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The Impact of Diet Quality on Structural Neurodevelopment in Children: an MRI Study

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ABSTRACT

Magnetic resonance imaging (MRI) was used to investigate the effects of dietary quality on structural neurodevelopment in middle childhood. Poor dietary quality has been a consistent issue across the United States, with most children not receiving sufficient nutrition to optimize brain development. Inadequate nutrition leads to structural and functional impairments in neurodevelopment (Mout et al., 2023), especially in those parts of the brain dealing with decision-making, executive function and cognitive control, as well as reward and motivation. Dysregulation of these key brain regions may be implicated in the development of risky behavior such as substance use disorders (SUDs) (Jakubiec et al., 2022). While there is a broad spectrum of research investigating the effects of poor dietary quality on structural neurodevelopment, there is little research exploring the unique role of poor dietary quality in comparison to more general SES-related impacts on SUD risk. Furthermore, it is still largely unknown which structural neurodevelopmental changes could underlie an association between poor dietary quality and the development of SUD in low SES individuals. This study is aimed to fill this gap and aid in understanding whether the kinds of structural brain changes already associated with poor nutrition, might constitute a risk factor for later SUD. Results revealed that there was a significant positive association between brain volume, particularly in the dorsal striatum, and dietary quality (left striatum: $T(27) = 5.08$, p (uncorrected) < 0.001; right striatum: $T(27) = 4.53$, p (uncorrected) < 0.01) as measured by the Dietary Guideline Index for Children and Adolescents (DGI-CA). There were no significant correlations between brain volume and cognitive performance as measured by IQ, impulse control, or attention. These findings indicate those with poorer dietary quality may have decreased executive control and are possibly more at

risk for developing a future SUD. However, there remains a need for further study using larger samples with a wider range of dietary quality and exploring whether during at-rest or goal-oriented tasks, the brain's networks are engaged in the same way irrespective of dietary quality.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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Chapter 1

Introduction

The importance of good nutrition for healthy development

Adequate nutrition is essential across development, but especially for children experiencing critical neurodevelopmental milestones. Childhood is a significant period for neurodevelopmental change (Luna & Sweeney, 2001), thus, adequate nutrition to support optimal brain development in childhood is imperative. The developing brain requires a balance of the essential food groups to function. In other words, children should be on a diet of equal amounts of protein, fat, dairy, fruits, vegetables, sugar, and grains. With poor dietary quality comes a myriad of negative cognitive outcomes that can last a lifetime.

Research has shown that deficits in certain nutrients during childhood are associated with poor performance on tests of motor development, inadequate social skills, and attention and learning difficulties (DiGirolamo & O'Keefe, 2020). Furthermore, studies indicate that early nutritional insults during childhood have a significant effect on both neural cell growth and the number of cells (Winick & Rosso, 1969). For example, the formation of new synapses allows one neuron to pass a signal to another and depends on the dietary intake of fatty acids (DiNicolantonio & O'Keefe, 2020). Even in utero, if a mother's diet consists of too few carbohydrates, the child is born with reduced brain development – both physically in size and functionally in terms of glial cell formation – and a growth restriction that manifests as an array of other health concerns down the line (Hardy et al., 2022). During childhood, particularly in middle childhood (7-11 years old), children begin to think more concretely and logically, which set the foundation for the development of crucial abstract cognitive abilities such as reasoning, planning, and application of knowledge. Without adequate nutrition, the development of these reasoning skills may be impaired.

Who is most at risk for poor nutrition and why?

Certain populations of children suffer more than others from poor nutrition. Unfortunately, millions of American families are at, or below, the poverty line and, as a result, are not able to provide the necessary dietary nutrients their children require for adaptive brain development. Worldwide, 650 million families are impoverished (i.e., deficient in or deprived of certain qualities needed to maintain a basic standard of living which allows the people concerned to enjoy the basic amenities of life) or come from a background of low socioeconomic status (SES) (low educational achievement and/or low household income) (Company-Córdoba et al., 2021). Low SES is closely related to poor health, lower academic achievement, and poverty. Inequalities in health distribution, including access to nutritious food, is becoming a bigger issue both in the United States and globally, resulting in a lower quality of life for those impacted (American Psychological Association, 2024). Investigating the disparities in SES allow us to understand some of the social inequalities in health, especially through dietary quality. In general, individuals with low SES tend to inconsistently follow dietary guidelines and are not able to afford high quality, nutritious food (Alkerwi et al., 2015). Therefore, children from low SES families are more at risk than children from high SES families of suffering some of the cognitive impacts of poor nutrition previously mentioned. However, high SES is no protection against poor nutrition due to the plethora of highly processed foods available to high SES families (Marchese et al., 2022).

Strong correlations have been found between the level of SES and cognitive ability in childhood (Kishiyama et al., 2008). Children who are from lower SES backgrounds tend to perform worse than children from higher SES backgrounds on various cognitive assessments including academic achievement, intelligence, and language proficiency (Kishiyama et al., 2008; Bradley & Corwyn, 2002). Low SES has been associated with poor cognitive, emotional, and physical development (Hackman & Farah, 2009). Therefore, it is important to assist children who come from low SES communities to enhance their cognitive functioning. To do this, we must discern the mechanisms that underlie the association between poor nutrition and its related outcomes, through understanding the impact of nutrition on brain structure, and to a lesser extent, function.

The general impacts of poor nutrition on brain structure and function

As already mentioned, the brain is extremely vulnerable to poor nutrition during childhood. This ongoing period of growth entails structural and functional brain plasticity (Mou et al., 2023). Because children are developing critical reasoning and executive functioning skills, particularly during middle childhood, providing a developing child with nutritious food is extremely important. A deficit in fatty acids in a child's diet can create insufficient neuronal connections in multiple brain networks, including the default mode network (DMN), salience network (SN), and executive control network (ECN) (Georgieff, 2007). Importantly, these altered connections lead to long term consequences for the child's overall executive control capabilities. Furthermore, impaired connectivity between the SN and DMN has been significantly associated with poorer executive control and is seen mostly in individuals experiencing food insecurity or poor dietary quality (Guerithault et al., 2022). Decreased executive control can in later life be linked to increased susceptibility of risky behavior like substance use. Identifying inadequate nutrition and poor dietary quality in middle childhood assists researchers in detecting high risk behaviors in adolescents and adults, culminating in substance use disorders (SUDs).

Why structural MRI data is so important

Structural brain data, specifically through structural magnetic resonance imaging (MRI), is helpful for volumetric analyses. The volumetric analyses can include voxel based morphometry, cortical thickness, surface area, and subcortical volume. In other words, structural scans provide spatial visualizations and analysis of anatomical regions of the brain. This is especially useful in the current study in terms of visualizing any anatomical differences in the brains of children with varying dietary qualities.

In fact, structural MRI studies suggest that adequate levels of whole grains, soft fat – unsaturated fat commonly found in avocado, nuts, and seeds – and dairy are linked to larger brain volume compared to children who consume lower levels of these vital food groups (Mou et al., 2023). Additionally, lower dietary quality is linked to smaller hippocampal and amygdala volumes (Mout et al., 2023). Decreased hippocampal and amygdala volumes are associated with vulnerability to stressful life events and a reduced ability to normally process emotions like fear and anger (Weismann et al., 2020). Neuroimaging studies have also identified links between IQ and higher brain volumetric measures in children through structural MRI (Pietschnig et al., 2015). Taken together, the importance of good dietary quality for appropriate structural brain development cannot be disputed.

Why functional data can be useful

Resting state fMRI includes gathering functional imaging data while participants fixate their gaze on a cross and do not engage in any other goal-directed task. This technique analyzes fluctuations in blood oxygenation level dependent (BOLD) signals to locate brain networks like the DMN, SN, and ECN, which are so heavily impacted by poor nutrition. Fluctuations in BOLD signals help with understanding the organization and coordination of functional brain networks (Raichle, 2010). These scans can be used to interpret further investigations of the functional connectivity that spans the whole brain (Uddin et al., 2010) and are helpful in studying age-related changes in neural systems.

Importantly, studies based upon the use of MRI has demonstrated that brain systems related to language and executive functioning show the greatest anatomical and functional differences between low and high SES children (Company-Córdoba et al., 2021; Farah et al., 2006). These findings may point to decreased executive control in children with low dietary quality from low SES families, which may be linked to increased susceptibility of SUDs in the future as adolescents or adults. The nutritional insults seen in children along with the increased predisposition to SUDs may be predicted through targeted structural and resting state functional analysis. For the purposes of this study, there will be more of a focus on the structural rather than functional analysis.

How are these structural and functional impacts relevant for the emergence of SUDs?

Deficits in executive control are a precursor to and an outcome of developing an SUD (Jakubiec et al., 2022). Executive control relates to reasoning, planning, memory, self-monitoring, self-regulation, and cognitive flexibility (Company-Córdoba et al., 2021). Deficits in these functions have been extensively studied in those with SUDs (Domínguez-Salas et al., 2016). People with SUDs tend to exhibit poor executive regulation and cognitive control. This loss of control can result in repetitive relapse and compulsive use to maintain daily life (Jakubiec et al., 2022); in other words, there is a reduced ability to override goals in order to regulate cognition and actions (Shenav et al., 2017; Botvinick and Braver, 2015). As mentioned, it has been found that adequate nutrition during childhood promotes appropriate development in those parts of the brain that support cognitive control (Riggs et al., 2010). That is, poor nutrition may result in a decrease in behavioral control and possible susceptibility to SUDs in the future.

Furthermore, not only children but also adults with inadequate dietary quality display poor executive functioning (Guerithault et al., 2022). Structural MRI data has been helpful in examining not only the impact of poor nutrition but also the emergence of SUDs in adults, particularly in nicotine addiction and gambling disorders. Adults with SUDs are shown to have reduced grey matter volume of the ventral striatum, amygdala, and posterior insula (Wadsley & Ihssen, 2023), which play a role in decision making and reward seeking. Studies have reported volumetric changes in white matter in the anterior cingulate cortex, insula, and thalamus (Murnane et al., 2023), as measured by structural MRI. Specifically, SUDs involving alcohol, cocaine, nicotine, opioids, methamphetamines, and cannabis lead to decrease grey and white matter volume in the thalamus, an area important for emotional homeostasis, wakefulness, memory, and sleep. Reduced volume in these areas of the brain associated with behavioral regulation is highly correlated with more severe SUDs (Murnane et al., 2023).

As seen in those with poor dietary quality, SUD can lead to impairments in the functioning of the DMN, SN, and ECN, which in turn are potential predictive biomarkers of SUD (Jakubiec et al., 2022; Tolomeo & Yu, 2022). The posterior cingulate cortex (PCC) and medial prefronal cortex (mPFC) are within the DMN and are involved in self-reflection and self-confidence. In those with severe gambling addictions, there is decreased and dysregulated activation in the PCC and mPFC as shown by resting state scans (Jung et al., 2014). Additionally, those with an SUD tend to exhibit hyperconnectivity in the basal ganglia, amygdala, insula, and paraphippocampal gyrus (Tolomeo & Yu, 2022), areas which regulate emotion, memory, and executive control and are part of the reward network and SN. Consequently, altered connectivity is related to dysregulation in cognitive control networks such as the DMN, SN, and ECN, and creates heightened sensitivity to drugs and drug-related cues (Tolomeo & Yu, 2022).

By understanding the structural brain-related changes that occur in adults with poor nutrition and already developed SUDs, we can evaluate in poorly nourished children the neurological biomarkers that may be predictive of heightened susceptibility to risky behavior. These findings may point to impaired brain structure and hence decreased executive control in children with poor dietary quality, which may be linked to increased risk of developing SUDs in the future. Along with the nutritional insults seen in children, the increased predisposition to SUD may be predicted through targeted structural analysis.

Developing this foundation can allow for specific and effective prevention methods to be implemented to reduce the likelihood of a child from a low SES community developing an SUD in the future.

The importance of targeted prevention prior to the onset of high risk behavior

Prevention of cognitive and behavioral disorders associated with poor dietary quality can be achieved with early interventions. Understanding the relationship between poor dietary quality and increased risky behavior, due to structural impairments in the areas of the brain associated with executive control and reward seeking, prior to the onset of the high-risk behaviors, is critical for developing potential preventative methods. Such prevention methods would need to target adaptable mechanisms of risk, such as poor dietary quality. Ultimately, identifying novel risk factors of SUD, such as structural neurodevelopmental changes due to poor nutrition may hold potential for more effective substance use prevention in at-risk communities.

There is currently little empirical research exploring the unique role of poor dietary quality in comparison to more general SES-related impacts on SUD risk or the structural neurodevelopmental changes that could underlie an association between poor dietary quality and the development of SUD in low SES communities. This study is aims to fill this gap and aid in understanding whether the kinds of structural brain changes already associated with poor nutrition, might constitute a risk factor for later SUD. Substance use is a developmental disorder because neurobiologically speaking, it has its origins in childhood and adolescent contexts of adversities (Cicchetti & Handley, 2019; Joutsa et al., 2022), some of which may include nutrition as a significant factor of psychosocial adversity.

Aims for the current study

1. To ascertain how the association between dietary quality and brain structure in SUD-relevant brain areas predicts cognitive performance through:
    a. IQ
    b. Impulse control
    c. Attention
2. To determine whether the quality of children's diets in middle childhood (7-11 years) predicts structural variability in brain areas that are implicated in the development of SUD

Hypotheses

1. Dietary quality index scores will be correlated with brain structure in brain areas that are implicated in high-risk outcomes, such as SUD, including areas associated with:
    a. Decision-making (e.g. mPFC and hippocampus)
    b. Executive function and cognitive control (e.g. anterior cingulate cortex and dorsolateral prefrontal cortex)
    c. Reward and motivation (e.g. striatum (i.e., nucleus accumbens, caudate, and putamen) and insula)
2. Dietary quality will correlate with cognitive functioning as measured by IQ, impulse control, and attention

Chapter 2

Methods

Participants

Participants in this study were children between the ages of 7 – 11 years (N=30; 43.33% female; mean age = 9.79 years (SD = 1.30)) who together with their parent or legal guardian participated in the *Hungry Brain Study* at Penn State. All participants were residents of Center County, Pennsylvania or from the surroundings areas. The subsample of participants included in the current analysis was selected based on the quality of their structural MRI scans. The quality of the scans was based on a quality control (QC) value that is calculated based on the presence of any artifacts in the scans (see details under MRI Data Preprocessing).

Recruitment

Recruitment efforts included multiple approaches. Flyers describing the study were distributed at family-oriented community events (e.g., popular seasonal and holiday-related events which tend to attract families with children in the intended age group). Since a focus of the parent study is the impact of food insecurity on brain development, the study team also circulated flyers at local food distribution points including churches, YMCA centers, and malls. Furthermore, flyers were distributed to children in the target age-range attending a selection of local elementary schools and advertisements were posted in local parents' groups for the study on social media sites such as Facebook. Additionally, parents of children who participated in the study were asked to pass on study flyers to other friends and families whom they believed would be interested in participating. Finally, recruitment efforts included contacting families through the First Families database, which is a database of contact information for families who have expressed interest in participating in Penn State research and is managed by the Child Study

Center. As part of each of the recruitment effort, parents who expressed interest in participating in the study were given a brief description of the purpose of the study, along with the approach and the basic characteristics of the families eligible for recruitment. To reduce the stigma surrounding low socioeconomic status (SES), study team members emphasized the focus on how food and hunger effects brain processes related to reward rather than on issues of how SES might relate to study outcomes (e.g., measures of brain structure and function).

Screening

Screening of interested families involved the completion of a screening phone call with a research assistant from the study. This process included gathering contact information, general demographic details, and confirmation of inclusion and exclusion criteria. Verbal consent to gathering the necessary information to determine inclusion/exclusion criteria was obtained before the screening was carried out. This process allowed the study team to determine whether the study procedures would be safe and appropriate for the family.

The screening process determined a participant's eligibility for MRI, based on both safety and scientific criteria (including history of serious head injury, prior substance use, current or prior neurological or psychiatric conditions, major medical illnesses, the presence of any implanted metallic or electronic devices, or metal objects that could present a safety hazard in the scanner), and completion of the following measures:

(1) Food insecurity was assessed using the *Household Food Security Survey Model (HFSSM)*- 6 item version. This is a standard USDA food insecurity measure (Coleman-Jensen et al., 2018) that allows the researchers to determine the level of food security.

(2) SES was evaluated on a nine-point index in which scores for parental education (range: 0 (less than high-school) – 3 (Masters or Doctoral degree), family annual income (% of

federal poverty line; range: 0 (100% or less) – 3 (>401%), employment (past 6 months; 0 (unemployed) or 1 (employed), and housing (0 (rent) or 1 (own)) (Berzofsky et al., 2014) were summed. It was important to have a representative spread of SES throughout our sample without only individuals with either very high or very low SES. The inclusion of sufficient low SES participants was needed because low SES predicts neurodevelopmental trajectories that indicate increased risky decision-making due to alterations in brain structure in regions associated with SUD.

(3) Pubertal development was assessed using the *Tanner Stage Sexual Maturity Rating* (Marshall & Tanner, 1969). Since puberty influences the development of reward network areas in the brain (a key outcome for the parent study) it was deemed important to focus recruitment on children who were pre-pubertal during screening to minimize the impact of these developmentally-related changes in brain structure and function on the study outcomes. Children with a Tanner score of 3 or greater are at a more advanced stage of pubertal development. Children in this range were excluded from the study.

Eligible participants were between 7 and 11 years of age, had no metal in their body, were not claustrophobic, and had no other medical conditions that presented a safety hazard in the scanner. Ineligible participants met one or more of the following exclusion criteria:

(1) Prior drug or alcohol use: As the study is focused on the impact of food insecurity on neurodevelopment in children before the onset of drug and alcohol use, children who have already used drugs or alcohol were excluded.

(2) Tanner stage 3 or greater: As described above.

(3) Age < 7 years: Imaging studies with young children can be impacted by logistical issues related to imaging, such as reduced compliance with study procedures and

greater levels of head motion. To minimize data loss due to attrition or quality concerns, no individual under age 7 was recruited for participation.

(4) Cognitive impairment: Individuals, including parents and children, who are cognitively impaired to the extent that they cannot give consent or assent or provide accurate self-reports were excluded. Inability to give informed consent or assent cannot be ethically justified and would pose an unnecessary risk for the participants.

(5) HIV positive status: HIV status is an exclusion criteria due to its potential impact on MRI outcome variables. Participants were not tested for HIV infection, although parents and children were asked to provide information regarding general and relevant medical history prior to scanning. Endorsing positive HIV status would be exclusionary.

(6) Contraindications for MRI: Participants were excluded for any condition that was contraindicated for MRI, including the following:

   a. History of serious head injury

   b. Current or prior neurological conditions (e.g. migraine, multiple sclerosis, movement disorders, seizure disorders, CNS tumors)

   c. Current or prior psychiatric or neurodevelopmental conditions (e.g. intellectual disability, autism spectrum disorder)

   d. Major medical conditions that may affect central nervous system function (e.g. clinically significant arrhythmia, cardiovascular disease, uncontrolled asthma, diabetes, peripheral vascular disease, superficial or deep vein thrombosis, or HIV)

   e. Being unable to undergo MRI due to metallic devices that are in (e.g. cardiac pacemaker, neurostimulator, metal pins or clips) or on (e.g. certain types of non-removable orthodontic devices or piercings that cannot be removed) the body

(7) A history of food allergies that would mean that the child would be at risk of adverse reactions due to study procedures (e.g. an allergy to specific ingredients in the candy rewards or food items that were offered to children during their participation)

All psychiatric, neurological, and medical histories were based on parental report and did not include any diagnostic testing or access to participant medical records. The above-mentioned exclusion criteria resulted in (N=13) exclusions.

Procedures

The study (approved by the Penn State Institutional Review Board) involved two sessions (FED and FASTED; see details below) and all study sessions took place in the Chandlee Laboratory on Penn State's University Park Campus. The Hungry Brain Study is primarily focused on how acute hunger impacts brain function in children who are food insecure as compared to their food secure peers.

In the FED session participants were given breakfast prior to beginning the other study imaging procedures. In the FASTED condition, they underwent scanning and then received breakfast. The first session was randomized and counter-balanced across participants. Each session lasted about 3.5-4 hours in total, and the sessions were scheduled at least one week apart. Participants were compensated for their time and effort and reimbursed for travel to the lab.

The study covered a broad range of measures, however, only those measures included in the current analyses are described here.

(1) Consent and Assent: Written informed consent was obtained from parents, and included a ten-question consent quiz to confirm understanding of study procedures. If

the parent scored 80% or above, then they proceeded to sign the consent form. If they scored less than 80%, the questions were reviewed and the test was repeated until a score of at least 80% was obtained. Failure to obtain at least 80% on the 2nd attempt resulted in exclusion, however, this never occurred. Assent was obtained from the child by describing the study procedures using age-appropriate language for the child to understand. This was followed by a similar ten-question assent quiz. The same rules applied to the scores of the quiz and processes with assent. Even if the parent consented, we did not include any family where the child could not, or would not, provide assent. However, all children gave assent to participate.

(2) Breakfast: Following consent and assent, the child completed a form indicating their choices for the breakfast meal. Standard breakfast items were offered, such as cereals, yoghurts, granola bars, fruit cups, and toast. In order to estimate for total energy consumption, the items selected and proportion consumed were noted. If the session was a FED session, breakfast was consumed before proceeding with other study procedures; for FASTED sessions, breakfast was consumed after the end of the brain imaging procedures.

(3) Mock Scanning: The child was familiarized with the reward task and MRI by completing a mock session before entering the real MRI. First, the task was explained to the child during a bench practice, in which the child sat next to a research associate and practiced one version of the task using the game controllers. Once the child was comfortable with the task, they were invited to lie inside the “mock scanner”, which is like the real MRI but with no magnet or radiofrequency pulses. While inside the mock scanner, the child practiced the task again using the same controllers. Various scanner noises were also played to the child, to get them familiar with the sounds they

would be hearing in the real scanner. Once comfortable with the task, the scanner, and the scanner noises, the child could enter the MRI facility to complete the "real" assessment.

(4) MRI: Prior to entering the MRI facility, parents were instructed to complete the necessary MRI safety forms for both themselves (in the case of an emergency where they would need to enter the MRI room) and their child. The form details any potential safety-related contraindications for MRI. These include any history of serious head injury, details of current or prior neurological or psychiatric conditions, major medical illnesses that affect central nervous system functioning, or the presence of any implanted metallic or electronic devices or other metal objects that could present a safety hazard in the scanner. This form was reviewed by the MRI technologist before the child was allowed in the scanner. No individual could enter the scanner room without completion of the form. Each scanning session lasted approximately 45 minutes. Because of the long scanning time, the research assistant running the session frequently checked on the participant in between scans to ensure comfort and understanding of what was required. A Siemens 3T Magnetom Prisma Fit scanner was used with a 64-channel head coil. A variety of scans were completed during the session; however, this analysis will focus on the high-resolution 3D T1 MPRAGE scan with the following parameters: TR(ms)=2300; TE(ms)=2.98; TI(ms)=900; No. of slices/slice thickness(mm)=176/1; Effective resolution=1mm3; FoV=256 x 256; Flip angle=9˚; Matrix=256 x 256; GRAPPA acceleration factor/No. phase encoding line=2/32. This T1 scan was needed for volumetric analyses including voxel based morphometry analysis in CAT12. Spatial registration of functional imaging data can also be accomplished, however, in the current study, only structural

images were processed. Below is an example of the T1 structural imaging data that was acquired from participants and used for imaging analysis.

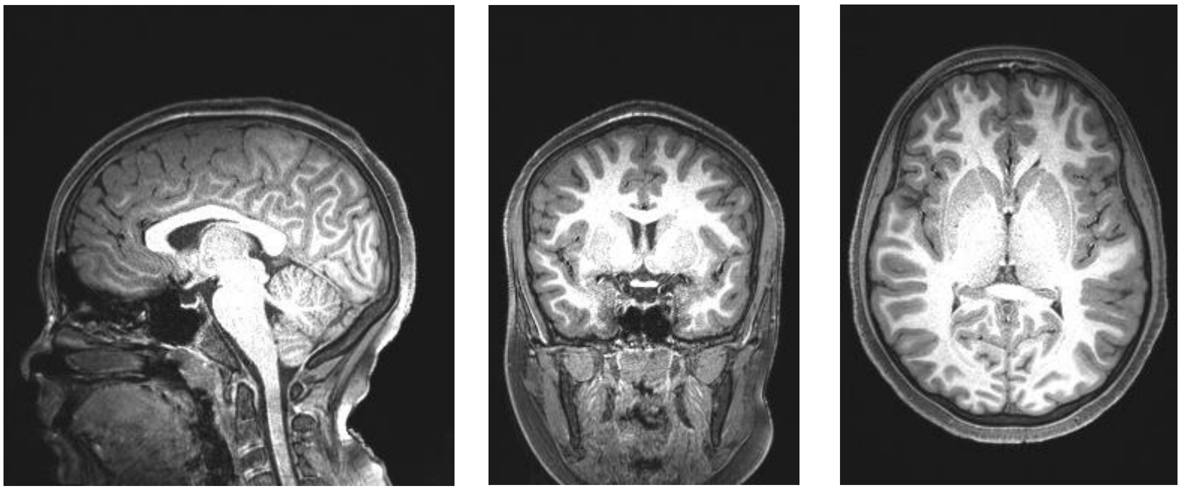

Figure 1: An example of T1 structural imaging data used in the imaging analysis. The images are presented in order from left to right: sagittal, coronal, and axial. The orientation of the sagittal image is to the left which is the participant's left.

In addition to the T1 scan, a number of other scans were completed. Field maps were used to correct for any inhomogeneity to reduce image distortion and potential blurring. Resting state fMRI allowed for analysis of fluctuations in BOLD signals to locate and understand the organization and coordination of functional brain networks. Participants also underwent functional brain imaging while completing two counter-balanced versions of an age-appropriate gambling paradigm that measures sensitivity and decision-making; one version assesses these functions in response to primary rewards (candy) and the other considers secondary reward processes (money). In both versions of the reward task, participants were shown an image of a playing card numbered 1-9. They were asked to guess whether the next card would be a lower or higher number and bet either a small or large amount of their money or candy on their decision. At the end of each trial, participants were shown the outcome and their total winnings. Finally, T2-weighted scans allowed for further structural analysis using a different contrast. As mentioned, only the T1 scan will be included in the final analysis of the current study.

(5) Food Diary: Between the first and second sessions, parents were asked to complete a food diary for seven consecutive days, detailing what their child ate or drank during that week. To aid compliance, parents were sent a reminder email every day to ensure that they completed all seven days and received an additional incentive by being paid for every day they completed with an additional bonus if all seven days were completed. Parents submitted their information through a Qualtrics survey. The Dietary Guideline Index for Children and Adolescents (DGI-CA) was used to score the food diary data. The DGI-CA characterizes diet quality (frequency of consumption of core food groups) and is predictive of SES (Golley et al., 2011). The DGI-CA provides guidance on the kinds of foods and food portions that children should eat each day. These recommendations were based on scientific evidence and high impact research. Furthermore, the guidelines were developed under supervision of the National Health and Medical Research Council (NHMRC), which is governed by public health authorities as well as individuals with expertise in public health and medical research (Baghurst, 2003). The measure consists of 11 components: dietary variety (10), fruit (10), vegetables (10), breads and cereals (5), wholegrain cereal (5), meat (10), dairy food (5), reduced fat dairy (5), fluids (10), extra food (20), and healthy nuts, fats, and oils (10), all adding up to a possible score of 100. The closer a score is to 100 the better the overall dietary quality is assumed to be. In order to convert the dietary information provided by the parent to a score on the DGI-CA, each food item was categorized into one of the 11 groups with its associated serving size. Depending on the number of servings of each food consumed daily, a score was given based on the DGI-CA guideline. Foods that contained additional salt, sugar, or any other type of significant processing (e.g. American cheese or deli meat) was

considered an “extra food”. Each day of the children’s diets were scored individually out of 100 in Excel using the DGI-CA, to evaluate diet quality and its correlation to the family’s SES. A median split of the observed DGI-CA scores was used to create a categorical variable for the data analysis (i.e. median score = 30; group 1 > 30, group 2 < 30).

(6) Parent Survey Battery: While the child was in the scanner, the parent completed several questionnaires.

a. The full version of the HFSSM was administered in this measure, compared to the six-item version used in the screening. Although the six-item version provides a quicker and somewhat accurate estimate of the level of food security, the full version was used in the sessions as a way of gaining a more comprehensive understanding of the experiences within the households. The full HFSSM assesses about food security experiences over the preceding 12 months, across 4 domains: (1) anxiety about household food supply; (2) perceptions that the quality and quantity of accessible food is adequate; (3) reduced adult food intake; and (4) reduced food intake by children (Coleman-Jensen et al., 2018). Across the domains, families are categorized as having high food security (raw score of 0), marginal food security (1-2), low food security (3-7), or very low food security (8-18). Households with high or marginal food security are classified as food secure. Those with low or very low food security are classified as food insecure.

b. The Household Food Insecurity Access Scale (HFIAS) (Jones et al., 2013) monitors food insecurity over the past month and provides a single statistical dimension of food security that correlates with indices of wellbeing.

c. The Adverse Childhood Experiences Questionnaires (ACE-Q) asks parents to indicate from a predefined list of event-types, the number of adverse events their child has experienced since birth. This does not ask for the specific events but rather how many.

d. The Family Tree Questionnaire (Mann et al., 1985) asks parents to report on family history of drug and alcohol abuse.

e. The Neighborhood Characteristics Questionnaire (NCQ) (McGuire, 1997) assesses neighborhood quality and is a modified version of the Neighborhood Questionnaire. The NCQ is used to understand neighborhood friendliness, satisfaction with the area, frequency of problems, and whether the neighborhood is a good place to raise children. It includes 44 items that can be organized around 4 subscales: (1) danger and disorder, (2) neighborhood attachment, (3) local social networks, and (4) street crime and neighborhood quality.

f. Finally, a COVID questionnaire was also administered. To determine the impact of the recent pandemic on the processes under study, parents completed a survey on pandemic-related experiences they had encountered and which had the potential to be stressful or upsetting. Parents were asked to rate the impact of such experiences on themselves and other members of the household (including the participating child).

(7) Child Survey Battery: After the scan, the child completed a similar questionnaire to evaluate their level of lifetime stress (Sarason et al., 1978). These measures were completed without the parent present to allow for the child to answer honestly without the influence of the parent. They were asked to identify stressful events they

had experienced, some in the past year, and indicate their impact (e.g. none, minimal, major). The measure also included the 10-item Child Food Insecurity Experiences Scale (CFIES) to assess the children's experiences of food insecurity, as reported by them personally (Frongillo et al., 2022). The child survey battery was also adapted to include questions regarding stressful experiences relating to food insecurity and the COVID-19 pandemic; additionally, children completed the Edinburgh Handedness Inventory (Oldfield, 1971) to assess handedness. Although the neural processes assessed in this study may be lateralized in the brain, we did not exclude for handedness. Having data on participants' handedness may be useful in the future to assess whether handedness corresponded to any neural changes in the brain.

(8) The Kaufman Brief Intelligence Test (K-BIT) was used to measure child IQ (Kaufman & Kaufman, 1990). The K-BIT is a brief measure of both verbal and non-verbal intelligence. Two tests were used to measure verbal knowledge. In one, the child was shown a group of pictures and was asked to point to which picture represents a certain word. In the other verbal test, children were read a riddle and asked which word the riddle referred to. In the nonverbal test, matrices were presented as a 4 or 9 box matrix with pictures and figures. The children were asked to point to the picture among the answer choices that fits the rest of the matrix. A final IQ score was calculated using a K-BIT scoring manual. The primary research associate administered the test in an observation room, without the presence of the parent.

(9) The Balloon Analogue Risk Task – Youth Version (BART-Y) is a computerized task that simulates a real-world situation involving risky behavior, where taking a risk could result in a reward (Lejuez et al., 2002). Participants were asked to click the

mousepad of the computer to pump 30 balloons individually. Each click increased the size of the balloon, however, it was unknown how much air would result in the balloon bursting. The participant could add to their reward meter if they stopped adding air before the balloon burst. The participants received a reward based on the height of their reward meter. The task was administered on one of the study laptops in the same observation room.

(10) The Local-Global task was used to measure cognitive control (Rauch et al., 2012). In this task, participants were shown geometric figures. The outline of the "global" larger figure was composed of smaller "local" figures – larger squares were made up of smaller squares or triangles, and vice versa. Participants responded by pressing one of two computer keys. In the first block, participants responded to the local figure (in green), in the second block they responded only to the global figure (in blue), and in the third block the figures were randomized (blue or green) (Rauch et al., 2012). This allowed us to determine whether the impact of food insecurity on mechanisms underlying substance abuse risk are specific to reward neurobiology. A related goal was to delineate food insecurity-specific effects or general impacts of SES.

The parent and child batteries, the K-BIT, BART-Y, and Local-Global tasks were all completed only once, as they each measure trait-level characteristics (i.e., we did not expect them to vary between sessions or due to session-related factors, such as hunger). Ideally these measures were all completed during the first session, to prevent data loss in instances of participant attrition. However, if we were unable to collect them all (e.g., due to time constraints), those omitted during the first session were completed during the second session. At the end of each session, the family was debriefed and paid. The child also received their rewards for completing the scans and additional measures.

MRI Data Preprocessing

The T1 weighted MPRAGE scans were evaluated using a previously validated approach for estimating structural data quality. This quality control procedure was used to determine whether participants were included or excluded from MRI analysis. The scoring involves rating on multiple parameters of data quality: i.e., ghosting (a faint displaced copy of the head, brain, or eyes), ringing (light or dark bands or arcs on the image that often follow the curve of the head), and blurriness (the image appears to be smudged or indistinct) from 0 (none) to 5 (severe), clipping (a grey background behind the brain) (0 or 1), and wrapping (the scan cuts off part of the head and "wraps" it around to the far side of the image) (0 or 1). These artifacts and distortions affect the quality and viability of the scans. A final QC value was calculated for each scan (QC = (4*Wrap) + (10*Clip) + (2*Ring) + (1*Ghost)). The lower the score, the better the quality of the scan. Any scans with a score of 10 or higher were of poor quality and were excluded from further analysis (N = 5).

Voxel Based Morphometry with CAT12

The Computational Anatomy Toolbox (CAT) is a powerful software program that facilitates the accurate estimation of volumetric measures of brain volume and thickness. The most recent version of the toolbox, CAT12, can be used to generate estimates of cortical thickness and brain volume via voxel based morphometry (VBM) in SPM12 (Ashburner et al., 2014). VBM procedures facilitate the segmentation of the brain into grey and white matter, which are then co-registered and normalized to a standard brain template. This allows the estimation of relative brain density between participants across the whole brain or within specific regions of interest (Gaser et al., 2022). The estimates derived from VBM processing can be used to determine any significant associations between brain volume and other pertinent variables; in this case, the DGI-CA scores.

Chapter 3

Results

Demographics

Thirty participants took part in this study (N=17 male; N=13 female; mean age = 9.64 years (SD = 1.43) (*Table 1*). While, female participants were on average a few months older than the males (*Figure 2*), there was no statistically significant difference in age between male and female participants, $t(28) = 1.36$, $p = 0.70$. For those participants who had both structural MRI data and complete DGI-CA scores (N=30), only 28 passed the MRI quality control measures. These participants were included in the final MRI analysis (average age 9.82 years (SD = 1.34)). In terms of SES, the majority of participants were within the middle SES range (N=14), while 8 had a high SES, and 3 had low SES (*Figure 3*), with the average SES level being 4.40 (SD = 1.66) (*Table 1*). Based on the HFSSM-6 scores from screening the participants, 57% of families were rated as food secure and 43% were rated as food insecure. In general, both parents and children indicated their families as food secure (70% of parents and 79% of children). Of the families that were classed as food insecurity, only 33% of parent-rated food insecurity and child-rated food insecurity were matched; if a parent indicated that their family as food insecure, the child was more likely to indicate that the family as food secure.

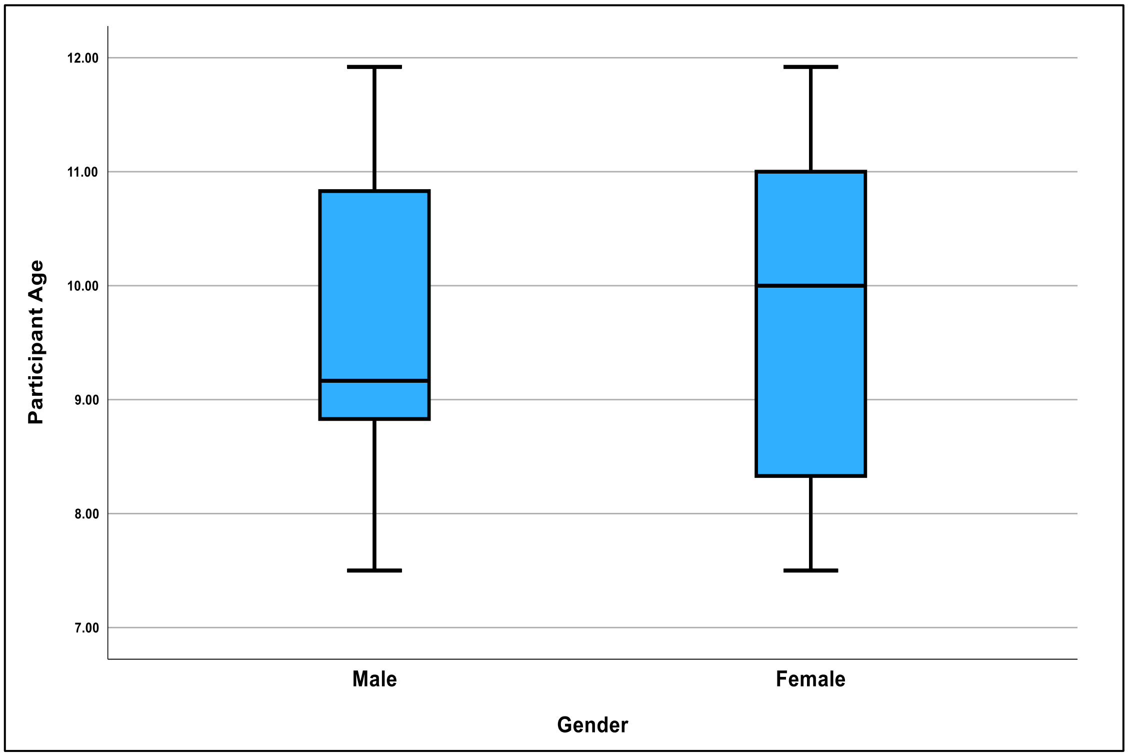

Figure 2: Average participant age across males and females within the sample (N=30).

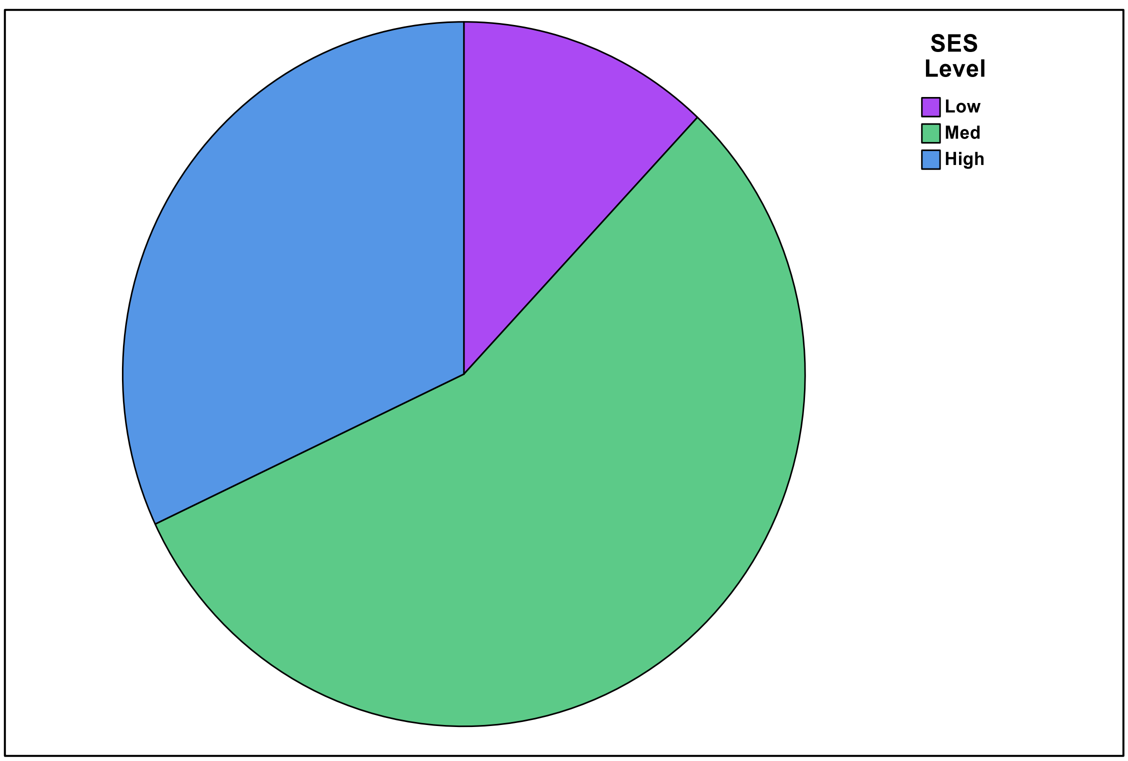

Figure 3: Pie chart showing breakdown of SES level (low, medium, and high) across participants. Level of SES was determined using a 9-point index to classify individuals as having low (0-2), medium (3-5), or high (6-8) SES.

The average food diary score across seven consecutive days was 27.72 (SD = 11.30) (*Table 1*), which indicated a low dietary quality across the sample (i.e. since the score is out of 100). Unexpectedly, those with below average DGI-CA food diary scores were from higher SES levels, while those with above average DGI-CA scores were from a lower SES bracket (*Figure 4*).

Table 1. Participant Demographics

	Whole Sample (N=30)			*MRI Sample (N=28)*		
Variable	N	M (SD)	Range	N	M (SD)	Range
Age	-	9.79 (1.30)	4.42	-	9.82 (1.34)	4.42
Gender (M:F)	17:13	-	-	15:13	-	-
IQ	-	109.97 (14.51)	61.00	-	109.86 (14.81)	61.00
SES Level	-	4.40 (1.66)	6.00	-	4.48 (1.70)	6.00
Screening Food Security	-	3.03 (3.62)	10.00	-	3.21 (3.69)	10.00
Parent Rated Food Security	-	3.23 (4.50)	13.00	-	3.07 (4.46)	13.00
Child Rated Food Security	-	1.14 (2.03)	9.00	-	1.22 (2.08)	9.00
Food Diary Score	-	27.72 (11.29)	47.58	-	27.82 (11.29)	47.58
BMI Session 1	-	21.96 (5.72)	19.01	-	21.96 (5.72)	19.01
BMI Session 2	-	21.90 (5.58)	18.82	-	21.90 (5.58)	18.82

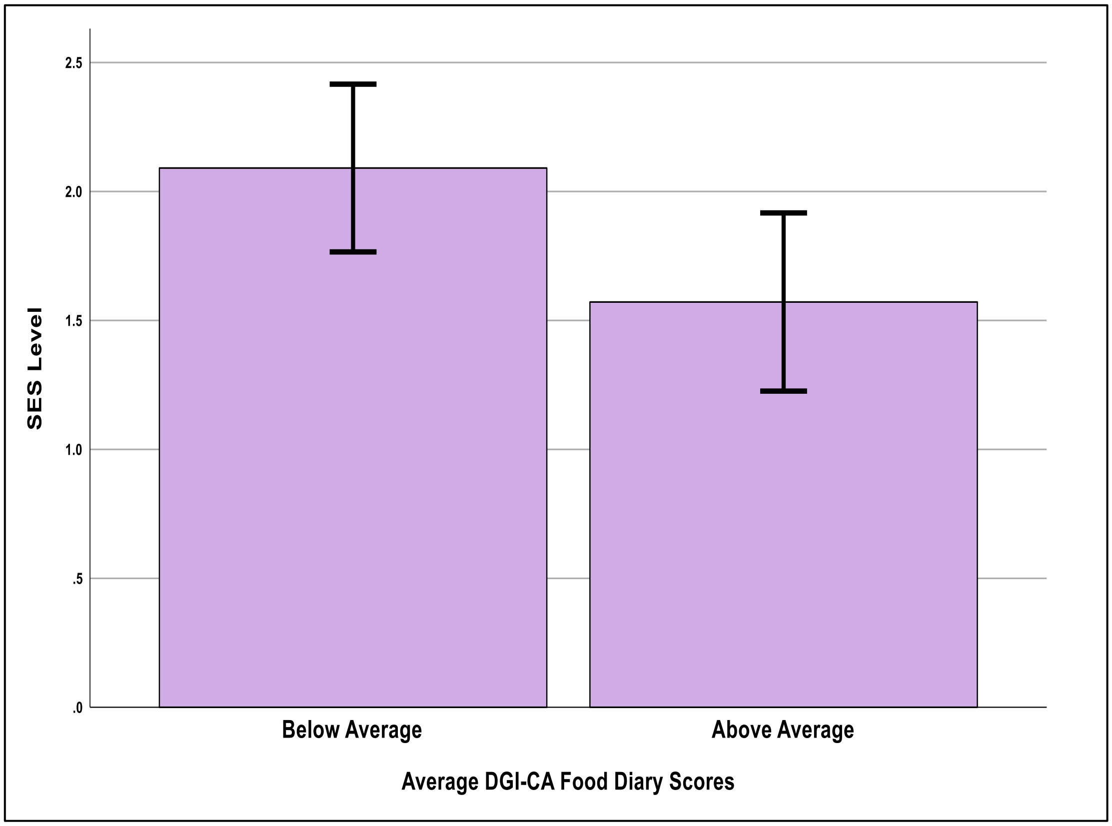

Figure 4: Below and above average (score of 30) DGI-CA food diary scores across level of SES.

Cognitive measures

The average IQ score for participants was 109.97 (SD = 14.51) (*Table 1*), which was higher than average for children in the same developmental phase (85-100). The average IQ for females was 113.50 (SD = 13.48), whereas males obtained a slightly lower IQ overall (M = 109.50, SD = 15.64). However, while there was a small difference in IQ scores between males and females, this was not a statistically significant difference, $t(28) = 0.92$, $p = 0.99$.

Participants had a BART-Y average balloon pump count of 20.67 (SD = 11.61) (*Table 2*). Females had higher average pump counts than males (24.54 vs. 18.88) (*Figure 5*). However, an independent samples t-test revealed no statistically significant difference in BART-Y average balloon pump count between males and females, $t(26) = 1.39$, $p = 0.37$.

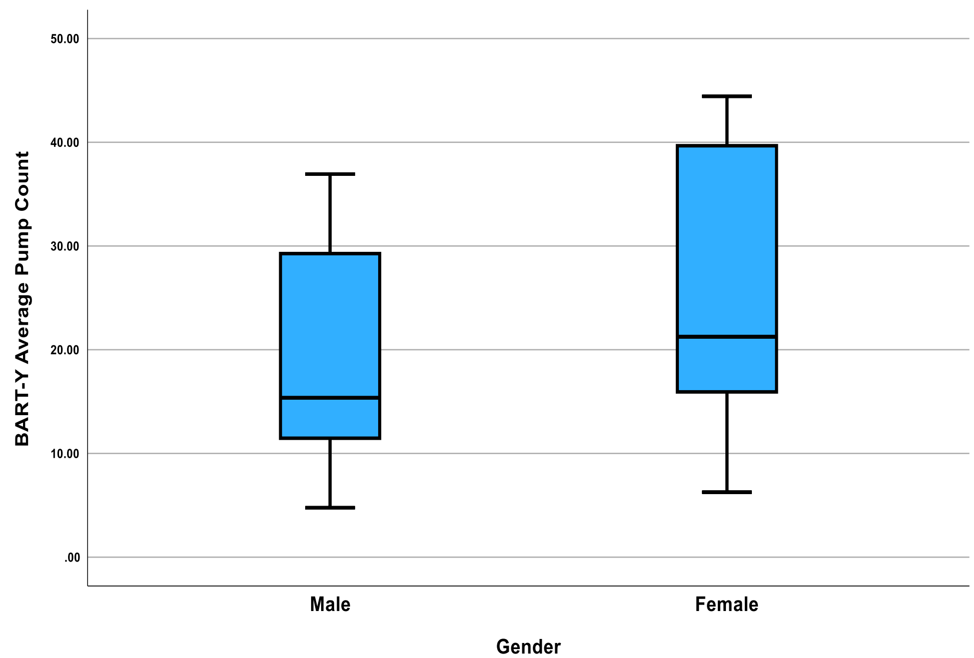

Figure 4. Average BART-Y balloon pump count for male (17) and female (13) participants.

Figure 5: Average BART-Y balloon pump count for male (17) and female (13) participants.

Across all participants and across all trial types (local, global, and mixed) within the Local-Global Task, the average reaction time was 1076.06ms (SD = 272.21) and the average percent correct was 60.21% (SD = 16.03) (*Table 2*). Participants achieved an overall accuracy of 73.71% in the global trials in comparison to 70.79% in the local trials, and 65.86% in the mixed trials. Similarly, the average reaction time for the global trials (M = 962.09, SD = 295.91) was quicker in comparison to the local trials (M = 999.24, SD = 325.16) or mixed trials (M = 1293.99, SD = 322.00) trials (*Table 2*). Individuals with a below average DGI-CA food diary score had statistically significantly slower reaction times across all the Local-Global tasks ($t(26) = 1.52$, $p = 0.05$), while those with above average DGI-CA scores had quicker responses across the tasks (*Figure 6*). Furthermore, participants in both the whole sample and in the sub sample that completed MRI were more accurate and faster to respond in the congruent conditions compared to the incongruent conditions for all trials (*Table 2*). A repeated measures general linear model indicated that females had a statistically significantly higher level of accuracy across all three tasks as compared to males (*Figure 7*) (F (1, 26) = 4.83, p = 0.037). There was a significant difference in percentage accuracy for the local trials between males and females, t(26) = 2.46, p = 0.002, however, was no significant difference in either the reaction time or in the percentage accuracy for the other trials (global and mixed) between males and females.

Table 2: Cognitive Summary of Mean BART-Y (Pump Count) and Local-Global Scores (Percent Accuracy and Reaction Time in ms)

Task	Whole Sample (N = 30) M (SD)	MRI Sample (N = 28) M (SD)
BART-Y	20.67 (11.61)	20.57 (11.70)
		Local Trials
RT Overall	999.24 (325.16)	999.56 (334.06)
RT Congruent	967.78 (322.12)	981.14 (330.84)
RT Incongruent	1016.35 (340.57)	1026.54 (351.41)
%Acc Overall	70.79 (26.45)	72.31 (25.59)
%Acc Congruent	74.14 (30.95)	76.77 (29.52)
% Acc Incongruent	65.00 (28.40)	66.62 (28.67)
		Global Trials
RT Overall	962.09 (295.91)	973.01 (303.45)
RT Congruent	940.71 (302.97)	919.76 (293.78)
RT Incongruent	997.96 (322.59)	978.96 (312.80)
%Acc Overall	73.71 (21.86)	74.92 (21.78)
%Acc Congruent	74.29 (30.20)	76.62 (27.89)
% Acc Incongruent	71.57 (25.21)	71.38 (26.14)
		Mixed Trials
RT Overall	1293.99 (322.00)	1314.83 (324.71)
RT Congruent	1234.37 (377.54)	1247.80 (387.09)
RT Incongruent	1949.78 (292.51)	1306.12 (301.20)
%Acc Overall	65.86 (18.75)	66.92 (17.81)
%Acc Congruent	70.50 (27.75)	73.15 (26.27)
% Acc Incongruent	58.79 (13.17)	59.69 (13.17)
		Across Trials
RT Across Trials	1076.06 (272.21)	1076.72 (279.55)
%Acc Across Trials	60.21 (16.03)	61.58 (15.33)

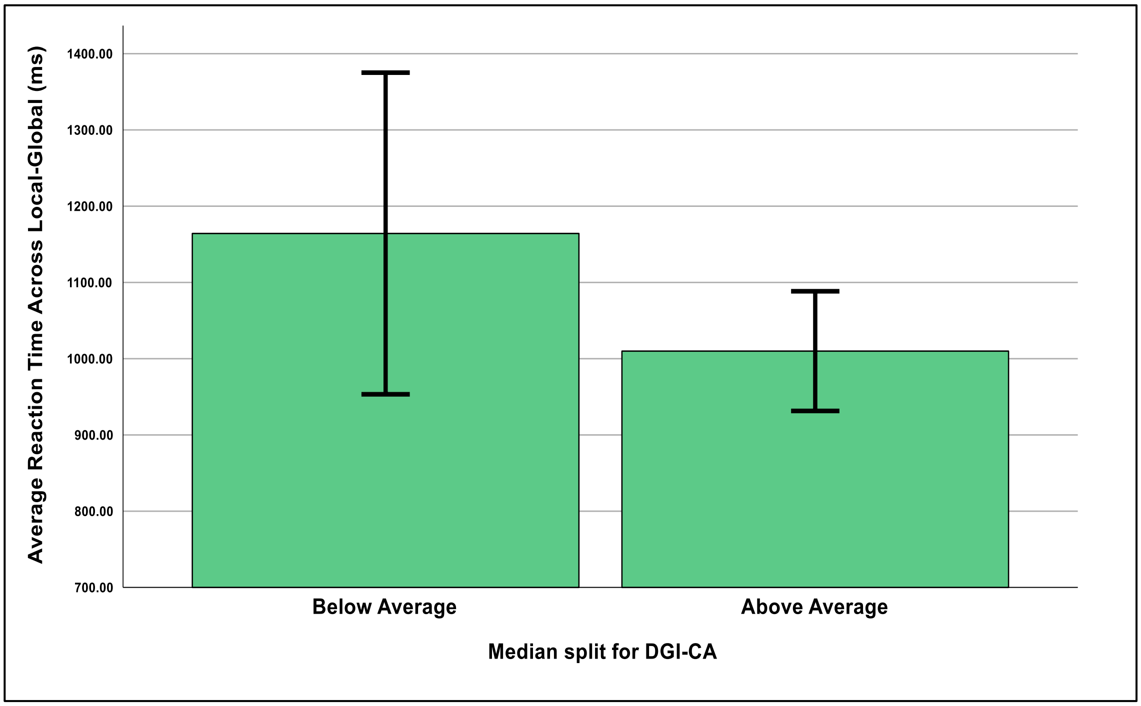

Figure 6: Below and above average DGI-CA food diary scores vs. reaction time (ms) for all participants across the Local-Global trials (local, global, and mixed).

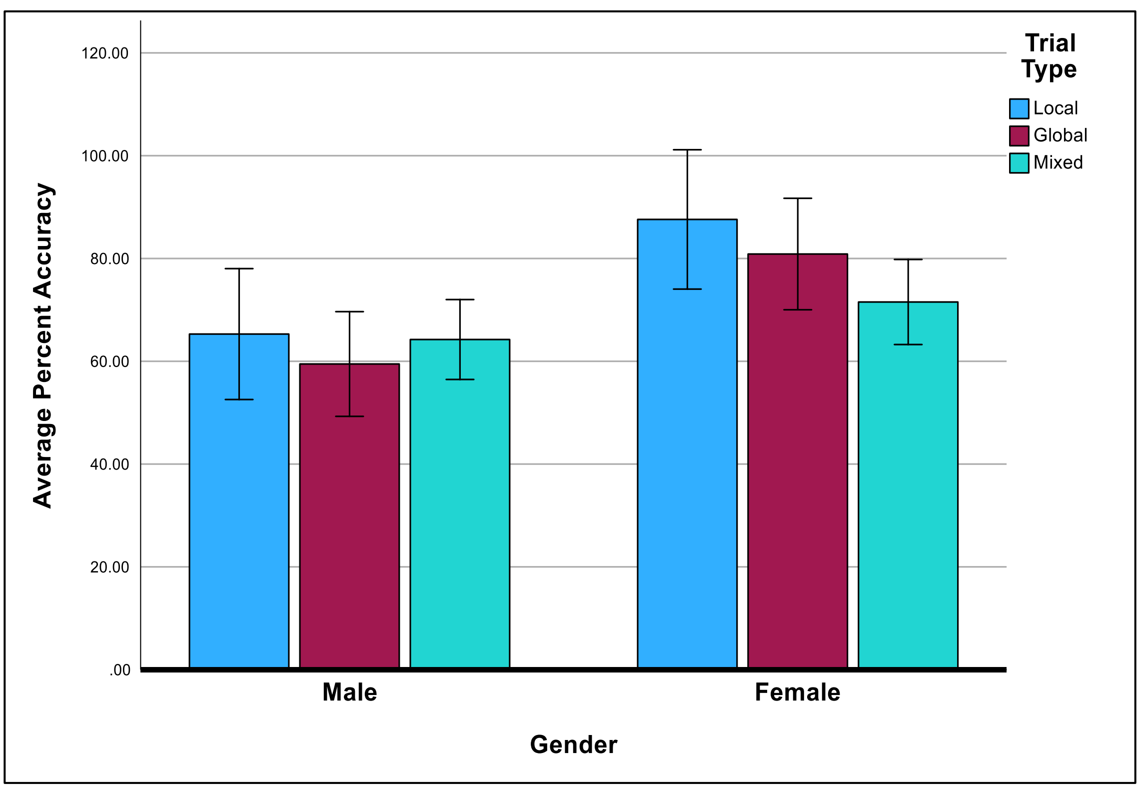

Figure 7: Average percent accuracy for males and females across each trial type within the Local-Global task.

Correlation between brain volume and DGI-CA scores

Results of multiple regression analyses in CAT12 are shown in *Figure 8*, with *p* (uncorrected) < 0.001 and a minimum cluster extent of 100 voxels. While it is typical to use a family-wise correction for these types of analyses, given our small sample size this is likely to be an overly stringent correction for multiple comparisons. Therefore, we opted for more liberal criteria that would allow us to explore associations in the data. The analyses revealed a significant positive association between brain volume and DGI-CA scores in two clusters shown in yellow. The first cluster was in the left dorsal striatum (MNI Coordinates: -16 6 10; T (27) = 5.08, p (uncorrected) < 0.001, cluster extent (K_E) = 1387 voxels) and the second was the right dorsal striatum (MNI Coordinates: 18 9 9; T (27) = 4.53, p (uncorrected) < 0.01, K_E = 1205. Both clusters included parts of the caudate and putamen, parts of the dorsal striatum and that are important for reward and motivation processes, and which play a critical role in habit formation. There was no statistically significant correlation between average BART-Y balloon pump count and striatal clusters, (left: $t(25) = 0.24$, $p = 0.81$; right: $t(25) = 0.46$, $p = 0.65$). However, there was a significant correlation between average reaction time for the Local-Global task and the left, $t(25) = 3.22$, $p = 0.004$, and right cluster, $t(25) = 3.31$, $p = 0.003$. There was no significant correlation between average percent accuracy for either the left cluster, $t(26) = 1.26$, $p = 219$, or the right cluster, $t(25) = 1.483$, $p = 0.151$.

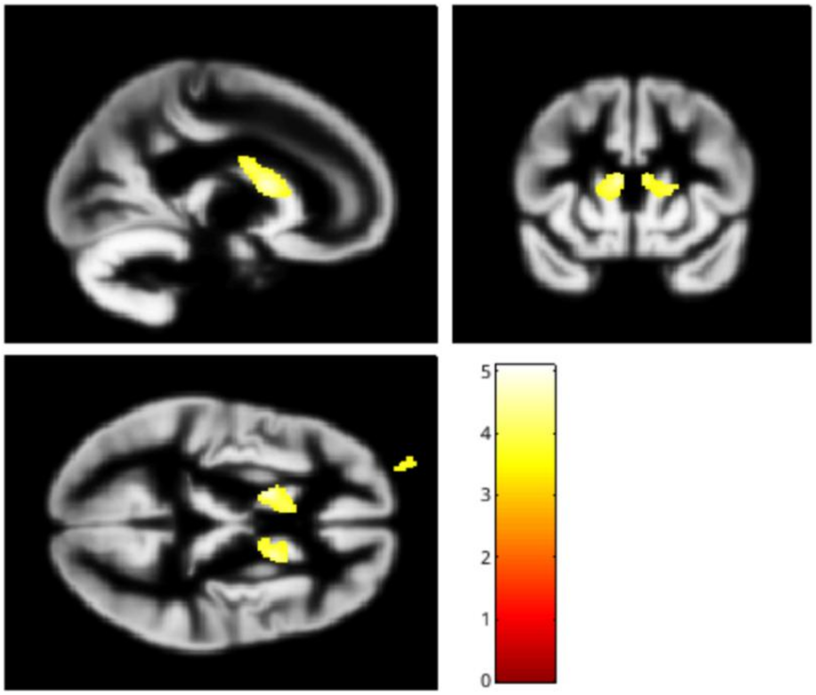

Figure 8: Tissue-based probability map from SPM12, using multiple regression analysis to determine the association between DGI-CA scores and brain volume. The left and right dorsal striatum are highlighted in yellow. The brighter yellow color indicates a significant correlation between DGI-CA scores and the striatum and corresponds to larger, significant values of t. A deeper red color would indicate a weaker association and smaller values of t.

Chapter 4

Discussion

Our first hypothesis was that dietary quality would correlate with brain structure in brain areas that are implicated in high-risk outcomes, such as SUD. Based on the results described above, there is support for this hypothesis. As shown in *Figure 8*, there were clusters in the left and right dorsal striatum. Participants with higher dietary quality as measured by the DGI-CA had a higher grey matter density in the dorsal striatum than those with lower dietary quality. This is important because the striatum is known to play a significant role in reward seeking and decision making (Wadsley & Ihssen, 2023). It has been shown that individuals with decreased grey matter density in the right striatum exhibited emotional dysregulation and decreased executive control (Stegmayer et al., 2013). Hence, these individuals may be more at risk for developing a future SUD due to a lack of executive functioning and increased sensitivity to rewards. Both the caudate and putamen, two areas in which the clusters are present in *Figure 8*, assist in learning action-reward associations and can be vital for stimulus-action coding during goal-directed behavior (Balleine, 2007). Furthermore, studies have shown that in those with severe drug addictions like cocaine, there is a significant reduction in grey matter volume in the caudate and other parts of the striatum (Cadet et al., 2014). Individuals with decreased dorsal striatum activation during reward anticipation tend to use substances more frequently (Bart et al., 2021). For the sample in this study, it is important to note that the children with lower dietary quality, and lower volume in the striatum, may be vulnerable to developing risky-behavior as an adolescent or adult, possibly involving the use of the substances.

Our second hypothesis was that dietary quality would correlate with cognitive functioning as measured by IQ, impulse control, and attention. There are few significant results relating DGI-CA scores and cognitive performance as measured by IQ, impulse control using the

BART-Y, or attention using the Local-Global task. However, individuals with a below average DGI-CA food diary score had statistically significantly slower reaction times across all the Local-Global tasks (*Figure 6*), $t(26) = 1.52$, $p = 0.05$. The non-significant pattern in the data align with research that has found that lower dietary quality during childhood is associated with decreased attention capabilities and learning difficulties (DiGirolamo & O'Keefe, 2020). Consequently, it is reasonable to assume that dietary quality may play some role in cognitive performance in childhood, however, we are unable to come to a definitive conclusion due to limited variability in dietary quality index scores in our sample, the homogenous nature of the sample in terms of SES, and the exploratory nature of this analysis (see below for a discussion of these potential limitations). Given the highly similar ratings of dietary quality across participant, it may be that further studies require a sample with more variability in dietary quality levels to be able to assess more conclusively whether cognitive performance in children varies according to levels of dietary quality.

While there weren't many significant effects regarding dietary quality and cognitive functioning, there was a significant association between average reaction time for the Local-Global task and the left, $t(25) = 3.22$, $p = 0.004$, and right cluster, $t(25) = 3.31$, $p = 0.003$. This significant result might indicate that brain volume does in fact play some role in cognitive performance in childhood. Specifically, brain volume seems to be influencing motor functioning but not accuracy. Not only are the basal ganglia structures identified in the VBM analysis involved in reward motivation and executive functioning, but they are also known to affect motor control and motor learning (Lanciego et al., 2012). Disruption of the basal ganglia can lead to higher sensitivity to reward and forms the basis for numerous movement disorders like Parkinson's disease (Yin, 2016). Highlighting this point further emphasizes the importance of understanding the relationship between brain structure and cognitive functioning. Pinpointing a discrepancy in brain volume or structure in a child from an early age can allow for the prevention of future motor-developmental disorders.

In addition to those analyses focused on the main hypotheses, our analysis also included an exploration of the impact of gender on outcomes. There were no meaningful differences in IQ and BART-Y average balloon pump count between males and females. However, on the local-global trials, there was a significant difference in percent accuracy for the local trials between males and females, $t(26) = 2.46$, $p = 0.002$. It is also worth noting that females were more impulsive when playing the BART-Y than males as they had a higher average balloon pump count (*Figure 5*).

As mentioned previously, one methodological concern with this study was the lack of variability in the dietary quality index. Irrespective of the level of SES or whether families were food insecure or not, most children had very poor diets. A score of 50 or below would have been considered a poor diet, highlighting how low this study average score of 27.72 (SD = 11.30) was. Even with a maximum potential score of 100, all scores fell within the 6.65 to 54.23 range, making it challenging to predict future outcomes based on the children’s diets. Unexpectedly, even those with high SES or food security had relatively low dietary quality (*Figure 4*). This is curious as we would tend to anticipate improved dietary quality for children with greater access to financial resources When trying to delineate this outcome, it is important to note that our sample was made up of predominantly middle and low SES families (i.e., there were very few truly high SES participants). Thus, those families with higher means and poorer quality diets were not high SES but rather middle SES. It may be that these families while lacking the resources to access more high-quality food items may have been able to access pre-processed foods that are more costly than low SES families might be able to access. If so, a larger sample size with a greater range of SES scores and with a more equal distribution of low, middle, and high SES families might facilitate an exploration of how children's diets vary across SES – including between food secure or insecure families – and how this might contribute to brain development and cognition.

Another limitation was the high variability in performance on the local-global task. On this measure, some children were significantly less accurate compared to others. For those that did do worse, it does not appear to be the case that their poor performance was due the task not working as intended. For example, participants tended to be most accurate in the global condition (i.e., the easiest condition) and least accurate in the mixed condition (i.e., the most challenging condition). Furthermore, all participants tended to have lower percentage accuracy and slower reaction times for trials in which the local and global elements where incongruent, compared to those where they were congruent. It is expected that the incongruent trials would be more challenging and would require more attention, resulting in both lower accuracy and slower reaction times. Taking this into account, it is unclear whether for those children who performed more poorly on the task, if they were trying to perform accurately but simply did not understand the task, or whether they were tired and bored due to the length of the sessions. For example, the sessions began very early in the morning (approximately 7:30 am for most participants) and the task was completed at the end of a 2 – 3-hour session, depending on whether it was the first or second session and whether it was a fed or fasted session. It is reasonable to assume that the participants would become tired after a few hours, especially after being in an MRI for an hour.

Overall our results suggest that there may be some potential impacts of dietary quality on the structural development of brain areas (i.e., the dorsal striatum) that are important for cognitive and emotional processes that are altered in those that are at increased risk for high-risk behaviors. While our exploration of the cognitive impacts of dietary quality did not support our hypothesis, there were some interesting trends in the data that are suggestive of impacts of dietary quality on cognitive processes (e.g., reward, motivation, decision-making) that are supported by the striatum, which aligns well with prior literature in this field. Replication of these results in larger, more varied samples may facilitate a more conclusive exploration of these relationships. Indeed, understanding the relationship between dietary quality, neurodevelopment, and cognition may be a crucial step in developing appropriate prevention methods against SUD development in at-risk individuals. In addition, given the significant body of research exploring the relationship between whole brain networks (DMN, SN, and ECN) and nutrition in low SES communities, it may be helpful to utilize at-rest or goal-oriented data in the future to understand whether dietary quality is instrumental in alternating the nature and strength of the connections in these functional networks. Appreciating the impact that nutritionally-related impairments in certain brain networks may play in the development of SUDs, will allow for more targeted prevention methods to be devised for a wider range of at-risk children.

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Estelle Beneke

Education

Pennsylvania State University — Graduation: May 2024

Schreyer Honors College

Bachelor of Science: Biological Sciences and Health Professions Option

Volunteering and Shadowing

Hospital Volunteer — *Jun 2020 – Aug 2020*

- Volunteered at the Hospital of Hope Intermediate Care Facility at the Cape Town International Convention Center in Cape Town, South Africa at the height of the COVID-19 pandemic in 2020
- Hand created and distributed hundreds of personal care packages for incoming COVID-19 patients and coordinated with hospital staff to arrange the distribution of food for over two hundred frontline doctors, nurses, and other essential hospital staff

THON Rules and Regulations Committee Member — *Aug 2021 – Feb 2022*

- Spread awareness and assisted in funding for pediatric cancer research
- Promoted safety for all THON events and fundraising practices

General Surgery Shadowing — *Jun 2022 – Jul 2022*

- Shadowed a general surgeon for six weeks, obtaining a total of 88 clinical hours
- Learnt the nuances of laparoscopic abdominal surgery including hernia repairs, laparoscopic cholecystectomies, and metastasis removals from breast cancer patients
- Attended and participated in a day-long training course on how to tie surgical knots laparoscopically, as taught by general surgery specialists

Research Experience

Research Assistant — *Aug 2022 – Present*

- Assess the impact of dietary quality on pediatric neurodevelopment through MRI
- Collect vitals for over 40 incoming pediatric participants including blood glucose levels, height, weight, BMI, fullness level, and time of last meal
- Administer a computerized reward task through fMRI alongside the MRI operator
- Train new research assistants by giving extensive and specific instructions on the study's standard operating procedures, how to operate the reward task, and ensure they understand how to administer an IQ test and a computerized cognitive task

Leadership Experience

International Student Council at Penn State

Assistant Treasurer — *Sep 2021 – Aug 2022*

- Worked alongside the treasurer to fundraise for the committee and assisted and in collaborative problem solving to expand the international student community

Treasurer — *Aug 2022 – Apr 2023*

- Fundraised $3000 through raffle ticket sales at a football game and managed over $5000 for the committee for our biggest international student event of the year
- Recruited students for membership positions in the committee and worked as a team member with other executive board members to plan events through the year

President — *Apr 2023 – Present*

- Promote diversity, equity, and inclusion throughout the Penn State community
- Assist with peer mentoring for incoming international students who need further guidance with building their international and domestic community

Licenses and Certifications	*Issued Sep 2022*
Adult and Pediatric First Aid/CPR/AED	*Issued Jul 2023*
OSHA Bloodborne Pathogens	*Issued Nov 2022*
Social and Behavioral Human Subjects Research (IRB)	*Issued Aug 2022*
Food Safety in Schools	*Issued Jun 2022*
Fundamental Neuroscience for Neuroimaging Research with Children	*Issued May 2022*