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An Examination of the Relationship Between Child IQ and Diet Quality

A Capstone Project Submitted in Partial Fulfillment of the
Requirements of the Renée Crown University Honors Program at
Syracuse University

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and Renée Crown University Honors
Spring 2019

Honors Capstone Project in Nutrition Science

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Abstract

The objective of this study was to evaluate the relationship between diet quality and intelligence quotient (IQ) in children who participated in the Syracuse Lead Study. The sample consisted of 266 African-American and Caucasian children ages 9 to 11 years old living in the city of Syracuse. Participants completed 2 days of dietary recalls and Healthy Eating Index-2015 scores were calculated to determine diet quality. Parent and child IQ were measured by the Kaufman Brief Intelligence Test. Seafood and plant protein intake was the only dietary component that significantly predicted a higher child IQ. Better HEI scores for fatty acids, refined grains, and saturated fat were all sigificanlty associated with a lower IQ. However, no dietary components were significant predictors after controlling for race and parent IQ.

Executive Summary

This research paper addresses the importance of diet quality in children. Currently, the average child in the United States does not meet the Dietary Guidelines, which can have negative implications for their development (Krebs- Smith et al., 2010). After reviewing the existing literature in this field, I found that many nutritional markers have been studied in relation to various cognitive factors. The research suggests that a better diet quality and eating practices lead to better cognitive outcomes in children. However, IQ specifically has not been studied in relation to diet quality. In this research, I analyzed relationships between intelligence quotient (IQ) and overall diet quality in children. In addition, BMI, and micronutrient intake were analyzed. The aim of this study was to determine whether or not IQ and nutritional health are related in children.

This research involved secondary data analysis of data that were collected as a part of the Syracuse Lead Study. The sample population used for this cross- sectional study consisted of 266 children aged 9-11 residing in the city of Syracuse, NY. The sample was restricted to children from certain zip codes in order to target low socioeconomic status neighborhoods. All participants identified as either African- American or Caucasian. Participants that did not have complete dietary data were excluded from this study. Measures that were taken at the time of the study that are relevant to this analysis include demographics, anthropometrics, dietary recalls and intelligence quotient data. Height and weight were used to calculate body mass index (BMI) and to classify participants as underweight, healthy weight, overweight, and obese.

Dietary data were collected using the Automated Self-Administered 24 hour (ASA 24) dietary assessment tool. This is a computer-based tool that collects 24 hour dietary recall data. Dietary recalls can be used to get an idea of a person's current intake. In the case of this study, 2

days of dietary information were collected, and both the children and parents provided recall information for the child. The dietary data were then used to calculate Healthy Eating Index (HEI) scores. The Healthy Eating Index yields a total score and subscores that assess the quality of the diet in comparison to the 2015 Dietary Guidelines for Americans. The subcategories assessed by the HEI include total fruits, whole fruits, total vegetables, greens and beans, whole grains, dairy, total protein foods, seafood and plant proteins, fatty acids, refined grains, sodium, added sugars, and saturated fats.

The Kaufmann Brief Intelligence Test (KBIT) was used to collect IQ data for the study population and their parents. The KBIT is a screening tool that is used to assess the intelligence of an individual. Three subtests are administered and yield a verbal, non-verbal and composite IQ score.

Overall, the HEI scores of the population were lower than average for children in this age group. The KBIT scores on the other hand were normal compared to the standard scores. When conducting data analysis, all of the HEI scores were examined in relation to both child and parent IQ scores. Parent IQ score was assessed in relation to the child's dietary intake because parents play a large role in food selection of young children. IQ scores were also assessed across race and gender. There was no significant difference among gender, however, there was a significant difference in the distribution of high and low IQ scores between the two race groups. Therefore, race was included as a variable in the regression that was run to determine any significant predictors of IQ. Iron, zinc, folate, fiber, and vitamin A are all micronutrients that previous research has shown to be important for cognitive development in children. This study also assessed their relationship to IQ. Finally, BMI was used to group the participants into either a healthy weight or overweight category to look for differences in IQ scores between the two groups.

This project was designed to identify the dietary components that are related to IQ in children. Diet quality is important in children for both physical and cognitive growth and development. However, I was interested in looking at its importance in intelligence. Even though research has proven diet quality to be an important factor in child health, many children fall far short of reaching the requirements. Being able to pinpoint the specific nutrients and food groups that are most important for certain aspects of development and educate the public about them may help to improve child diet quality in the future.

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Introduction

The purpose of this study is to assess the relationship between a child's diet quality and their intelligence quotient (IQ). There is a lot of current literature that suggests a better diet quality should have a positive effect on child IQ. Many dietary components including foods groups, macro and micronutrient intake, and overall diet pattern have been used to assess the relationship between diet and intelligence. However, these studies used cognitive measures other than IQ to assess intelligence. In this research, the association between IQ and overall diet quality in children was analyzed.

The sample population consisted of 266 children that participated in the Syracuse Lead Study who had complete dietary data. Dietary data were collected and used to calculate Healthy Eating Index (HEI) scores. Verbal, non verbal, and composite IQ data were collected using the Kaufman Brief Intelligence Test (KBIT). A regression was then run to determine if any of the HEI components were significant predictors of child IQ while controlling for race, gender, and parent IQ.

Literature Review

Childhood diet has been in the spotlight in recent years, even amongst the general public. Connections between the nutritional adequacy of one's diet in relation to a number of factors, such as proper physical and psychological growth and a better quality of life, have been major points of interest. Many different nutritional markers have been studied in association with cognitive function and development in children; however, the overall diet quality in relation to cognitive ability has not been readily studied. Currently, the average child in the United States is not meeting the federal dietary guidelines (Krebs-Smith et al., 2010). In one study, children with a lower overall diet quality showed inferior cognitive flexibility compared to those with a diet that met the recommendations (Khan et al., 2014).

Food Groups and Macronutrient intake

The frequency in which a child eats from a certain food group or consumes one macronutrient has been shown to impact the cognitive development of that child. One longitudinal study assessed 589 children at birth, at one year, at three and a half years, and at seven years (Theodore et al., 2009). Dietary data were collected using a food frequency questionnaire at both 3.5 and 7 years and intelligence data using the Intelligence Quotient (IQ) score were collected at the same time. The researchers found that at 3.5 years of age, children who consumed foods from the grains group more than four times per day displayed a significant increase in intelligence. While certain types of fats may be beneficial to cognitive functioning, a cross-sectional study of 65 children aged 7 to 9 years old found that increase in overall fat intake may lead to a decrease in cognitive control (Khan et al., 2014). The nutrient data for this study were collected using a 3- day food record and the mean macronutrient intakes were determined.

The researchers also analyzed intake of saturated fatty acids, omega-3 fatty acids, and fiber. A prospective 4.4 year cohort study of 496 Finnish children assessed diet in relation to cognitive functions at 13, 24, 36, 48, and 60 months (Rask-Nissilä et al., 2002). The researchers found that high protein intake is associated with improved speech and language skills in boys five years of age.

In one test of cognitive function performed by 7 to 9 year old children, short chain fatty acids were negatively correlated with cognitive function while omega 3 fatty acids were positively correlated (Khan et al., 2014). In this cross-sectional study, 58% of the participants were of a healthy weight, 25% were obese and 26% of the sample were categorized as low socioeconomic status. The researchers found a negative correlation between response accuracy in a cognitive task and dietary cholesterol intake in children. Increased intakes of saturated fats have also been associated with lower cognitive functioning. Polyunsaturated fat intake has been linked to better short term memory and visual motor skills (Khan et al., 2014). In another study, researchers created a fish food group which contained all fish including oily fish and shellfish, and found that children who ate from this group at least once a week had significantly higher total IQ scores than those who did not regularly consume fish (Theodore et al., 2009). They attributed this association to the marine omega-3 fatty acids found in fish.

Fiber

Fiber is another nutrient that has been studied in regard to its effect on cognitive functioning in children. It has been found previously that a diet low in dietary fiber is associated with a higher risk of obesity in children and a lower overall diet quality that may have cognitive implications. Soluble fibers act as a substrate for bacterial fermentation to occur, which enhances the microbiome of the gut. This, in turn strengthens cognitive development and function via the gut-brain axis. Insoluble fiber plays a role in regulating insulin sensitivity that may benefit one's cognitive health. A positive correlation has been found between intelligence and cognitive control (Blair, 2006). One study of children aged seven to nine years old examined attentional inhibition (the ability to suppress cognitive information that is irrelevant to the task) as the measure of cognitive control (Khan et al., 2014). They found that total dietary fiber intake was associated with better response accuracy on the cognitive task, with total and insoluble fiber having a greater impact than soluble fiber intake. They also concluded that fiber intake in children plays an important role in increasing cognitive control when cognitive demands are increased (Khan et al., 2014).

Micronutrients associated with cognitive functioning

There are many micronutrients that have been found to be associated with cognitive development and functioning. The United Nations Children's Fund conducted a study in many developing countries around the world and found that even when macronutrient needs are being met, deficiencies in iron, vitamin A, iodine, and folic acid can limit intellectual growth (UNICEF, 2004). Researchers have found that iron deficiencies can have negative cognitive impacts on the developing brain that are difficult to reverse (Sansdstead et al., 1998). Sandstead and colleagues studied children aged 6-24 months because this is the most likely time a child would develop an iron deficiency. The researchers noted that the most noticeable and irreversible effects on the myelin will likely occur before the age of three, however it can be concluded that children's cognition may be affected by iron deficiency anemia to some extent as long as their brain is still developing.

Zinc is another nutrient that has effects on brain growth. A randomized control trial of 740 Chinese children aged 6-9 years from low income areas studied the effects of zinc repletion

(Sansdstead et al., 1998). They found that neurophysiological performance was increased after the period of zinc supplementation, proving that zinc is important to brain health and function. Moderate iodine deficiency has been found to cause a reduced verbal IQ in elementary school children, while mild deficiency did not have any cognitive effects (Fenzi et al., 1990).

Breakfast Habits

The importance of breakfast is well known, even among the general public. One of the benefits of eating breakfast is that children perform better in the classroom when they eat breakfast. Breakfast also may improve overall cognitive measures such as concentration level, memory, and attention. Liu and colleagues conducted a recent cross-sectional study of 1269 Chinese children ages five and six and found that a breakfast that consists of higher levels carbohydrate may have greater effects on cognition than other types of breakfast (Liu et al., 2013). However, children who ate any type of breakfast at least four days a week had higher IQ scores than those who did not eat breakfast regularly. While children who ate breakfast had a higher IQ overall and scored better on the verbal and performance IQ tests, verbal scores were benefited the most by regular breakfast consumption. This study also showed that children who often skipped breakfast consumed less vegetables, grains, and dairy leading to a poorer overall diet quality. They also did not get as much energy from protein compared to children who ate breakfast, which may have an effect on cognitive performance (Liu et al., 2013).

Dietary Pattern

Due to the fact that we do not eat foods in isolation, but rather in combination with one another, nutrients interact with each other within our body and can have a different impact on the body when consumed together than when eaten alone. For this reason, it can be useful to look at dietary patterns rather than specific food groups or nutrients when studying how diet and IQ are related. One longitudinal study used a food frequency questionnaire to assess children's diet at ages 3,4,7 and 8.5 years (Northstone et al., 2011). Researchers used this information to classify three main types of dietary patterns including processed, traditional, and health conscious. The processed pattern included mainly processed and convenience foods that tend to be high in both fat and sugar. Some examples include chips, pizza, and sugar sweetened beverages. The traditional diet consisted of meals that were based mostly on meat, potatoes, and cooked vegetables. The health- conscious pattern focused on salad, fruit, legumes, pasta, non- white bread, and fish. This pattern resembled a healthy vegetarian diet. A fourth pattern was added for only the three year old age group labeled the snack pattern which consisted mainly of finger foods. A number of confounding factors were considered in this study including gender, age, number of stressful life events, breastfeeding duration, estimated energy intake, measure of parenting, maternal education, housing, social class, and maternal consumption of oily fish during pregnancy. The researchers found that children who ate a generally health conscious diet had a higher IQ during childhood. The way that the dietary patterns were grouped provides helpful insight into the children's diet as a whole, without focusing on any one aspect individually. While it is known that certain foods and nutrients contribute to brain health more than others, this study showed that overall diet quality has a greater effect on health outcomes, specifically IQ (Northstone et al., 2011).

Maternal Feeding Practices

Maternal feeding practices can also have an effect on the health and IQ of the child. While it is known that breastfeeding has many benefits for the child including a heightened immune system, a number of studies have also found a correlation between breastfeeding and cognitive development (Oddy et al., 2003; Quinn et al., 2001). These studies have found that in general, the longer a child is breastfed, the higher their IQ will be. While breastfeeding is beneficial to any baby, more of an impact on IQ was found in children that were born small for gestational age than those who had a normal birth weight (Rao et al., 2007). Another study found that children who breastfed for more than a year had an IQ almost four points higher than those who had been breastfed for less than one month. The group that was breastfed for over a year had completed more schooling and had a higher income than those who were breastfed for a shorter amount of time. Contrary to popular belief the outcomes seen in this research were independent of the family's socioeconomic status at the time of birth. One theory as to why "breast is best", is that human milk has evolved to provide us optimal levels of nutrition, and while formula tries to replicate breastmilk as closely as possible it is still not as good as the real thing ("Breast really is Best; Nutrition, IQ and Income.", 2014). The nutritional benefits of breastmilk include its essential fatty acids, long chanin polyunsaturated fats and high lactose content. The enzymes in the milk also increase its digestibility and therefore bioavailability. Breastfeeding also provides immunological benefits as maternal antibodies are transferred to the baby and provide protection against infection and disease (Mathur & Dhingra, 2013).

Physical Activity

In a cross- sectional study of - 235,663 male and 169,259 female adolescents, physical activity was found to have a mediating effect between IQ and obesity (Goldberg et al., 2013). The study used an assessment which evaluated the participants involvement in "health- related physical activities" like hiking and extracurricular activities such as sports. They rated the amount of physical activity each subject gets on average on a scale from one to five with one being the lowest amount of activity and five being the highest. The researchers found that a low IQ score was significantly associated with lower levels of physical activity and that less physical activity was associated with an increased risk of obesity. This shows that physical activity is a significant mediating factor between IQ and obesity. While the relationship was significant for both the male and female adolescents it was stronger among the male population. The explanation that the researchers proposed for the relationships between IQ, physical activity, and obesity is that those with a lower level of intelligence are less likely to display healthy behaviors such as engaging in physical activity (Goldberg et al., 2013).

One theory that explains this phenomenon is the Savanna-IQ Interaction Hypothesis, which states that children who are more intelligent will adopt evolutionary behaviors while those who are less intelligent will not and more closely mimic the actions of our ancestors. Because of the scarcity of food that our ancestors faced, our brains are designed to crave foods high in calories, sugar, and fat. They also got plenty of exercise in their daily lives and therefore our brains are not programmed to engage in intentional physical activity. Children who are more intelligent are more likely to evolve away from these behaviors and therefore may have better health habits (Kanazawa, 2013).

BMI

Studies have shown that in children, a low IQ is associated with having a higher BMI (Goldberg et al., 2013). Both children and adults with a lower IQ tend to engage in less healthy behaviors, including a poor diet that is associated with obesity (Kanazawa, 2013). In the cross-sectional study of 16 and 17 year old adolescents previously discussed, the association between IQ and obesity was assessed (Goldberg et al., 2013). The researchers classified the subjects according to their BMI categories; underweight (less than 18.5), normal (18.5-24.9), overweight (25-29.9), and obese (30 and over). In order to perform the analysis, IQ scores were divided two ways. The low IQ group was at least one standard deviation below the population mean, and the other subjects were placed in the normal to high group. The researchers found that those in the obese category had the lowest IQ scores and that those with a normal BMI had the highest IQ scores for both males and females. While a low IQ significantly increases the risk for obesity for both genders, this relationship was found to be much stronger in the female subjects than the males. While overweight and obese subjects had the lowest IQs, those in the underweight group had IQ scores lower than that of the normal group, but not as low as the overweight group. This shows that both undernutrition and overnutrition may be associated with lower level of intelligence. Many times socioeconomic status is regarded as a predictor of obesity in children, however this study found the association between BMI and IQ among all levels of socioeconomic status (Goldberg et al., 2013).

IQ Testing

IQ tests are a tool widely used to asses a person’s intelligence. There are different versions of the test, but most contain both a verbal and performance section. Traditionally called “IQ tests”, they are now typically referred to in the scientific community as measures of cognitive ability. This terminology gives a broader meaning to what is being tested instead of what we would normally think of as intelligence. These tests are used as predictors for academic and social success and to screen for cognitive strengths and weaknesses. There is some controversy involving the use of IQ tests as they may display discrimination against certain ethnic groups (Lang, 2008). While the test can be administered in Spanish, the test is not recommended for those whose are not fluent in English. In addition, it is not recommended for those from different cultural backgrounds because cultural differences may lead to an incorrect measure of intelligence (Bain & Jaspers, 2010).

KBIT IQ Test

The Kaufman Brief Intelligence test (KBIT) is an intelligence test that can be administered in about twenty minutes. While this is a relatively short test, it gives the researcher more information that most other brief intelligence test. This can be used as somewhat of a screening tool to get a basic idea of the intelligence of an individual. It was found to be both valid and reliable for subjects aged four to 90 years old (Bain & Jaspers, 2010). It has both a verbal and non- verbal component that are scored separately as well as a total IQ score. There are three subtests that comprise the KBIT, the verbal knowledge subtest, the matrices subtest, and the riddles subtest. The verbal knowledge and riddles subtests examine verbal intelligence, while the matrices subtests looks at non-verbal intelligence. The raw scores from both verbal subtests are added together and then converted into a standardized score, and the non- verbal test is converted directly into a standard score. The non-verbal score is an assessment of the subjects' fluid assessment and visual processing ability, while the verbal score tests crystallized ability- the ability to use learned knowledge. The composite IQ score is then calculated by combining the standard score from both the verbal and non- verbal portions. The standardized scores are found to be depictive of the United States population, however it is not recommended for those from other cultures or those that speak a different language as it may not provide an accurate assessment of their intelligence.

Diet Assessment in Children

One of the main challenges that arises when seeking to collect dietary data about children is who to collect it from- the parents or the child themselves. Only one study, published in 1989 validated the use of joint recalls by the mother, father, and child together (Eck et al., 1989). This method was found to be a more accurate representation of the meal that the child had eaten than when the information was gathered from the mother or father alone. However, this study design had many flaws. The sample size was only 34 participants aged 4 to 9.5 years old, from one race and socioeconomic status. In addition, the researchers performed the individual assessment first and the joint assessment second, which may have contributed to a greater response accuracy as it was acting like the multiple pass method used in 24 recalls. The researchers also failed to include assessments from the child only, without the mother or father present.

Two more recent studies have compared the accuracy of recall in children vs parents. In both studies, the children had the most accurate record of what they had eaten. The first study was conducted on nine children aged 8 to 11 (Burrows et al., 2013). The mother, father, and child all filled out food frequency questionnaires separately. The child's assessment of their diet was more accurate than both the mother and fathers. The second study used a recall of the previous days school lunch to determine the response accuracy of parents vs. children (Hunsberger et al., 2013). This was a study of 25, 6 to 8 year old children. Recalls were taken from the parents, teachers, and children alone. The actual composition of the child's meal was determined by the duplicate plate method. They found that the children reported most accurately what they had eaten the day before. Only four out of twenty-five parents knew what foods their child had eaten, and none knew how much they consumed. The results from these two studies and the flawed design of the study that validated joint-recalls suggest that child-only recalls may be a better way of analyzing a child's diet than the joint-recall method.

ASA-24

The Automated Self Administered 24 hour (ASA 24) Dietary assessment tool is a self-administered computer-based system to collect 24 hour dietary recall data. Depending on the version used, it may also be able to collect single or multiple day food records ("Automated Self-

Administered 24-Hour (ASA24®) Dietary Assessment Tool.”). The website has two components, a researcher website and a respondent website. The respondent website allows participants to complete the study. The researcher website allows the researchers to monitor the study as well as collect food and nutrient analyses from the data that were collected (Subar et al., 2012). This tool uses the USDA Automated Multiple- Pass Method in order to gather the most complete and accurate recall information from the participant (Suber et al., 2007). This method of data collection has been validated to properly estimate total energy expenditure in study participants (Moshegh et al., 2008). In the data that were collected for this study, both the 2011 and 2016 versions of the ASA 24 were used because the 2011 version was discontinued during data collection. Validation studies were done on the 2011 version, and it was found to be valid in adults (“ASA24® Evaluation & Validation.”). The researchers in this study chose to use this version because it provided a wide range of foods and dietary intake for the child was provided by both the parents and children.

Healthy Eating Index

The Healthy Eating Index (HEI) is a tool used to asses diet quality in relation to the Dietary Guidelines for Americans. The 2015- 2020 Dietary Guidelines focused heavily on eating patterns and overall diet as opposed to certain components when assessing the effect diet has on health outcomes (Kirkpatrick et al., 2018). The HEI yields a total score, assessing the individuals overall diet quality as well as component scores which can be used to analyze specific parts of the diet and can be combined to examine patterns in the diet. The components are broken up into the two categories of adequacy and moderation. The adequacy components of the 2015 HEI include total fruits, whole fruits, total vegetables, greens and beans, whole grains, dairy, total protein foods, seafood and plant proteins, and fatty acids. The moderation groups include refined grains, sodium, added sugars, and saturated fats. In order to calculate a score, the HEI uses densities rather than absolute amounts. For each component, the standards for scoring look at the quantity per 1,000 calories or as a percentage of energy consumed. This allows for the calculation of a score reflective of quality rather than quantity. Most of the minimum and maximum scores are derived from the least restrictive recommendations in the 1200-2400 kcal patterns of the USDA Healthy US- Style Eating Patterns. Therefore, for all the components in the adequacy category the maximum score is achieved by consuming an amount greater than or equal to the dietary guideline, while the minimum score of zero would be achieved by eating none of the foods included in that component (with the exception of fatty acids). For the moderation category, a maximum score is achieved by eating an amount that is less than or equal to the guideline for that component (Krebs- Smith et al., 2018). While 24 hour recalls and short term food records only give a limited picture of the diet due to the small sample time frame, these are recommended in data collection for use with the HEI because they are less effected by systematic bias than other forms of data collection (Kirkpatrick et al., 2018). The Healthy Eating Index is an effective tool for assessing overall diet quality in relation to other factors and health outcomes.

The HEI is scored on a scale of 0-100. A score of 100 would indicate that the person's diet aligns perfectly with the Dietary Guideline recommendations from the USDA ("HEI Scores for Americans."). In the latest version of this tool, the HEI- 2015, the average score among Americans of all ages was 58.9 out of 100. This suggests that on average, Americans do not have a healthy diet when compared with the Dietary Guidelines. In addition, children aged 2-17 had the lowest average HEI score when compared with all other age groups. The average for this group in the HEI-2015 was 54.9. Children aged 2-17 had better average scores than all

Americans in the total fruit, whole fruit, whole grains, dairy, and sodium categories. They had worse average score than all Americans in the total vegetable, greens and beans, total protein, seafood and plant protein, fatty acid, refined grains, added sugar, and saturated fat categories ("HEI Scores for Americans."). The scores on the HEI-2015 indicate that the American diet, especially in children, needs to improve greatly in order to achieve a healthy population.

Purpose

Existing research has evaluated the link between various cognitive factors and nutritional markers in children. However, most of the studies that have been conducted use cognitive measures other than Intelligence Quotient (IQ) to determine correlation between diet and intelligence level. In addition, the research that has already been done in this area usually looks at specific macronutrients, micronutrients, or food groups in relation to cognition. The purpose of this study is to evaluate the associations between IQ and overall diet quality as measured by the Healthy Eating Index (HEI) in children.

Research questions

What is the association between overall diet quality as measured by the Healthy Eating Index (HEI) and Intelligence Quotient in children aged 9,10, and 11 from the city of Syracuse?

How are the adequacy and moderation sub categories of the HEI related to IQ?

What is the relationship between BMI and diet quality as measured by the HEI?

What is the relationship between BMI and IQ?

What macro and micronutrients have the greatest effect on IQ in children?

Manuscript

Currently, the average child in the United States is not meeting the dietary guidelines (Krebs-Smith et al., 201). This may have implications for their growth, both physical and psychological, and their quality of life. There are many studies that have assessed how certain nutrients affect cognitive functioning. Research shows that better nutritional markers and dietary habits are associated with increased cognitive ability in children. However, the association between overall diet quality and intelligence quotient (IQ) in children has not been extensively studied.

Consuming certain food groups and macronutrients have been shown to influence the cognitive development of children. One longitudinal study of 589 children found that at 3.5 years old children who consumed foods from the grains group more than four times per day showed a significant increase in intelligence (Theodore et al., 2009). In the same study the researchers also found that children who consumed fish, including oily fish and shellfish, at least once a week had significantly higher total IQ scores than those who did not (Theodore et al., 2009). In a cross-sectional study of 65 children aged 7 to 9 years old, researchers found that a higher overall intake of fat was related to lower cognitive control while fiber was related to higher cognitive control (Khan et al., 2014). In the same study, short chain fatty acids were significantly negatively correlated with cognitive function while omega 3 fatty acids were significantly positively correlated (Khan et al., 2014). In prospective cohort study of 496 Finnish children, researchers found that high protein intake was significantly associated with improved speech and language skills in boys at five years of age (Rask-Nissilä et al., 2002).

Micronutrients have been studied for their role in cognitive development and functioning. A study conducted by the United Nations Children's Fund in developing countries found that deficiencies of iron, vitamin A, iodine, and folic acid can have negative consequences for brain development and cognition ("UNICEF report on IQ and nutrition."). A randomized control trial of 740 Chinese children aged 6-9 years old studied the effects of zinc repletion. The researchers found that after the supplementation, neurophysiological performance increased (Sandstead et al., 1998).

One longitudinal study of children aged 3,4,7 and 8.5 examined the relationship between dietary pattern and IQ. Dietary data were collected using a food frequency questionnaire and were used to classify the subjects into one of three diet patterns including processed, traditional, and health conscious. Researchers found that the children who had a health conscious diet pattern had a significantly higher IQ (Northstone et al., 2011).

Body mass index (BMI) has also been studied in relation to IQ. In a cross- sectional study of 16 and 17 year olds, researchers found that those in the obese category had the lowest IQ scores and those in the normal weight category had the highest scores (Goldberg et al., 2013). One theory of explaining this is that those with a lower IQ generally have less healthy behaviors. This includes poor diet which is associated with an increased risk of obesity (Kanazawa, 2013).

The aim of this study was to evaluate the relationship between diet quality as measured by the 2015 Healthy Eating Index (HEI-2015) and IQ in children. Relationships between BMI and IQ, and BMI and diet quality were also assessed. Although they are not a part of the HEI, specific macronutrients and micronutrients were also examined in relation to their effect on IQ in children.

Methods

Study Design and Participants

The data in this cross-sectional research study were collected as a part of the Syracuse Lead Study. Although the data used was from the Lead Study, the participants had lead levels well below the acceptable range and did not receive any intervention regarding lead and their diet. The sample population consisted of 266 children living in the city of Syracuse, NY. Recruitment was restricted to certain zip codes in order to target low socioeconomic status neighborhoods. Only participants with complete dietary data were included in the analysis. All of the participants identified as either Black or White and were aged 9-11 years old.

Measures

Anthropometrics. Height and weight were measured in triplicate using a mechanical physician scale and stadiometer. BMI was calculated as weight (kg)/ height $(m)^2$. BMI percentiles were also calculated ("Growth Charts - Data Table of BMI-for-Age Charts."). In children, BMI percentile is used with child BMI growth charts to assess weight status.

Dietary Assessment. The dietary data were collected using the Automated Self-Administered 24 hour (ASA 24) dietary assessment tool (Subar et al., 2012). This computer-based system uses the USDA multiple pass method to obtain a 24-hour recall from the subject. For this study, two days of dietary data was collected by a trained researcher. Both the parent and child provided recall information for the child. The ASA24-2014 and ASA24-2016 were the two versions used. All data were merged and any differences in the data collected were accounted for during data cleaning. The dietary data gathered in the ASA 24 was used to calculate Healthy Eating Index (HEI) scores using SAS code provided by the National Cancer Institute ("Epidemiology and Genomics Research Program."). The HEI score considers the amount of a specific food groups or nutrients consumed in relation to 1000 kcalories consumed. This allows diet quality to be compared among individuals or groups, even if their overall energy intake is not the same. The HEI yields a total score and component scores that analyze specific parts of the diet. The component scores are broken up into adequacy and moderation categories. The adequacy components of the 2015 HEI include total fruits, whole fruits, total vegetables, greens and beans, whole grains, dairy, total protein foods, seafood and plant proteins, and fatty acids. The maximum score for the adequacy categories is achieved by consuming an amount greater than or equal to the dietary guideline. The moderation groups include refined grains, sodium, added sugars, and saturated fats. For the moderation categories, a maximum score is achieved by consuming an amount less than or equal to the dietary guideline (Krebs- Smith et al., 2018).

Intelligence. Both subject and parent IQ data were collected using the Kaufman Brief Intelligence test (KBIT) during their research assessment visit to the laboratory. This test can be administered in approximately twenty minutes and is used as a screening tool to get a general idea of the subject's intelligence. It consists of three subtests; the verbal knowledge and riddles subtests examine verbal intelligence while the matrices subtest examines non-verbal intelligence (Bain & Jaspers, 2010). The test yields a raw verbal, non-verbal, and composite IQ score. The raw scores obtained directly from the test are then converted into standard scores, which were used for the data analysis.

Data Analysis

Descriptive statistics (measures of central tendency, normality, and frequencies) were conducted for variables of interest. Participants were divided into BMI categories (underweight, healthy weight, overweight, obese) based on their BMI percentile. Additionally, the participants were divided into two group to indicated healthy weight versus overweight status. A median split was computed for grouping children into low and high IQ groups. The same procedure was done to divide parents into low and high IQ groups. Inferential statistics were run to answer the study research questions. Pearson correlations were conducted to examine the relationship between dietary factors and IQ. Independent samples t-tests were used to assess differences in HEI total and subscores between healthy weight and overweight child participants. Independent samples t-tests were also used to examine differences in KBIT scores between the two weight status groups. Chi square analysis was performed to determine if there was a difference in the distribution of low and high IQ scores among race and gender. A regression was conducted to examine whether any of the HEI-2015 components predicted child IQ while controlling for child race, child gender, and parent IQ.

Results

Demographics

The study population consisted of 266 children residing in the city of Syracuse, NY at the time of the study. The sample was 53% male and 47% female. The age distribution was as follows, 34% were either 8 or 9 years old, 32% were 10 years old, and 34% were 11 years old. Only children identifying as African-American or Caucasian participated in the study. The sample was comprised of 57% African- American children and 43% Caucasian children. The majority (54%) of the population were of a healthy weight. Only 2% of the sample was classified as underweight, while 16% and 27% of the population were overweight or obese, respectively. The demographic characteristics of the study population are summarized in Table 1.

Table 1- Demographic characteristics of study participants

	n	%
Gender		
Male	142	53
Female	124	47
Race		
African- American	153	57
Caucasian	113	43
Age		
8 or 9 Years Old	91	34
10 Years Old	85	32
11 Years Old	89	34
Weight Status		
Underweight	6	2
Healthy Weight	144	54
Overweight	43	16
Obese	73	28

Dietary Quality

The HEI- 2015 scores were calculated for the population as a whole. This includes the total score as well as all of the adequacy and moderation subcategories. Overall, the diet of the study participants was quite poor. The maximum total score for the HEI is 100, which would mean that the persons diet is perfectly aligned with the recommendations. The mean and standard deviation for the total HEI score of all the participants was 46.6±10.0.

The results of the HEI analysis (maximum possible scores, means and standard deviations) for the study population are summarized in Table 2. The maximum score for the adequacy subcategories of total vegetables, greens and beans, total fruits, whole fruit, total protein foods, and seafood and plant protein is 5. Of these subcategories, greens and beans had the lowest score (mean= 1.0 ± 1.7) and total protein foods had the highest score (mean= 4.0 ±

1.3). The rest of the adequacy subcategories (whole grains, total dairy, and fatty acids) have a maximum score of 10. Of these, whole grains had the lowest score (mean= 2.2 ± 2.3) and total dairy had the highest score (mean= 6.6 ± 2.8).

The moderation categories all have a maximum score of 10. Even in the moderation categories, a higher score is reflective of a diet that adheres more strictly to the dietary guidelines and is therefore considered healthier. Sodium intake had the lowest scores with a mean of 3.7 ± 2.9. Added sugars had the best scores in the moderation group with a mean of 5.7 ± 2.9.

While they are not part of the HEI-2015, daily calorie and macronutrient intakes were also assessed. Daily calorie intake had a mean of 1986 kcalories, with a standard deviation of 33 kcalories. The mean protein intake of the population was 73.4 ± 1.6 grams. Fat and carbohydrate intake had means and standard deviations of 74.1 ± 1.6 and 261.5 ± 4.7 grams, repectively.

Table 2- HEI- 2015 Scores For Children

Component	**Maximum Score**	**Mean**	**SD**
Total Score	100	46.6	10.0
Adequacy			
Total Vegetables	5	2.0	1.3
Greens and Beans	5	1.0	1.7
Total Fruits	5	2.9	1.8
Whole Fruit	5	2.5	2.1
Whole Grains	10	2.2	2.3
Total Dairy	10	6.6	2.8
Total Protein Foods	5	4.0	1.3
Seafood and Plant Proteins	5	2.0	2.1
Fatty Acids	10	3.9	3.1
Moderation			

Sodium	10	3.7	2.9
Refined Grains	10	4.3	3.2
Saturated Fats	10	5.6	2.7
Added Sugars	10	5.7	2.9

Child and Parent Intelligence

Reference values for KBIT scores have a mean of 100 and standard deviation of 15 for the composite, verbal, and nonverbal scores. Our sample had a composite score mean of 99 ± 17. The scores for the nonverbal portion were the lowest among the children with a mean of 98 ± 15. The verbal portion had the highest mean score of 100 ± 17. Parental IQ was also assessed. The verbal portion had the lowest scores among the parents with a mean of 94 ± 16. Non-verbal scores were the highest for this group with a mean of 96 ± 15. The parental composite scores had a mean of 95 ± 16. The results of the KBIT data analysis are summarized in Table 3.

Table 3- KBIT Scores for Children and Parents

	Verbal	**Non-Verbal**	**Composite**
Children in Sample			
Mean	100	98	99
Standard Deviation	17	15	17
Minimum	52	64	60
Maximum	146	136	146
Parents			
Mean	94	96	95
Standard Deviation	16	15	16
Minimum	61	46	56
Maximum	156	131	147

Intelligence and Dietary Quality

Correlations were conducted to assess the relationship between dietary component scores from the HEI-2015 and IQ measures. The child verbal IQ score and fatty acid score were significantly negatively correlated (r=0.13; p=0.032). Child verbal IQ score was also significantly negatively correlated with refined grain scores (r=0.17; p=0.006). Child verbal IQ score had a significant positive correlation with seafood and plant protein (r=0.18; p=0.003). Child non-verbal IQ and refined grain scores were significantly negatively correlated (r=0.12; p=0.047). Child composite IQ score was significantly positively correlated with seafood and plant protein score (r=0.17; p=0.006). Parent verbal IQ score and child fatty acid intake were significantly negatively correlated (r=0.13; p=0.040). Parent verbal IQ score and total protein score were significantly negatively correlated (r=0.19; p=0.002). Parent composite IQ score and child total protein score were also significantly negatively correlated (r=0.14; p=0.023). Parent composite IQ score and fatty acid score were significantly negatively correlated (r=0.13; p=0.045).

Participants were grouped into under/healthy weight or overweight/obese weight status categories and HEI scores were examined based on child weight status. Children in the under/heathy weight group had significantly higher scores for the whole grains and seafood/plant proteins categories of the HEI-2015 compared to overweight/ obese children (p values <.05). No significant differences were found between groups for total HEI scores or for other subcategory scores.

The KBIT scores were split into low and high groups for both children and parents. For the child standard verbal scores, there was a statistically significant difference in the fatty acid (p=0.042), refined grains (p=0.024), saturated fat (p=0.004), and seafood and plant protein (p=0.009) scores between the two groups. The high IQ group scored better in the seafood and plant protein, while the low IQ group had significantly better scores in the other three categories. For the non-verbal split, the only significant difference between the two IQ groups was that the low group had a higher total vegetable score (p=0.011). Finally, the composite scores for the study population were split and it was found that the refined grain scores were significantly higher in the low IQ group than in the high (p=0.022).

Data were analyzed similarly for the IQ scores of the parents of the children in the study population. Their IQ scores were then analyzed with the HEI-2015 scores of the children. This was done because in young children, the parents usually have a significant role in determining what the child eats. The children who had parents with a verbal IQ in the low category had a significantly higher total protein intake (p=0.019). Children had a significantly higher HEI score for total protein (p=.007), added sugars (p=0.003), and total score (p=0.021) if their parent had a non- verbal KBIT score in the low group. The children who had parents with a high composite IQ had significantly better HEI scores for sodium (p=0.014). Children with parents in the low composite IQ group had significantly higher HEI scores for total protein (p=0.014) and added sugar (p=0.010).

Crosstabs were conducted to examine the breakdown of race and gender within the same in relation to IQ groups. Chi square analysis revealed that there was no significant difference between the distribution of males and females among the low and high IQ groups. However, there was a significant difference in the distribution of African-Americans and Caucasians between the two IQ groups. There were 105 African-Americans in the low IQ group, and only 48 in the high. While there were 29 Caucasians in the low group and 84 in the high.

A regression was run to examine whether any of the HEI scores predicted child composite IQ, while accounting for child race, child gender, and parent composite IQ. The results of the regression indicated that two predictors explained 32.3% of the variance ($R2=.323$, $F(16,242)=8.69$, $p<.001$). It was found that race significantly predicted child IQ ($\beta=.28$, $p<.001$) as did parent composite IQ score ($\beta=.39$, $p<.001$). No HEI-2015 components were significant predictors in this model.

Correlations were conducted to assess the relationship between IQ scores and certain micronutrients. Iron, zinc, folate, fiber, and vitamin A were the nutrients analyzed against both parent and child IQ scores. While there were correlations between nutrients, there were no statistically significant correlations between any of the selected nutrients and IQ scores for either the parents or children.

Discussion

The findings of this research indicate that there was no significant association between child overall diet quality and IQ for this sample population. On average, HEI-2015 scores were lower than average. In a study of 9000 American children aged 2-18, the average composite HEI-2015 score for the entire sample population was 54.9. The researchers found that HEI-2015 scores significantly decreased as age increased (Thomson et al., 2018). The average composite score for the 6-11 year old age group was 53.9, while the average in our study population was 46.6. In general, our study population was of low socioecomic status which could explain the lower than average HEI socres. A review conducted on multiple cross- sectional studies showed that lower socioeconomic status was related to a lower diet quality across all measure of SES including occupation, education, and income (Darmon & Drewnowski, 2008). The KBIT scores of this sample were representative of the standard population.

The seafood and plant protein score was the only HEI component significantly associated with child IQ. One possible explanation for this is that low maternal seafood consumption is associated with a lower child IQ (Hibbelin et al., 2007). If the mother consumed more seafood during pregncancy, they are more likely to feed it to their children on a regular basis, hence the positive relationship between seafood consumption and child IQ. For both parent and child IQ, there was a significantly higher number of African- Americans in the low group and Caucasians in the high group. Some of this variation could be explained by cultural or language related bias in the KBIT test (Bain & Jaspers, 2010). In this model, no HEI components were found to be significant predictors of child IQ, however both race and parent IQ were significant predictors. Overall, the trend in these results show that where there is a significant difference between HEI score and IQ, those with a lower IQ have a better diet quality. This is inconsistent with the findings of other literature in this field of research.

The findings of other research in this area suggest that diet quality should have a positive influence on a child's cognitive development and therefore IQ. One limitation of this study is that subject recruitment targeted only low socioeconomic status neighborhoods. Additionally, data about maternal feeding practices were not collected in this study although breastfeeding has been shown to have an impact on child IQ (Oddy et al., 2003 & Quinn et al., 2001). There are also known limitations to providing accurate dietary recall data, especially when using joint parent- child recall (Hunsberger et al., 2013). One major barrier when collecting dietary data is underreporting by the participants. In a study of 7769 adults, that reported dietary data via 24 hour recall, 18% of men and 28% of women were found to be underreporters (Briefel et al., 1997). The cross- sectional nature of this study is also a limitation because causality can not be established. Strengths of this study include the use of the validated ASA 24 tool and the use of the HEI which allows for an accurate comparison of diet quality among the sample.

Further research into the relationship between child diet and IQ using a sample population that is more representative of the general population may yield different results. This study examined diet quality in relation to child intelligence but there are other factors that contribute to child intelligence that were not measured. Researchers are currently analyzing the data to examine diet and heavy metal intake in this sample. When including lead in the regression model to predict child IQ, lead was not a significant predictor.

Conclusion

Although there were no significant relationships between diet quality and child IQ after controlling for other factors, there are still some important takeaways from this research. Overall, the diet quality of children is poor. There should be more focus placed on this issue including efforts to inform the public on how to feed children a well balanced diet that is benefical for growth and development. Aditonally, children in the overweight/ obese group had significantly lower scores for seafood and plant protein intake, which was predicitive of child IQ before controlling for confounding factors. Due to the growing obesity epidemic, this relationship should be further explored. The discrimination in IQ scores between racial groups is another important finding of this research that needs to be further explored to explain the factors that cause it.

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