laird, A. R., & Eickhoff, S. B. (2010). ALE meta-analysis of action observation and imitation in the human brain. *NeuroImage, 50*(3), 1148-1167. doi:https://doi.org/10.1016/j.neuroimage.2009.12.112

Cechetto, D. F., & Topolovec, J. C. (2002). Cerebral Cortex. In V. S. Ramachandran (Ed.), *Encyclopedia of the Human Brain* (pp. 663-679). New York: Academic Press.

Chai, W. J., Abd Hamid, A. I., & Abdullah, J. M. (2018). Working Memory From the Psychological and Neurosciences Perspectives: A Review. *Frontiers in Psychology, 9*. doi:10.3389/fpsyg.2018.00401

Chein, J. M., Moore, A. B., & Conway, A. R. A. (2011). Domain-general mechanisms of complex working memory span. *NeuroImage, 54*(1), 550-559. doi:https://doi.org/10.1016/j.neuroimage.2010.07.067

Chen, F. R., & Raine, A. (2018). Effects of harsh parenting and positive parenting practices on youth aggressive behavior: The moderating role of early pubertal timing. *Aggressive Behavior, 44*(1), 18-28.

Chen, J. E., & Glover, G. H. (2015). Functional Magnetic Resonance Imaging Methods. *Neuropsychology Review, 25*(3), 289-313. doi:10.1007/s11065-015-9294-9

Clark, D. B., Chung, T., Pajtek, S., Zhai, Z., Long, E., & Hasler, B. (2013). Neuroimaging methods for adolescent substance use disorder prevention science. *Prev Sci, 14*(3), 300-309. doi:10.1007/s11121-012-0323-0

Clark, D. B., Fisher, C. B., Bookheimer, S., Brown, S. A., Evans, J. H., Hopfer, C., . . . Pfefferbaum, A. (2018). Biomedical ethics and clinical oversight in multisite observational neuroimaging studies with children and adolescents: The ABCD experience. *Developmental Cognitive Neuroscience, 32*, 143-154.

Cohen, J. D., Perlstein, W. M., Braver, T. S., Nystrom, L. E., Noll, D. C., Jonides, J., & Smith, E. E. (1997). Temporal dynamics of brain activation during a working memory task. *Nature, 386*(6625), 604-608.

Cohen, M. M., Jing, D., Yang, R. R., Tottenham, N., Lee, F. S., & Casey, B. (2013). Early-life stress has persistent effects on amygdala function and development in mice and humans. *Proceedings of the National Academy of Sciences, 110*(45), 18274-18278.

Colcombe, S. J., Kramer, A. F., Erickson, K. I., & Scalf, P. (2005). The Implications of Cortical Recruitment and Brain Morphology for Individual Differences in Inhibitory Function in Aging Humans. *Psychology and Aging, 20*(3), 363-375. doi:10.1037/0882-7974.20.3.363

Cowan, N. (2008). Chapter 20 What are the differences between long-term, short-term, and working memory? In W. S. Sossin, J.-C. Lacaille, V. F. Castellucci, & S. Belleville (Eds.), *Progress in Brain Research* (Vol. 169, pp. 323-338): Elsevier.

Cowan, N. (2014). Working Memory Underpins Cognitive Development, Learning, and Education. *Educational psychology review, 26*(2), 197-223. doi:10.1007/s10648-013-9246-y

Cox, R. W. (1996). AFNI: software for analysis and visualization of functional magnetic resonance neuroimages. *Computers and Biomedical research, 29*(3), 162-173.

Cummings, E. M., & Schatz, J. N. (2012). Family conflict, emotional security, and child development: translating research findings into a prevention program for community families. *Clinical Child and Family Psychology Review, 15*(1), 14-27.

Curtis, C. E., & D'Esposito, M. (2003). Persistent activity in the prefrontal cortex during working memory. *Trends in Cognitive Sciences, 7*(9), 415-423.

D'angiulli, A., Lipina, S. J., & Olesinska, A. (2012). Explicit and implicit issues in the developmental cognitive neuroscience of social inequality. *Frontiers in Human Neuroscience, 6*, 254.

Davey, C. G., Pujol, J., & Harrison, B. J. (2016). Mapping the self in the brain's default mode network. *NeuroImage, 132*, 390-397. doi:https://doi.org/10.1016/j.neuroimage.2016.02.022

Dawson, J. F. (2014). Moderation in management research: What, why, when, and how. *Journal of business and psychology, 29*(1), 1-19.

De Bellis, M. D., Keshavan, M. S., Shifflett, H., Iyengar, S., Beers, S. R., Hall, J., & Moritz, G. (2002). Brain structures in pediatric maltreatment-related posttraumatic stress disorder: a sociodemographically matched study. *Biol Psychiatry, 52*(11), 1066-1078. doi:10.1016/s0006-3223(02)01459-2

DeJoseph, M. L., Herzberg, M. P., Sifre, R. D., Berry, D., & Thomas, K. M. (2022). Measurement matters: An individual differences examination of family socioeconomic factors, latent dimensions of children’s experiences, and resting state functional brain connectivity in the ABCD sample. *Developmental Cognitive Neuroscience, 53*, 101043.

Del Giudice, M. (2020). Rethinking the fast-slow continuum of individual differences. *Evolution and Human Behavior, 41*(6), 536-549. doi:https://doi.org/10.1016/j.evolhumbehav.2020.05.004

Del Missier, F., Mäntylä, T., Hansson, P., Bruine de Bruin, W., Parker, A. M., & Nilsson, L.-G. (2013). The multifold relationship between memory and decision making: an individual-differences study. *Journal of experimental psychology. Learning, memory, and cognition, 39*(5), 1344-1364.

doi:10.1037/a0032379

Demeusy, E. M., Handley, E. D., Rogosch, F. A., Cicchetti, D., & Toth, S. L. (2018). Early neglect and the development of aggression in toddlerhood: The role of working memory. *Child maltreatment, 23*(4), 344-354.

Desikan, R. S., Ségonne, F., Fischl, B., Quinn, B. T., Dickerson, B. C., Blacker, D., . . . Hyman, B. T. (2006). An automated labeling system for subdividing the human cerebral cortex on MRI scans into gyral based regions of interest. *NeuroImage, 31*(3), 968-980.

Dodaj, A., Krajina, M., Sesar, K., & Šimić, N. (2017). The Effects of Maltreatment in Childhood on Working Memory Capacity in Adulthood. *Europe's journal of psychology, 13*(4), 618-632. doi:10.5964/ejop.v13i4.1373

Doom, J. R., Peckins, M. K., Hein, T. C., Dotterer, H. L., Mitchell, C., Lopez-Duran, N. L., . . . Abelson, J. L. (2022). Differential associations of parental harshness and parental disengagement with overall cortisol output at 15 years: Implications for adolescent mental health. *Development and Psychopathology, 34*(1), 129-146.

Duda, B. M., Owens, M. M., Hallowell, E. S., & Sweet, L. H. (2019). Neurocompensatory Effects of the Default Network in Older Adults. *Frontiers in aging neuroscience, 11*. doi:10.3389/fnagi.2019.00111

Duerden, E. G., Arsalidou, M., Lee, M., & Taylor, M. J. (2013). Lateralization of affective processing in the insula. *NeuroImage, 78*, 159-175. doi:https://doi.org/10.1016/j.neuroimage.2013.04.014

Edmiston, E. E., Wang, F., Mazure, C. M., Guiney, J., Sinha, R., Mayes, L. C., & Blumberg, H. P. (2011). Corticostriatal-Limbic Gray Matter Morphology in Adolescents With Self-reported Exposure to Childhood Maltreatment. *Archives of Pediatrics & Adolescent Medicine, 165*(12), 1069-1077. doi:10.1001/archpediatrics.2011.565

Ehrlich, K. B., Ross, K. M., Chen, E., & Miller, G. E. (2016). Testing the biological embedding hypothesis: Is early life adversity associated with a later proinflammatory phenotype? *Development and Psychopathology, 28*(4pt2), 1273-1283. doi:10.1017/S0954579416000845

Ekstrom, A. (2010). How and when the fMRI BOLD signal relates to underlying neural activity: the danger in dissociation. *Brain research reviews, 62*(2), 233-244. doi:10.1016/j.brainresrev.2009.12.004

Elliott, W. (2013). The effects of economic instability on children's educational outcomes. *Children and Youth Services Review, 35*(3), 461-471.

Ellis, B. J., Figueredo, A. J., Brumbach, B. H., & Schlomer, G. L. (2009). Fundamental dimensions of environmental risk. *Human Nature, 20*(2), 204-268.

Eluvathingal, T. J., Chugani, H. T., Behen, M. E., Juhász, C., Muzik, O., Maqbool, M., . . . Makki, M. (2006). Abnormal Brain Connectivity in Children After Early Severe Socioemotional Deprivation: A Diffusion Tensor Imaging Study. *Pediatrics, 117*(6), 2093-2100. doi:10.1542/peds.2005-1727

Enders, C. K., & Bandalos, D. L. (2001). The relative performance of full information maximum likelihood estimation for missing data in structural equation models. *Structural equation modeling, 8*(3), 430-457.

Evans, G. W., Gonnella, C., Marcynyszyn, L. A., Gentile, L., & Salpekar, N. (2005). The role of chaos in poverty and children's socioemotional adjustment. *Psychological science, 16*(7), 560-565.

Evans, G. W., & Schamberg, M. A. (2009). Childhood poverty, chronic stress, and adult working memory. *Proceedings of the National Academy of Sciences, 106*(16), 6545-6549. doi:doi:10.1073/pnas.0811910106

Fair, D. A., Dosenbach, N. U., Moore, A. H., Satterthwaite, T. D., & Milham, M. P. (2021). Developmental Cognitive Neuroscience in the Era of Networks and Big Data: Strengths, Weaknesses, Opportunities, and Threats. *Annual Review of Developmental Psychology, 3*, 249-275.

Farokhian, F., Yang, C., Beheshti, I., Matsuda, H., & Wu, S. (2017). Age-Related Gray and White Matter Changes in Normal Adult Brains. *Aging and disease, 8*(6), 899-909. doi:10.14336/AD.2017.0502

Fava, N. M., Trucco, E. M., Martz, M. E., Cope, L. M., Jester, J. M., Zucker, R. A., & Heitzeg, M. M.

(2019). Childhood adversity, externalizing behavior, and substance use in adolescence: Mediating effects of anterior cingulate cortex activation during inhibitory errors. *Development and Psychopathology, 31*(4), 1439-1450. doi:10.1017/S0954579418001025

Fay-Stammbach, T., Hawes, D. J., & Meredith, P. (2017). Child maltreatment and emotion socialization: Associations with executive function in the preschool years. *Child Abuse & Neglect, 64*, 1-12.

Fischl, B. (2012). FreeSurfer. *NeuroImage, 62*(2), 774-781.

Flouri, E., Ruddy, A., & Midouhas, E. (2017). Maternal depression and trajectories of child internalizing and externalizing problems: the roles of child decision making and working memory. *Psychological medicine, 47*(6), 1138-1148.

Friedman, N. P., & Robbins, T. W. (2022). The role of prefrontal cortex in cognitive control and executive function. *Neuropsychopharmacology, 47*(1), 72-89. doi:10.1038/s41386-021-01132-0

Fries, A. B. W., Shirtcliff, E. A., & Pollak, S. D. (2008). Neuroendocrine dysregulation following early social deprivation in children. *Developmental Psychobiology: The Journal of the International Society for Developmental Psychobiology, 50*(6), 588-599.

Garavan, H., Bartsch, H., Conway, K., Decastro, A., Goldstein, R., Heeringa, S., . . . Zahs, D. (2018). Recruiting the ABCD sample: Design considerations and procedures. *Developmental Cognitive Neuroscience, 32*, 16-22.

Gee, D. G. (2021). Early adversity and development: parsing heterogeneity and identifying pathways of risk and resilience. *American Journal of Psychiatry, 178*(11), 998-1013.

Gee, D. G., & Cohodes, E. M. (2021). Influences of caregiving on development: A sensitive period for biological embedding of predictability and safety cues. *Current Directions in Psychological Science, 30*(5), 376-383.

Geerligs, L., Renken, R. J., Saliasi, E., Maurits, N. M., & Lorist, M. M. (2014). A Brain-Wide Study of Age-Related Changes in Functional Connectivity. *Cerebral cortex, 25*(7), 1987-1999. doi:10.1093/cercor/bhu012

Gerst, E. H., Cirino, P. T., Fletcher, J. M., & Yoshida, H. (2017). Cognitive and behavioral rating measures of executive function as predictors of academic outcomes in children. *Child Neuropsychology, 23*(4), 381-407.

Glover, G. H. (2011). Overview of functional magnetic resonance imaging. *Neurosurgery clinics of North America, 22*(2), 133-vii. doi:10.1016/j.nec.2010.11.001

Gluckman, P. D., Hanson, M. A., Cooper, C., & Thornburg, K. L. (2008). Effect of in utero and early-life conditions on adult health and disease. *New England Journal of Medicine, 359*(1), 61-73.

Glynn, L. M., Howland, M. A., Sandman, C. A., Davis, E. P., Phelan, M., Baram, T. Z., & Stern, H. S. (2018). Prenatal maternal mood patterns predict child temperament and adolescent mental health. *Journal of Affective Disorders, 228*, 83-90.

Goetschius, L. (2021). *Violence Exposure and Social Deprivation: Neural Connectivity Correlates and Protective Factors.*

Gonzalez, R., Thompson, E. L., Sanchez, M., Morris, A., Gonzalez, M. R., Feldstein Ewing, S. W., . . . Zucker, R. A. (2021). An update on the assessment of culture and environment in the ABCD Study®: Emerging literature and protocol updates over three measurement waves. *Developmental Cognitive Neuroscience, 52*, 101021. doi:https://doi.org/10.1016/j.dcn.2021.101021

Goodman, J. B., Freeman, E. E., & Chalmers, K. A. (2019). The relationship between early life stress and working memory in adulthood: A systematic review and meta-analysis. *Memory, 27*(6), 868-880.

Govindan, R. M., Behen, M. E., Helder, E., Makki, M. I., & Chugani, H. T. (2010). Altered water diffusivity in cortical association tracts in children with early deprivation identified with tract-based spatial statistics (TBSS). *Cerebral cortex, 20*(3), 561-569.

Grady, C. L. (2012). The cognitive neuroscience of ageing. *Nature reviews. Neuroscience, 13*(7), 491-505. doi:10.1038/nrn3256

Granger, S. J., Glynn, L. M., Sandman, C. A., Small, S. L., Obenaus, A., Keator, D. B., . . . Davis, E. P. (2021). Aberrant maturation of the uncinate fasciculus follows exposure to unpredictable patterns of maternal signals. *Journal of Neuroscience, 41*(6), 1242-1250.

Green, J. G., McLaughlin, K. A., Berglund, P. A., Gruber, M. J., Sampson, N. A., Zaslavsky, A. M., &

Kessler, R. C. (2010). Childhood adversities and adult psychiatric disorders in the national comorbidity survey replication I: associations with first onset of DSM-IV disorders. *Archives of general psychiatry, 67*(2), 113-123.

Griskevicius, V., Tybur, J. M., Delton, A. W., & Robertson, T. E. (2011). The influence of mortality and socioeconomic status on risk and delayed rewards: a life history theory approach. *Journal of personality and social psychology, 100*(6), 1015-1026. doi:10.1037/a0022403

Guadagno, A., Kang, M. S., Devenyi, G. A., Mathieu, A. P., Rosa-Neto, P., Chakravarty, M., & Walker, C.-D. (2018). Reduced resting-state functional connectivity of the basolateral amygdala to the medial prefrontal cortex in preweaning rats exposed to chronic early-life stress. *Brain Structure and Function, 223*(8), 3711-3729.

Guidi, J., Lucente, M., Sonino, N., & Fava, G. A. (2021). Allostatic Load and Its Impact on Health: A Systematic Review. *Psychotherapy and Psychosomatics, 90*(1), 11-27. doi:10.1159/000510696

Gunnar, M., & Quevedo, K. (2007). The Neurobiology of Stress and Development. *Annual Review of Psychology, 58*(1), 145-173. doi:10.1146/annurev.psych.58.110405.085605

Hagler Jr, D. J., Hatton, S., Cornejo, M. D., Makowski, C., Fair, D. A., Dick, A. S., . . . Harms, M. P. (2019). Image processing and analysis methods for the Adolescent Brain Cognitive Development Study. *NeuroImage, 202*, 116091.

Hanson, J. L., Adluru, N., Chung, M. K., Alexander, A. L., Davidson, R. J., & Pollak, S. D. (2013). Early neglect is associated with alterations in white matter integrity and cognitive functioning. *Child development, 84*(5), 1566-1578. doi:10.1111/cdev.12069

Hanson, J. L., Chung, M. K., Avants, B. B., Rudolph, K. D., Shirtcliff, E. A., Gee, J. C., . . . Pollak, S. D. (2012). Structural variations in prefrontal cortex mediate the relationship between early childhood stress and spatial working memory. *Journal of Neuroscience, 32*(23), 7917-7925.

Hawkes, K. (2006). Slow life histories and human evolution. *The evolution of human life history*, 95-126.

Heeringa, S. G., & Berglund, P. A. (2020). A guide for population-based analysis of the Adolescent Brain Cognitive Development (ABCD) Study baseline data. *BioRxiv*.

Heeringa, S. G., West, B. T., & Berglund, P. A. (2017). *Applied survey data analysis*: chapman and hall/CRC.

Hertzman, C. (2012). Putting the concept of biological embedding in historical perspective. *Proceedings of the National Academy of Sciences, 109*(Supplement 2), 17160-17167.

Herzberg, M. P., & Gunnar, M. R. (2020). Early life stress and brain function: Activity and connectivity associated with processing emotion and reward. *NeuroImage*, *209*, 116493. doi:https://doi.org/10.1016/j.neuroimage.2019.116493

Herzberg, M. P., Hodel, A. S., Cowell, R. A., Hunt, R. H., Gunnar, M. R., & Thomas, K. M. (2018). Risk taking, decision-making, and brain volume in youth adopted internationally from institutional care. *Neuropsychologia*, *119*, 262-270. doi:https://doi.org/10.1016/j.neuropsychologia.2018.08.022

Hester, R. L., Murphy, K., Foxe, J. J., Foxe, D. M., Javitt, D. C., & Garavan, H. (2004). Predicting success: patterns of cortical activation and deactivation prior to response inhibition. *Journal of Cognitive Neuroscience, 16*(5), 776-785.

Hillman, E. M. C. (2014). Coupling mechanism and significance of the BOLD signal: a status report. *Annual review of neuroscience, 37*, 161-181. doi:10.1146/annurev-neuro-071013-014111

Hodel, A. S., Hunt, R. H., Cowell, R. A., Van Den Heuvel, S. E., Gunnar, M. R., & Thomas, K. M. (2015). Duration of early adversity and structural brain development in post-institutionalized adolescents. *NeuroImage, 105*, 112-119. doi:10.1016/j.neuroimage.2014.10.020

Holland, D., Kuperman, J. M., & Dale, A. M. (2010). Efficient correction of inhomogeneous static magnetic field-induced distortion in Echo Planar Imaging. *NeuroImage, 50*(1), 175-183.

Hostinar, C. E., Stellern, S. A., Schaefer, C., Carlson, S. M., & Gunnar, M. R. (2012). Associations between early life adversity and executive function in children adopted internationally from orphanages. *Proceedings of the National Academy of Sciences, 109*(Supplement 2), 17208-17212.

Howland, M. A., Sandman, C. A., Davis, E. P., Stern, H. S., Phelan, M., Baram, T. Z., & Glynn, L. M. (2021). Prenatal maternal mood entropy is associated with child neurodevelopment. *Emotion*, *21*(3), 489.

Hu, L. t., & Bentler, P. M. J. S. e. m. a. m. j. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *6*(1), 1-55.

Hu, S., Ide, J. S., Zhang, S., & Li, C.-s. R. (2016). The Right Superior Frontal Gyrus and Individual Variation in Proactive Control of Impulsive Response. *The Journal of Neuroscience, 36*(50), 12688. doi:10.1523/JNEUROSCI.1175-16.2016

Huang-Pollock, C., Shapiro, Z., Galloway-Long, H., & Weigard, A. (2017). Is Poor Working Memory a Transdiagnostic Risk Factor for Psychopathology? *Journal of abnormal child psychology, 45*(8), 1477-1490. doi:10.1007/s10802-016-0219-8

Hudson, D. L., Neighbors, H. W., Geronimus, A. T., & Jackson, J. S. (2016). Racial Discrimination, John Henryism, and Depression Among African Americans. *J Black Psychol, 42*(3), 221-243. doi:10.1177/0095798414567757

Humphreys, K. L., Machlin, L. S., Guyon-Harris, K. L., Nelson, C. A., Fox, N. A., & Zeanah, C. H. (2020). Psychosocial deprivation and receptive language ability: a two-sample study. *Journal of neurodevelopmental disorders, 12*(1), 1-11.

Humphreys, K. L., & Zeanah, C. H. (2015). Deviations from the Expectable Environment in Early Childhood and Emerging Psychopathology. *Neuropsychopharmacology, 40*(1), 154-170. doi:10.1038/npp.2014.165

Hur, J., Iordan, A. D., Dolcos, F., & Berenbaum, H. (2017). Emotional influences on perception and working memory. *Cognition and Emotion, 31*(6), 1294-1302.

Hyde, L. W., Gard, A. M., Tomlinson, R. C., Burt, S. A., Mitchell, C., & Monk, C. S. (2020). An ecological approach to understanding the developing brain: Examples linking poverty, parenting, neighborhoods, and the brain. *Am Psychol, 75*(9), 1245-1259. doi:10.1037/amp0000741

Iordan, A. D., Cooke, K. A., Moored, K. D., Katz, B., Buschkuehl, M., Jaeggi, S. M., . . . Reuter-Lorenz, P. A. (2020). Neural correlates of working memory training: Evidence for plasticity in older adults. *NeuroImage, 217*, 116887. doi:https://doi.org/10.1016/j.neuroimage.2020.116887

James, S. A., Keenan, N. L., Strogatz, D. S., Browning, S. R., & Garrett, J. M. (1992). Socioeconomic status, John Henryism, and blood pressure in black adults: The Pitt County Study. *American journal of epidemiology, 135*(1), 59-67.

Jenkinson, M., Beckmann, C. F., Behrens, T. E., Woolrich, M. W., & Smith, S. M. (2012). Fsl. *NeuroImage, 62*(2), 782-790.

Johns, P. (2014). Chapter 3 - Functional neuroanatomy. In P. Johns (Ed.), *Clinical Neuroscience* (pp. 27-47): Churchill Livingstone.

Johnson, D., Policelli, J., Li, M., Dharamsi, A., Hu, Q., Sheridan, M. A., . . . Wade, M. (2021). Associations of Early-Life Threat and Deprivation With Executive Functioning in Childhood and Adolescence: A Systematic Review and Meta-analysis. *JAMA Pediatrics, 175*(11), e212511-e212511. doi:10.1001/jamapediatrics.2021.2511

Johnson, M. H., & De Haan, M. (2015). *Developmental cognitive neuroscience: An introduction*: John Wiley & Sons.

Johnson, P. O., & Neyman, J. (1936). Tests of certain linear hypotheses and their application to some educational problems. *Statistical research memoirs*.

Jones, D. J., Lewis, T., Litrownik, A., Thompson, R., Proctor, L. J., Isbell, P., . . . Runyan, D. (2013). Linking Childhood Sexual Abuse and Early Adolescent Risk Behavior: The Intervening Role of Internalizing and Externalizing Problems. *Journal of Abnormal Child Psychology, 41*(1), 139-150. doi:10.1007/s10802-012-9656-1

Jones, J. S., Adlam, A. L. R., Benattayallah, A., & Milton, F. N. (2022). The neural correlates of working memory training in typically developing children. *Child development, 93*(3), 815-830.

Jovicich, J., Czanner, S., Greve, D., Haley, E., van Der Kouwe, A., Gollub, R., . . . MacFall, J. (2006). Reliability in multi-site structural MRI studies: effects of gradient non-linearity correction on phantom and human data. *NeuroImage, 30*(2), 436-443.

Kaas, J. H., & Stepniewska, I. (2002). Motor Cortex. In V. S. Ramachandran (Ed.), *Encyclopedia of the Human Brain* (pp. 159-169). New York: Academic Press.

Karcher, N. R., O’Brien, K. J., Kandala, S., & Barch, D. M. (2019). Resting-state functional connectivity and psychotic-like experiences in childhood: results from the adolescent brain cognitive development study. *Biological psychiatry, 86*(1), 7-15.

Karlsgodt, K. H. (2015). Working Memory. In A. W. Toga (Ed.), *Brain Mapping* (pp. 319-326). Waltham: Academic Press.

Karoly, H. C., Callahan, T., Schmiege, S. J., & Feldstein Ewing, S. W. (2016). Evaluating the Hispanic paradox in the context of adolescent risky sexual behavior: The role of parent monitoring. *Journal of pediatric psychology, 41*(4), 429-440.

Kaup, A. R., Mirzakhanian, H., Jeste, D. V., & Eyler, L. T. (2011). A review of the brain structure correlates of successful cognitive aging. *The Journal of neuropsychiatry and clinical neurosciences, 23*(1), 6-15.

Khurana, A., Romer, D., Betancourt, L. M., Brodsky, N. L., Giannetta, J. M., & Hurt, H. (2013). Working memory ability predicts trajectories of early alcohol use in adolescents: the mediational role of impulsivity. *Addiction, 108*(3), 506-515.

Khurana, A., Romer, D., Betancourt, L. M., & Hurt, H. (2017). Working memory ability and early drug use progression as predictors of adolescent substance use disorders. *Addiction, 112*(7), 1220-1228.

Kim, H., & Hillard, K. (1999). Life History Traits in Humans: Theory and Empirical Studies. *Annual Review of Anthropology, 28*(1), 397-430. doi:10.1146/annurev.anthro.28.1.397

Kirsch, L. P., Besharati, S., Papadaki, C., Crucianelli, L., Bertagnoli, S., Ward, N., . . . Fotopoulou, A. (2020). Damage to the right insula disrupts the perception of affective touch. *eLife, 9*, e47895. doi:10.7554/eLife.47895

Kobayashi, S. (2009). Reward Neurophysiology and Primate Cerebral Cortex. In L. R. Squire (Ed.), *Encyclopedia of Neuroscience* (pp. 325-333). Oxford: Academic Press.

Kokosi, T., Flouri, E., & Midouhas, E. (2021). The role of inflammation in the association between poverty and working memory in childhood. *Psychoneuroendocrinology, 123*, 105040.

doi:https://doi.org/10.1016/j.psyneuen.2020.105040

Koss, K. J., Mliner, S. B., Donzella, B., & Gunnar, M. R. (2016). Early adversity, hypocortisolism, and behavior problems at school entry: A study of internationally adopted children. *Psychoneuroendocrinology, 66*, 31-38.

Kreppner, J. M., O'Connor, T. G., & Rutter, M. (2001). Can inattention/overactivity be an institutional deprivation syndrome? *Journal of abnormal child psychology*, *29*(6), 513-528.

Lambert, H. K., King, K. M., Monahan, K. C., & McLaughlin, K. A. (2017). Differential associations of threat and deprivation with emotion regulation and cognitive control in adolescence. *Development and Psychopathology, 29*(3), 929-940. doi:10.1017/S0954579416000584

Leung, A. W., & Alain, C. (2011). Working memory load modulates the auditory “What” and “Where” neural networks. *NeuroImage, 55*(3), 1260-1269.

Levens, S. M., Armstrong, L. M., Orejuela-Dávila, A. I., & Alverio, T. (2017). The two sides of adversity: The effect of distant versus recent adversity on updating emotional content in working memory. *Cognition and Emotion, 31*(6), 1243-1251.

Levens, S. M., & Gotlib, I. H. (2010). Updating positive and negative stimuli in working memory in depression. *Journal of experimental psychology. General*, *139*(4), 654-664. doi:10.1037/a0020283

Levitt, P. (2003). Structural and functional maturation of the developing primate brain. *The Journal of Pediatrics, 143*(4, Supplement), 35-45. doi:https://doi.org/10.1067/S0022-3476(03)00400-1

Li, L., & Smith, D. M. (2021). Neural Efficiency in Athletes: A Systematic Review. *Frontiers in behavioral neuroscience*, 167.

Lim, L., Hart, H., Mehta, M. A., Simmons, A., Mirza, K., & Rubia, K. (2015). Neural correlates of error processing in young people with a history of severe childhood abuse: an fMRI study. *American Journal of Psychiatry, 172*(9), 892-900.

Lima, J., Caughy, M., Nettles, S. M., & O’Campo, P. J. (2010). Effects of cumulative risk on behavioral and psychological well-being in first grade: Moderation by neighborhood context. *Social Science*

& Medicine, 71(8), 1447-1454. doi:https://doi.org/10.1016/j.socscimed.2010.06.022

Little, T. D. (2013). *Longitudinal structural equation modeling*: Guilford press.

Liu, S., Cui, Z., Duprey, E. B., Kogan, S. M., & Oshri, A. (2020). Adverse Parenting Is Indirectly Linked to Delayed Reward Discounting via Blunted RSA Reactivity: the Protective Role of a Shift-and-Persist Coping Strategy. *Adversity and Resilience Science, 1*(3), 149-163.

Liu, S., & Fisher, P. A. (2022). Early experience unpredictability in child development as a model for understanding the impact of the COVID-19 pandemic: A translational neuroscience perspective. *Developmental Cognitive Neuroscience, 54*, 101091-101091. doi:10.1016/j.dcn.2022.101091

Liu, S., Oshri, A., Kogan, S. M., Wickrama, K. A. S., & Sweet, L. (2021). Amygdalar Activation as a Neurobiological Marker of Differential Sensitivity in the Effects of Family Rearing Experiences on Socioemotional Adjustment in Youths. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging, 6*(11), 1052-1062. doi:https://doi.org/10.1016/j.bpsc.2021.04.017

Loman, M. M., Johnson, A. E., Westerlund, A., Pollak, S. D., Nelson, C. A., & Gunnar, M. R. (2013). The effect of early deprivation on executive attention in middle childhood. *Journal of child psychology and psychiatry, and allied disciplines, 54*(1), 37-45. doi:10.1111/j.1469-7610.2012.02602.x

Luengo Kanacri, B. P., Eisenberg, N., Thartori, E., Pastorelli, C., Uribe Tirado, L. M., Gerbino, M., & Caprara, G. V. (2017). Longitudinal relations among positivity, perceived positive school climate, and prosocial behavior in Colombian adolescents. *Child development, 88*(4), 1100-1114.

Luna, B., & Sweeney, J. A. (2001). Studies of brain and cognitive maturation through childhood and adolescence: a strategy for testing neurodevelopmental hypotheses. *Schizophrenia bulletin, 27*(3), 443-455.

Luo, Y., Qin, S., Fernandez, G., Zhang, Y., Klumpers, F., & Li, H. (2014). Emotion perception and executive control interact in the salience network during emotionally charged working memory processing. *Human brain mapping, 35*(11), 5606-5616.

Lupien, S. J., Maheu, F., Tu, M., Fiocco, A., & Schramek, T. E. (2007). The effects of stress and stress hormones on human cognition: Implications for the field of brain and cognition. *Brain and cognition, 65*(3), 209-237.

Lupien, S. J., McEwen, B. S., Gunnar, M. R., & Heim, C. (2009). Effects of stress throughout the lifespan on the brain, behaviour and cognition. *Nature Reviews Neuroscience, 10*(6), 434-445.

Machlin, L., Miller, A. B., Snyder, J., McLaughlin, K. A., & Sheridan, M. A. (2019). Differential Associations of Deprivation and Threat With Cognitive Control and Fear Conditioning in Early Childhood. *Frontiers in behavioral neuroscience, 13*. doi:10.3389/fnbeh.2019.00080

Mackes, N. K., Golm, D., Sarkar, S., Kumsta, R., Rutter, M., Fairchild, G., . . . Schlotz, W. (2020). Early childhood deprivation is associated with alterations in adult brain structure despite subsequent environmental enrichment. *Proceedings of the National Academy of Sciences, 117*(1), 641-649. doi:doi:10.1073/pnas.1911264116

Magnusson, D., & Stattin, H. (2006). The Person in Context: A Holistic-Interactionistic Approach. In *Handbook of child psychology: Theoretical models of human development, Vol. 1, 6th ed.* (pp. 400-464). Hoboken, NJ, US: John Wiley & Sons Inc.

Mann, B. J., & Sanders, S. (1994). Child dissociation and the family context. *Journal of abnormal child psychology, 22*(3), 373-388.

Mason, M. F., Norton, M. I., Van Horn, J. D., Wegner, D. M., Grafton, S. T., & Macrae, C. N. (2007). Wandering minds: the default network and stimulus-independent thought. *Science, 315*(5810), 393-395.

Masten, A. S., Herbers, J. E., Desjardins, C. D., Cutuli, J., McCormick, C. M., Sapienza, J. K., . . . Zelazo, P. D. (2012). Executive function skills and school success in young children experiencing homelessness. *Educational Researcher, 41*(9), 375-384.

Matejko, A., & Ansari, D. (2012). Developmental Cognitive Neuroscience and Learning. In N. M. Seel (Ed.), *Encyclopedia of the Sciences of Learning* (pp. 961-966). Boston, MA: Springer US.

Mattay, V. S., Fera, F., Tessitore, A., Hariri, A. R., Berman, K. F., Das, S., . . . Weinberger, D. R. (2006). Neurophysiological correlates of age-related changes in working memory capacity. *Neuroscience* *letters, 392*(1-2), 32-37.

McCrory, E., De Brito, S., & Viding, E. (2011). The Impact of Childhood Maltreatment: A Review of Neurobiological and Genetic Factors. *Frontiers in Psychiatry, 2*. doi:10.3389/fpsyt.2011.00048

McDermott, J. M., Troller-Renfree, S. V., Vanderwert, R., Nelson, C. A., Zeanah, C. H., & Fox, N. (2013). Psychosocial deprivation, executive functions, and the emergence of socio-emotional behavior problems. *Frontiers in Human Neuroscience, 7*, 167.

McEwen, B. S. (2012). Brain on stress: how the social environment gets under the skin. *Proceedings of the National Academy of Sciences, 109*(supplement_2), 17180-17185.

McEwen, B. S., & Stellar, E. (1993). Stress and the Individual: Mechanisms Leading to Disease. *Archives of Internal Medicine, 153*(18), 2093-2101. doi:10.1001/archinte.1993.00410180039004

McLaughlin, K. A., Green, J. G., Gruber, M. J., Sampson, N. A., Zaslavsky, A. M., & Kessler, R. C. (2010). Childhood adversities and adult psychiatric disorders in the national comorbidity survey replication II: associations with persistence of DSM-IV disorders. *Archives of general psychiatry, 67*(2), 124-132.

McLaughlin, K. A., Sheridan, M. A., Gold, A. L., Duys, A., Lambert, H. K., Peverill, M., . . . Pine, D. S. (2016). Maltreatment Exposure, Brain Structure, and Fear Conditioning in Children and Adolescents. *Neuropsychopharmacology, 41*(8), 1956-1964. doi:10.1038/npp.2015.365

McLaughlin, K. A., Sheridan, M. A., Humphreys, K. L., Belsky, J., & Ellis, B. J. (2021). The Value of Dimensional Models of Early Experience: Thinking Clearly About Concepts and Categories. *Perspectives on psychological science : a journal of the Association for Psychological Science, 16*(6), 1463-1472. doi:10.1177/1745691621992346

McLaughlin, K. A., Sheridan, M. A., & Lambert, H. K. (2014). Childhood adversity and neural development: Deprivation and threat as distinct dimensions of early experience. *Neuroscience & Biobehavioral Reviews, 47*, 578-591. doi:https://doi.org/10.1016/j.neubiorev.2014.10.012

McLaughlin, K. A., Sheridan, M. A., & Nelson, C. A. (2017). Neglect as a Violation of Species-Expectant Experience: Neurodevelopmental Consequences. *Biological psychiatry, 82*(7), 462-

471. doi:https://doi.org/10.1016/j.biopsych.2017.02.1096

McLaughlin, K. A., Sheridan, M. A., Tibu, F., Fox, N. A., Zeanah, C. H., & Nelson, C. A. (2015). Causal effects of the early caregiving environment on development of stress response systems in children. *Proceedings of the National Academy of Sciences, 112*(18), 5637-5642.

McLaughlin, K. A., Sheridan, M. A., Winter, W., Fox, N. A., Zeanah, C. H., & Nelson, C. A. (2014). Widespread reductions in cortical thickness following severe early-life deprivation: a neurodevelopmental pathway to attention-deficit/hyperactivity disorder. *Biological psychiatry, 76*(8), 629-638.

McLaughlin, K. A., Weissman, D., & Bitrán, D. (2019). Childhood Adversity and Neural Development: A Systematic Review. *Annual Review of Developmental Psychology, 1*(1), 277-312. doi:10.1146/annurev-devpsych-121318-084950

McQuade, J. D., Murray-Close, D., Shoulberg, E. K., & Hoza, B. (2013). Working memory and social functioning in children. *Journal of Experimental Child Psychology, 115*(3), 422-435. doi:https://doi.org/10.1016/j.jecp.2013.03.002

Mehta, M. A., Golembo, N. I., Nosarti, C., Colvert, E., Mota, A., Williams, S. C., . . . Sonuga‐Barke, E. J. (2009). Amygdala, hippocampal and corpus callosum size following severe early institutional deprivation: the English and Romanian Adoptees study pilot. *Journal of Child Psychology and Psychiatry, 50*(8), 943-951.

Menon, V. (2015). Salience network. In A. W. Toga (Ed.), *Brain Mapping: An Encyclopedic Reference* (Vol. 2, pp. 597-611): Academic Press: Elsevier.

Menon, V., & Uddin, L. Q. (2010). Saliency, switching, attention and control: a network model of insula function. *Brain Structure and Function, 214*(5), 655-667. doi:10.1007/s00429-010-0262-0

Merz, E. C., & McCall, R. B. (2011). Parent ratings of executive functioning in children adopted from psychosocially depriving institutions. *Journal of Child Psychology and Psychiatry, 52*(5), 537-546. doi:https://doi.org/10.1111/j.1469-7610.2010.02335.x

Merz, E. C., McCall, R. B., & Wright, A. J. (2013). Attention and language as mediators of academic outcomes following early psychosocial deprivation. *International journal of behavioral development, 37*(5), 451-459.

Metz, S., Aust, S., Fan, Y., Bönke, L., Harki, Z., Gärtner, M., . . . Grimm, S. (2018). The influence of early life stress on the integration of emotion and working memory. *Behavioural Brain Research, 339*, 179-185. doi:https://doi.org/10.1016/j.bbr.2017.11.022

Mezzacappa, E., Kindlon, D., & Earls, F. (2001). Child abuse and performance task assessments of executive functions in boys. *The Journal of Child Psychology and Psychiatry and Allied Disciplines, 42*(8), 1041-1048.

Miller, G. E., Chen, E., & Parker, K. J. (2011). Psychological stress in childhood and susceptibility to the chronic diseases of aging: moving toward a model of behavioral and biological mechanisms. *Psychological bulletin, 137*(6), 959.

Ming, H., Zhang, F., Jiang, Y., Ren, Y., & Huang, S. (2021). Family socio-economic status and children’s executive function: The moderating effects of parental subjective socio-economic status and children’s subjective social mobility. *British Journal of Psychology, 112*(3), 720-740. doi:https://doi.org/10.1111/bjop.12490

Miró-Padilla, A., Bueichekú, E., Ventura-Campos, N., Flores-Compañ, M.-J., Parcet, M. A., & Ávila, C. (2019). Long-term brain effects of N-back training: an fMRI study. *Brain imaging and behavior, 13*(4), 1115-1127.

Mohanty, A., & Sussman, T. J. (2013). Top-down modulation of attention by emotion. In (Vol. 7, pp. 102): Frontiers Media SA.

Moos, R. H. (1990). Conceptual and empirical approaches to developing family‐based assessment procedures: Resolving the case of the Family Environment Scale. *Family process, 29*(2), 199-208.

Morcom, A. M., & Henson, R. N. (2018). Increased prefrontal activity with aging reflects nonspecific neural responses rather than compensation. *Journal of Neuroscience, 38*(33), 7303-7313.

Moser, D. A., Doucet, G. E., Ing, A., Dima, D., Schumann, G., Bilder, R. M., & Frangou, S. (2018). An integrated brain–behavior model for working memory. *Molecular Psychiatry, 23*(10), 1974-1980. doi:10.1038/mp.2017.247

Mothes, L., Kristensen, C. H., Grassi‐Oliveira, R., Fonseca, R. P., de Lima Argimon, I. I., & Irigaray, T. Q. (2015). Childhood maltreatment and executive functions in adolescents. *Child and Adolescent Mental Health*, *20*(1), 56-62.

Mueller, S. C., Maheu, F. S., Dozier, M., Peloso, E., Mandell, D., Leibenluft, E., . . . Ernst, M. (2010). Early-life stress is associated with impairment in cognitive control in adolescence: an fMRI study. *Neuropsychologia, 48*(10), 3037-3044.

Munakata, Y., Casey, B. J., & Diamond, A. (2004). Developmental cognitive neuroscience: progress and potential. *Trends in Cognitive Sciences, 8*(3), 122-128. doi:https://doi.org/10.1016/j.tics.2004.01.005

Muthén, L. K., & Muthén, B. O. (1998-2010). *Mplus User's Guide: Sixth edition*. Los Angeles, CA: Muthén and Muthén.

Nee, D. E., Brown, J. W., Askren, M. K., Berman, M. G., Demiralp, E., Krawitz, A., & Jonides, J. (2013). A meta-analysis of executive components of working memory. *Cerebral cortex (New York, N.Y. : 1991), 23*(2), 264-282. doi:10.1093/cercor/bhs007

Nelson III, C. A., Zeanah, C. H., & Fox, N. A. (2019). How early experience shapes human development: the case of psychosocial deprivation. *Neural Plasticity*.

Nettle, D. (2010). Dying young and living fast: Variation in life history across English neighborhoods. *Behavioral ecology, 21*(2), 387-395.

Neumann, J., Lohmann, G., Derrfuss, J., & Von Cramon, D. Y. (2005). Meta‐analysis of functional imaging data using replicator dynamics. *Human brain mapping, 25*(1), 165-173.

Nikulina, V., & Widom, C. S. (2013). Child maltreatment and executive functioning in middle adulthood:

a prospective examination. *Neuropsychology, 27*(4), 417-427. doi:10.1037/a0032811

Nissim, N. R., O'Shea, A. M., Bryant, V., Porges, E. C., Cohen, R., & Woods, A. J. (2017). Frontal Structural Neural Correlates of Working Memory Performance in Older Adults. *Frontiers in aging neuroscience, 8*, 328-328. doi:10.3389/fnagi.2016.00328

Nyberg, L., Dahlin, E., Stigsdotter Neely, A., & Bäckman, L. (2009). Neural correlates of variable working memory load across adult age and skill: Dissociative patterns within the fronto‐parietal network. *Scandinavian journal of psychology, 50*(1), 41-46.

Osaka, M., Osaka, N., Kondo, H., Morishita, M., Fukuyama, H., Aso, T., & Shibasaki, H. (2003). The neural basis of individual differences in working memory capacity: an fMRI study. *NeuroImage, 18*(3), 789-797. doi:https://doi.org/10.1016/S1053-8119(02)00032-0

Oshri, A., Gray, J. C., Owens, M. M., Liu, S., Duprey, E. B., Sweet, L. H., & MacKillop, J. (2019). Adverse Childhood Experiences and Amygdalar Reduction: High-Resolution Segmentation Reveals Associations With Subnuclei and Psychiatric Outcomes. *Child maltreatment, 24*(4), 400-410. doi:10.1177/1077559519839491

Oshri, A., Hallowell, E., Liu, S., MacKillop, J., Galvan, A., Kogan, S. M., & Sweet, L. H. (2019). Socioeconomic hardship and delayed reward discounting: Associations with working memory and emotional reactivity. *Developmental Cognitive Neuroscience, 37*, 100642. doi:https://doi.org/10.1016/j.dcn.2019.100642

Owen, A. M., McMillan, K. M., Laird, A. R., & Bullmore, E. (2005). N‐back working memory paradigm: A meta‐analysis of normative functional neuroimaging studies. *Human brain mapping, 25*(1), 46-59.

Owens, M. M., Duda, B., Sweet, L. H., & MacKillop, J. (2018). Distinct functional and structural neural underpinnings of working memory. *NeuroImage, 174*, 463-471.

Owens, M. M., Hahn, S., Allgaier, N., MacKillop, J., Albaugh, M., Yuan, D., . . . Garavan, H. (2021). One-year predictions of delayed reward discounting in the adolescent brain cognitive development study. *Experimental and clinical psychopharmacology*.

Paus, T. (2005). Mapping brain maturation and cognitive development during adolescence. *Trends in Cognitive Sciences, 9*(2), 60-68.

Peeters, M., Monshouwer, K., Janssen, T., Wiers, R. W., & Vollebergh, W. A. M. (2014). Working Memory and Alcohol Use in At-Risk Adolescents: A 2-Year Follow-Up. *Alcoholism: Clinical and Experimental Research, 38*(4), 1176-1183. doi:10.1111/acer.12339

Persson, J., Nyberg, L., Lind, J., Larsson, A., Nilsson, L.-G., Ingvar, M., & Buckner, R. L. (2005). Structure–Function Correlates of Cognitive Decline in Aging. *Cerebral cortex, 16*(7), 907-915. doi:10.1093/cercor/bhj036

Philip, N. S., Sweet, L. H., Tyrka, A. R., Carpenter, S. L., Albright, S. E., Price, L. H., & Carpenter, L. L. (2016). Exposure to childhood trauma is associated with altered n-back activation and performance in healthy adults: implications for a commonly used working memory task. *Brain imaging and behavior, 10*(1), 124-135.

Philip, N. S., Sweet, L. H., Tyrka, A. R., Price, L. H., Bloom, R. F., & Carpenter, L. L. (2013). Decreased default network connectivity is associated with early life stress in medication-free healthy adults. *European Neuropsychopharmacology, 23*(1), 24-32.

Philip, N. S., Sweet, L. H., Tyrka, A. R., Price, L. H., Carpenter, L. L., Kuras, Y. I., . . . Niaura, R. S. (2013). Early life stress is associated with greater default network deactivation during working memory in healthy controls: a preliminary report. *Brain imaging and behavior, 7*(2), 204-212.

Piccoli, T., Valente, G., Linden, D. E. J., Re, M., Esposito, F., Sack, A. T., & Di Salle, F. (2015). The default mode network and the working memory network are not anti-correlated during all phases of a working memory task. *PloS one, 10*(4), e0123354-e0123354. doi:10.1371/journal.pone.0123354

Piccolo, L. R., Merz, E. C., Noble, K. G., the Pediatric Imaging, N., & Study, G. (2019). School climate is associated with cortical thickness and executive function in children and adolescents. *Developmental Science, 22*(1), e12719. doi:https://doi.org/10.1111/desc.12719

Poldrack, R. A. (2007). Region of interest analysis for fMRI. *Soc Cogn Affect Neurosci, 2*(1), 67-70. doi:10.1093/scan/nsm006

Poldrack, R. A. (2015). Is “efficiency” a useful concept in cognitive neuroscience? *Developmental Cognitive Neuroscience, 11*, 12-17. doi:https://doi.org/10.1016/j.dcn.2014.06.001

Pollak, S. D., Nelson, C. A., Schlaak, M. F., Roeber, B. J., Wewerka, S. S., Wiik, K. L., . . . Gunnar, M. R. (2010). Neurodevelopmental effects of early deprivation in postinstitutionalized children. *Child development, 81*(1), 224-236.

Power, J. D., Mitra, A., Laumann, T. O., Snyder, A. Z., Schlaggar, B. L., & Petersen, S. E. (2014). Methods to detect, characterize, and remove motion artifact in resting state fMRI. *NeuroImage, 84*, 320-341.

Qiu, F., Pi, Y., Liu, K., Zhu, H., Li, X., Zhang, J., & Wu, Y. (2019). Neural efficiency in basketball players is associated with bidirectional reductions in cortical activation and deactivation during multiple-object tracking task performance. *Biological Psychology, 144*, 28-36. doi:https://doi.org/10.1016/j.biopsycho.2019.03.008

Quevedo, K., Johnson, A. E., Loman, M. L., LaFavor, T. L., & Gunnar, M. (2012). The confluence of adverse early experience and puberty on the cortisol awakening response. *International journal of behavioral development, 36*(1), 19-28.

Raichle, M. E. (2015). The brain's default mode network. *Annual review of neuroscience, 38*, 433-447.

Raine, A., Park, S., Lencz, T., Bihrle, S., LaCasse, L., Widom, C. S., . . . Singh, M. (2001). Reduced right hemisphere activation in severely abused violent offenders during a working memory task: an fMRI study. *Aggressive Behavior: Official Journal of the International Society for Research on Aggression, 27*(2), 111-129.

Ramchandran, K., Zeien, E., & Andreasen, N. C. (2019). Distributed neural efficiency: Intelligence and age modulate adaptive allocation of resources in the brain. *Trends in Neuroscience and Education, 15*, 48-61. doi:https://doi.org/10.1016/j.tine.2019.02.006

Raver, C. C., Blair, C., Garrett-Peters, P., & Investigators, F. L. P. K. (2015). Poverty, household chaos, and interparental aggression predict children's ability to recognize and modulate negative emotions. *Development and Psychopathology, 27*(3), 695-708.

Raymond, C., Marin, M.-F., Majeur, D., & Lupien, S. (2018). Early child adversity and psychopathology in adulthood: HPA axis and cognitive dysregulations as potential mechanisms. *Progress in Neuro-Psychopharmacology and Biological Psychiatry, 85*, 152-160. doi:https://doi.org/10.1016/j.pnpbp.2017.07.015

Reilly, E. B., & Gunnar, M. R. (2019). Neglect, HPA axis reactivity, and development. *International Journal of Developmental Neuroscience, 78*, 100-108. doi:https://doi.org/10.1016/j.ijdevneu.2019.07.010

Reuter-Lorenz, P. A., & Cappell, K. A. (2008). Neurocognitive Aging and the Compensation Hypothesis. *Current Directions in Psychological Science, 17*(3), 177-182. doi:10.1111/j.1467-8721.2008.00570.x

Roff, D. A., Mostowy, S., & Fairbairn, D. J. (2002). The evolution of trade‐offs: testing predictions on response to selection and environmental variation. *Evolution, 56*(1), 84-95.

Rogers, M., Hwang, H., Toplak, M., Weiss, M., & Tannock, R. (2011). Inattention, working memory, and academic achievement in adolescents referred for attention deficit/hyperactivity disorder (ADHD). *Child Neuropsychology, 17*(5), 444-458.

Romer, D., Betancourt, L., Giannetta, J. M., Brodsky, N. L., Farah, M., & Hurt, H. (2009). Executive cognitive functions and impulsivity as correlates of risk taking and problem behavior in preadolescents. *Neuropsychologia, 47*(13), 2916-2926.

Rosenberg, M. D., Martinez, S. A., Rapuano, K. M., Conley, M. I., Cohen, A. O., Cornejo, M. D., . . . Casey, B. J. (2020). Behavioral and Neural Signatures of Working Memory in Childhood. *The Journal of Neuroscience, 40*(26), 5090. doi:10.1523/JNEUROSCI.2841-19.2020

Sameroff, A. (2009). *The transactional model*: American Psychological Association.

Schäfer, J. L., McLaughlin, K. A., Manfro, G. G., Pan, P., Rohde, L. A., Miguel, E. C., . . . Salum, G. A.

(2022). Threat and deprivation are associated with distinct aspects of cognition, emotional processing and psychopathology in children and adolescents. *Developmental Science*.

Schneider, F., Bermpohl, F., Heinzel, A., Rotte, M., Walter, M., Tempelmann, C., . . . Northoff, G. (2008). The resting brain and our self: self-relatedness modulates resting state neural activity in cortical midline structures. *Neuroscience, 157*(1), 120-131.

Sedmak, D., Hrvoj-Mihić, B., Džaja, D., Habek, N., BM Uylings, H., & Petanjek, Z. (2018). Biphasic dendritic growth of dorsolateral prefrontal cortex associative neurons and early cognitive development. *Croatian medical journal, 59*(5), 189-202.

Sheridan, M. A., Fox, N. A., Zeanah, C. H., McLaughlin, K. A., & Nelson, C. A. (2012). Variation in neural development as a result of exposure to institutionalization early in childhood. *Proceedings of the National Academy of Sciences, 109*(32), 12927-12932.

Sheridan, M. A., & McLaughlin, K. A. (2014). Dimensions of early experience and neural development: deprivation and threat. *Trends in Cognitive Sciences, 18*(11), 580-585. doi:https://doi.org/10.1016/j.tics.2014.09.001

Sheridan, M. A., & McLaughlin, K. A. (2022). Introduction to the special issue on childhood adversity and neurodevelopment. *Developmental Cognitive Neuroscience, 54*, 101082. doi:https://doi.org/10.1016/j.dcn.2022.101082

Sheridan, M. A., Peverill, M., Finn, A. S., & McLaughlin, K. A. (2017). Dimensions of childhood adversity have distinct associations with neural systems underlying executive functioning. *Development and Psychopathology, 29*(5), 1777-1794.

Siegel, J. S., Power, J. D., Dubis, J. W., Vogel, A. C., Church, J. A., Schlaggar, B. L., & Petersen, S. E. (2014). Statistical improvements in functional magnetic resonance imaging analyses produced by censoring high‐motion data points. *Human brain mapping, 35*(5), 1981-1996.

Smith, S. M., Jenkinson, M., Woolrich, M. W., Beckmann, C. F., Behrens, T. E., Johansen-Berg, H., . . . Flitney, D. E. (2004). Advances in functional and structural MR image analysis and implementation as FSL. *NeuroImage, 23*, S208-S219.

Spear, L. P. (2013). Adolescent neurodevelopment. *The Journal of adolescent health : official publication of the Society for Adolescent Medicine, 52*(2 Suppl 2), S7-S13. doi:10.1016/j.jadohealth.2012.05.006

Sripada, R. K., Swain, J. E., Evans, G. W., Welsh, R. C., & Liberzon, I. (2014). Childhood Poverty and Stress Reactivity Are Associated with Aberrant Functional Connectivity in Default Mode Network. *Neuropsychopharmacology, 39*(9), 2244-2251. doi:10.1038/npp.2014.75

Stearns, S. C. (1992). *The evolution of life histories*.

Stern, Y. (2009). Cognitive reserve. *Neuropsychologia, 47*(10), 2015-2028.

Sturge-Apple, M. L., Davies, P. T., Cicchetti, D., Hentges, R. F., & Coe, J. L. (2017). Family instability and children's effortful control in the context of poverty: Sometimes a bird in the hand is worth two in the bush. *Development and Psychopathology, 29*(3), 685-696. doi:10.1017/S0954579416000407

Suor, J. H., Sturge-Apple, M. L., Davies, P. T., Cicchetti, D., & Manning, L. G. (2015). Tracing Differential Pathways of Risk: Associations Among Family Adversity, Cortisol, and Cognitive Functioning in Childhood. *Child development, 86*(4), 1142-1158. doi:https://doi.org/10.1111/cdev.12376

Sweet, L. H., Paskavitz, J. F., Haley, A. P., Gunstad, J. J., Mulligan, R. C., Nyalakanti, P. K., & Cohen, R. A. (2008). Imaging phonological similarity effects on verbal working memory. *Neuropsychologia, 46*(4), 1114-1123.

Sweet, L. H., Rao, S. M., Primeau, M., Durgerian, S., & Cohen, R. A. (2006). Functional magnetic resonance imaging response to increased verbal working memory demands among patients with multiple sclerosis. *Human brain mapping, 27*(1), 28-36.

Thompson, W. K., Barch, D. M., Bjork, J. M., Gonzalez, R., Nagel, B. J., Nixon, S. J., & Luciana, M. (2019). The structure of cognition in 9 and 10 year-old children and associations with problem behaviors: Findings from the ABCD study’s baseline neurocognitive battery. *Developmental*

Cognitive Neuroscience, 36, 100606.

Tibu, F., Sheridan, M. A., McLaughlin, K. A., Nelson, C., Fox, N., & Zeanah, C. (2016). Disruptions of working memory and inhibition mediate the association between exposure to institutionalization and symptoms of attention deficit hyperactivity disorder. *Psychological medicine, 46*(3), 529-541.

Tierney, A. L., & Nelson, C. A., 3rd. (2009). Brain Development and the Role of Experience in the Early Years. *Zero to three, 30*(2), 9-13. Retrieved from https://pubmed.ncbi.nlm.nih.gov/23894221

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3722610/

Tomoda, A., Suzuki, H., Rabi, K., Sheu, Y.-S., Polcari, A., & Teicher, M. H. (2009). Reduced prefrontal cortical gray matter volume in young adults exposed to harsh corporal punishment. *NeuroImage, 47*, T66-T71. doi:https://doi.org/10.1016/j.neuroimage.2009.03.005

Tran, N. K., Van Berkel, S. R., van Ijzendoorn, M. H., & Alink, L. R. A. (2017). The association between child maltreatment and emotional, cognitive, and physical health functioning in Vietnam. *BMC Public Health, 17*(1), 332. doi:10.1186/s12889-017-4258-z

Treat, A. E., Sheffield Morris, A., Williamson, A. C., Hays-Grudo, J., & Laurin, D. (2019). Adverse childhood experiences, parenting, and child executive function. *Early Child Development and Care, 189*(6), 926-937.

Tsuchida, A., & Fellows, L. K. (2009). Lesion evidence that two distinct regions within prefrontal cortex are critical for n-back performance in humans. *Journal of Cognitive Neuroscience, 21*(12), 2263-2275.

Tulsky, D. S., Carlozzi, N., Chiaravalloti, N. D., Beaumont, J. L., Kisala, P. A., Mungas, D., . . . Gershon, R. (2014). NIH Toolbox Cognition Battery (NIHTB-CB): list sorting test to measure working memory. *Journal of the International Neuropsychological Society, 20*(6), 599-610.

Uddin, L. Q., Kinnison, J., Pessoa, L., & Anderson, M. L. (2014). Beyond the tripartite cognition–emotion–interoception model of the human insular cortex. *Journal of Cognitive Neuroscience, 26*(1), 16-27.

Uddin, L. Q., Nomi, J. S., Hébert-Seropian, B., Ghaziri, J., & Boucher, O. (2017). Structure and Function of the Human Insula. *Journal of clinical neurophysiology : official publication of the American Electroencephalographic Society, 34*(4), 300-306. doi:10.1097/WNP.0000000000000377

Ullman, H., Almeida, R., & Klingberg, T. (2014). Structural Maturation and Brain Activity Predict Future Working Memory Capacity during Childhood Development. *The Journal of Neuroscience, 34*(5), 1592. doi:10.1523/JNEUROSCI.0842-13.2014

Uno, H., Eisele, S., Sakai, A., Shelton, S., Baker, E., DeJesus, O., & Holden, J. (1994). Neurotoxicity of glucocorticoids in the primate brain. *Hormones and behavior, 28*(4), 336-348.

Varangis, E., Habeck, C. G., Razlighi, Q. R., & Stern, Y. (2019). The Effect of Aging on Resting State Connectivity of Predefined Networks in the Brain. *Frontiers in aging neuroscience, 11*. doi:10.3389/fnagi.2019.00234

Vogel, S. C., Perry, R. E., Brandes-Aitken, A., Braren, S., & Blair, C. (2021). Deprivation and threat as developmental mediators in the relation between early life socioeconomic status and executive functioning outcomes in early childhood. *Developmental Cognitive Neuroscience, 47*, 100907. doi:https://doi.org/10.1016/j.dcn.2020.100907

Wade, M., Prime, H., Jenkins, J. M., Yeates, K. O., Williams, T., & Lee, K. (2018). On the relation between theory of mind and executive functioning: A developmental cognitive neuroscience perspective. *Psychonomic Bulletin & Review, 25*(6), 2119-2140. doi:10.3758/s13423-018-1459-0

Wang, X., Wu, Q., Egan, L., Gu, X., Liu, P., Gu, H., . . . Fan, J. (2019). Anterior insular cortex plays a critical role in interoceptive attention. *eLife, 8*, e42265. doi:10.7554/eLife.42265

Wei, T., Simko, V., & Levy, M. (2021). package “corrplot”: Visualization of a Correlation Matrix. 2017. *Version 0.84*.

Wells III, W. M., Viola, P., Atsumi, H., Nakajima, S., & Kikinis, R. (1996). Multi-modal volume registration by maximization of mutual information. *Medical image analysis, 1*(1), 35-51.

Wesarg, C., Van Den Akker, A. L., Oei, N. Y. L., Hoeve, M., & Wiers, R. W. (2020). Identifying pathways from early adversity to psychopathology: A review on dysregulated HPA axis functioning and impaired self-regulation in early childhood. *European Journal of Developmental Psychology, 17*(6), 808-827. doi:10.1080/17405629.2020.1748594

Wingo, A. P., Fani, N., Bradley, B., & Ressler, K. J. (2010). Psychological resilience and neurocognitive performance in a traumatized community sample. *Depression and anxiety, 27*(8), 768-774.

Wolf, S., & Morrissey, T. (2017). Economic instability, food insecurity, and child health in the wake of the Great Recession. *Social Service Review, 91*(3), 534-570.

Wu, L., Zhang, X., Wang, J., Sun, J., Mao, F., Han, J., & Cao, F. (2021). The associations of executive functions with resilience in early adulthood: A prospective longitudinal study. *Journal of Affective Disorders, 282*, 1048-1054. doi:https://doi.org/10.1016/j.jad.2021.01.031

Wu, M., Wang, Z., Cao, C., & He, Q. (2021). Family Socioeconomic Status and Executive Function in Urban Chinese Children: The Effects of Cortisol Reactivity. *Journal of Child and Family Studies, 30*(11), 2616-2626.

Xu, Z., Adam, K., Fang, X., & Vogel, E. (2018). The reliability and stability of visual working memory capacity. *Behavior Research Methods, 50*(2), 576-588.

Yaple, Z., & Arsalidou, M. (2018). N-back Working Memory Task: Meta-analysis of Normative fMRI Studies With Children. *Child development, 89*(6), 2010-2022. doi:https://doi.org/10.1111/cdev.13080

Yaple, Z., Stevens, W. D., & Arsalidou, M. (2019). Meta-analyses of the n-back working memory task: fMRI evidence of age-related changes in prefrontal cortex involvement across the adult lifespan. *NeuroImage, 196*, 16-31. doi:https://doi.org/10.1016/j.neuroimage.2019.03.074

Yuan, K.-H., & Bentler, P. M. (2000). 5. Three Likelihood-Based Methods for Mean and Covariance Structure Analysis with Nonnormal Missing Data. *30*(1), 165-200. doi:10.1111/0081-1750.00078

Zanto, T. P., & Gazzaley, A. (2013). Fronto-parietal network: flexible hub of cognitive control. *Trends in Cognitive Sciences, 17*(12), 602-603. doi:10.1016/j.tics.2013.10.001

Zarahn, E., Rakitin, B., Abela, D., Flynn, J., & Stern, Y. (2007). Age-related changes in brain activation during a delayed item recognition task. *Neurobiology of Aging, 28*(5), 784-798.

doi:https://doi.org/10.1016/j.neurobiolaging.2006.03.002

Zeev-Wolf, M., Levy, J., Goldstein, A., Zagoory-Sharon, O., & Feldman, R. (2019). Chronic Early Stress Impairs Default Mode Network Connectivity in Preadolescents and Their Mothers. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging, 4*(1), 72-80. doi:https://doi.org/10.1016/j.bpsc.2018.09.009

Zelazo, P. D. (2020). Executive function and psychopathology: a neurodevelopmental perspective. *Annual Review of Clinical Psychology, 16*, 431-454.

Zhang, G., Yao, L., Zhang, H., Long, Z., & Zhao, X. (2013). Improved working memory performance through self-regulation of dorsal lateral prefrontal cortex activation using real-time fMRI. *PloS one, 8*(8), e73735-e73735. doi:10.1371/journal.pone.0073735

Zhang, J., Zhao, T., Zhang, J., Zhang, Z., Li, H., Cheng, B., . . . Wang, J. (2022). Prediction of childhood maltreatment and subtypes with personalized functional connectome of large‐scale brain networks. *Human brain mapping*.

Zhang, L., Cui, Z., Sasser, J., Carvalho, C., & Oshri, A. (2022). Family stress during the pandemic worsens the effect of adverse parenting on adolescent sleep quality. *Child Abuse & Neglect, 123*, 105390.

Zhao, H., Dong, D., Sun, X., Cheng, C., Xiong, G., Wang, X., & Yao, S. (2021). Intrinsic brain network alterations in non-clinical adults with a history of childhood trauma. *European Journal of Psychotraumatology, 12*(1), 1975951. doi:10.1080/20008198.2021.1975951

Zhou, Y., Yu, N. X., Dong, P., & Zhang, Q. (2022). Stressful life events and children’s socioemotional difficulties: Conditional indirect effects of resilience and executive function. *Journal of Experimental Child Psychology, 216*, 105345.