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Factors Influencing Cognitive Intelligence Among Children 6-7 Years Old in Vietnam

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Bachelor of Science
University of Oklahoma
2014

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An abstract of
A thesis submitted to the Faculty of the
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Abstract

Factors Influencing Cognitive Intelligence Among Children 6-7 Years Old in Vietnam

By Kelley Raines

Background Countries are aspiring towards societies in which every child has the opportunity to complete primary or basic education; however, it is evident that many children fail to meet their developmental potential. A child's home learning environment and nutritional intake have been considered influential on cognitive ability in previous research, but there has been limited research including these two factors within analysis of Vietnamese children. The current study assesses these two factors along with other pertinent determinants to observe what significantly associates with childhood cognitive ability in Vietnamese children.

Method A cross-sectional analysis was conducted using data that were collected as part of the PRECONCEPT study, a randomized controlled trial of pre-pregnancy micronutrient supplementation that was conducted in rural Vietnam. The study subjects were a subsample (n=467) born to women who participated in this trial and were followed up at age 6-7 years. Descriptive statistics and multivariate regression analysis were carried out to examine the associations among household environment, maternal characteristics, and child attributes with the Wechsler Intelligence Scale for Children.

Results Socioeconomic status (Low*: Ref, Medium: β [95% CI] = 3.3 [0.6, 5.9], High: 5.7 [2.6, 8.8]), home environment quality (0.3 [0.0, 0.6]), maternal education (Elementary*, Middle: 1.8 [-2.4, 6.0], High:2.0 [-2.6, 6.6], College:6.3 [1.0, 11.7]) , and childhood growth retardation (-5.2 [-8.8, -1.5]) were significantly associated with children's full-scale IQ. Similar associations were seen for the subscales that measured working memory, verbal comprehension, and processing speed; whereas socioeconomic status (Low*, Med:4.1 [1.0, 7.3], High: 9.6 [6.2, 12.9]) and diet diversity (Low*, Med: 3.5 [-0.5, 7.], High: 5.5 [1.4, 9.6]) were significantly associated with perceptual reasoning.

Conclusion Child attained size was significantly and positively associated with full-scale IQ at age 6 years even after adjusting for the effects of household socioeconomic status, maternal education, and the quality of the learning environment. A similar relationship was seen for diet diversity and perceptual reasoning. Along with nutritional status, household environment and maternal characteristics produced consistent associations across cognitive indices. These findings indicate the importance of continued nutritional interventions into middle childhood, accompanied with household level improvements, to assure developmental potential.

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Chapter 1: Comprehensive Review of Literature

Methods of Review

In this review, literature analyzing cognitive development in children 5-11 years old was evaluated and summarized to provide a current status of research. The relative roles of socioenvironmental factors, including household environment, caregiver characteristics, and childhood attributes, have been reviewed from preconception to 11 years old to identify the framework in which a child's cognitive ability is formed. Specific inclusion and exclusion criteria were set to narrow the scope of relevant research (**Table 1**). Systematic reviews were initially analyzed to provide a high-quality understanding of the associations between each socioenvironmental factor and childhood cognitive ability. When systematic reviews were not available, other relevant study types were utilized, and all studies and reviews had essential information extracted.

Table 1: Methodology of Literature Review

Databases Utilized	PubMed, Web of Science, Google Scholar
Search Criteria	
Age	5 - 11 Years
Child Status	Healthy
Article Date	Post - 1980
Outcome	"Child Cognition", "Child Development", Child Intelligence", "Child Cognitive Function"

Cognitive Development in Middle Childhood

Middle childhood represents a period when children are starting school and developing relationships outside of the household. Theoretically, it is also a shift from children inordinately being tied to the concrete, readily perceptible characteristics of tasks to a logical and more systematic approach (National Research Council,1984). Based on Jean Piaget's theory of cognitive development, children become capable of logical thinking, reasoning, and problem-solving in a variety of tasks in this age period (National Research Council,1984).

A child's intelligence level is a vital determinant of future health outcomes and quality of life (Feinstein, 2004). The development of cognitive ability is genetically and environmentally determined, with the relative role of each unknown (Posthuma, 2005). Although a portion of a child's intelligence may be inherited, commonly, research focuses on socioenvironmental factors that influence cognitive ability since they are modifiable, and as such, can be improved through early life interventions (Engle, 2011). The remainder of this literature review will focus on these socioenvironmental factors, and how a child's household environment, caregiver characteristics, and childhood attributes influence cognitive development.

Household Determinants

Ethnicity: An individual's ethnicity has been reported to initially significantly associate with cognitive functioning in children, but this relationship is also frequently attenuated by other influences from the household or maternal level (Smith, 2016). In a cross-sectional study in the UK, Smith found significant inequality across migrant ethnic minorities and the UK born children at the age of three, with UK born children scoring significantly higher on standardized cognitive tests than ethnic minority groups. However, the differences found across groups diminished with increasing age when measured at five and seven years old. A cumulative exposure to a new environment post-migration minimized cognitive variations between ethnicities, ultimately minimizing the impact of generational inequalities and highlighting the influence of environmental exposure on intelligence (2016). Environmental factors including socioeconomic demographics, home environment/parenting styles, family structure, poverty levels, along with maternal mental and physical health, decreased or eliminated the association between ethnicity and childhood cognitive capability (Smith, 2016; Brooks-Gunn, 1996). Although the direct impact of ethnicity/race on childhood cognitive function is rarely supported by research, differences in appropriate measurements for factors such as socioeconomic status have been shown to differ by race/ethnicity (Nuru-Jeter, 2010). For example, financial resources were predictive of cognition for children of white families, but not black families (Nuru-Jeter, 2010). This implies that the dimensions of social class most critical for cognitive development among historically oppressed and marginalized social groups are different from the dimensions most salient to others and should be considered when analyzing factors that influence cognitive ability in differing races/ethnicities (Nuru-Jeter, 2010).

Family Composition: Another portion of the literature on the influence of childhood environment exams the effect of family structure on the development of cognitive and non-cognitive skills in children (Carlson, 2001; Dai Heckman, 2013). When compared to consistent two-parent households, children consistently reared in single-parent households were found to be at a higher risk of poorer behavioral and cognitive outcomes, with children scoring, on average, 13 points lower on reading recognition tests (Carlson, 2001). Children who experienced multiple changes in parental structure in early to late childhood scored, on average, 8 points lower (Carlson, 2001). Families with grandparents involved in parenting have shown both positive and negative associations with math and English test scores in early adulthood; however, the effects of these relationships have not shown to be significant in comparison to direct parental or sibling inputs (Dai Heckman, 2013). A growing amount of literature is contributing to the understanding of sibling relationships and the influence they have on child and adolescent development. A cross-sectional study of young adults (19-30) by Dai Heckman et al. found that older siblings affect young siblings to the same, if not greater degree than parents through their direct relationship with their sibling and indirect relationship with their parents (2013). Although several studies have reported the significant effect of various family structures, the association often becomes insignificant when maternal mental health, maternal aptitude test scores, and income are considered (Carlson, 2001). One hypothesis for this attenuation suggested that family structure could operate through other environmental factors, such as economic status, to influence childhood cognitive ability (Carlson, 2001).

Socioeconomic Status: Socioeconomic status (SES) is conceptualized as the social standing of a group or individual, commonly measured by the combination of household income, education, and head(s) of household occupation (APA, 2020). Investigations of socioeconomic status frequently reveal disparities in access to resources between individuals and groups and is rooted in issues related to privilege, power, and control (APA, 2020).

Low socioeconomic status, as measured by income, has shown to impact the well-being of children through birth outcomes, physical health, growth stunting, cognitive abilities, school achievement outcomes, and emotional and behavioral outcomes (Brooks-Gunn, 1997). Children who live below the poverty threshold are 1.3 times as likely as children who live above the line to experience developmental delays and learning disabilities (Brooks-Gunn, 1997), and those in extreme poverty (income less than half the poverty threshold) are at risk of scoring 6 –13 points lower on various standardized tests of IQ (Smith, 1997). The impact of SES on childhood cognitive ability has been reported to persist despite controlling for maternal age, marital status, education, and ethnicity lending to the theory that SES is a fundamental predictor of a child’s cognitive ability (Smith, 1997). The pathways through which low socioeconomic status operates could include a child’s health and nutrition, home environment, parental interactions with children, parental mental health, and neighborhood conditions (Brooks-Gunn, 1997). Of these, a substantial portion of the effects of family SES on cognitive outcomes has been accounted for by home environment (mother-child interaction, opportunities for learning, the physical state of home), with a higher status of SES associated with improved home environments and consequently higher achievement scores in pre-school children (Duncan, 1994).

Home Environment: A child's home environment encompasses a multitude of influencers within the proximal home, including the mother-child interaction, opportunities for learning, and the physical environment (Duncan, 1994). The quality of the childbearing environment is commonly measured by a semi-structured assessment involving the direct observation of the home and an interview (Bradley and Caldwell, 1988). Such assessments have linked a positive home environment to higher executive functioning and verbal intelligence scores in children during middle childhood, with significant contributions to cognitive intelligence scores accounting for up to 16% of the variation in IQ measurements (Fishbein, 2019; Luster, et al. 1992). However, a study by Coon found a child's home environment score to correlate as highly with parent IQ as child IQ, thus hypothesizing that the association between home environment and child IQ could be mediated by parental IQ (1990). Furthermore, in a longitudinal survey by Luster et al., this assumption was supported by mothers with a higher level of education commonly providing a more supportive environment for their school-aged children (1992). Although the quality of home environment is not correlated to such a degree to be considered a proxy for maternal intelligence or vice versa, excluding maternal intelligence from the analysis of childhood cognition could overestimate the impact of home environment. (Luster, et al., 1992).

Research on the influence of a community-level (distal) environment on a child's cognitive development is sparse in comparison to that of the proximal family. Kohen et al.

looked specifically at the effect of neighborhood socioeconomic conditions and five-year old's verbal and behavioral outcomes. While no overarching direct significance was found between the two, a mediated relation through the family-level process and neighborhood cohesion could possibly be an impactful pathway (2008). Fishbein supported this finding through a cross-sectional analysis, which reported minimal change in a child’s executive functioning when neighborhood conditions were accounted for, highlighting the influence of a child’s home environment over that of a community (2019).

Food Insecurity: Household food insecurity is another environmental exposure analyzed with childhood cognitive development and occurs, “. . . whenever the availability of nutritionally adequate and safe foods or the ability to acquire acceptable foods in socially acceptable ways is limited or uncertain.” (Gee, 2018). A systematic review of household food insecurity found that even at marginal levels, food insecurity was associated with behavioral, academic, and emotional problems from infancy to adolescents (Shankar, 2017). This association was found to be a dose-response relationship between household food insecurity and academic performance, with increasing levels of food insecurity significantly associated with decreasing math scores (Shankar, 2017; Winicki et al.2003). However, Belsky reported the relationship between food insecurity and childhood cognitive ability to be fully attenuated for 12-year-old children when household income and maternal personality traits were considered (Belsky, 2010). Mothers in food-insecure households were significantly more likely to have high-risk personality profiles, and the household as a whole was less sensitive to a child's needs. This environment proved to influence both childhood cognitive function and household food security, possibly mediating the relationship between the two (Belsky, 2010). Pathways in which food insecurity has been found to impact cognitive development include direct nutritional deficits and health consequences, and indirect impaired classroom functioning (Gershoff, 2007; Murphy et al., 1998). A cross-sectional study found a child reported as "hungry" or "at risk for hunger" to have increased hyperactivity, absenteeism, and occasional tardiness. Food insufficiency and "hunger" were associated with poor behavior and academic functioning (Murphy et. Al., 1998). However, reported sampling bias within the cross-sectional study warrants further review of the association between food insecurity, classroom performance, and cognitive development (Murphy et al., 1998).

Caregiver Determinants

Parental Education and Intelligence: At the center of socio-economic status (occupation, income, and education), maternal education reports the strongest association with a child's cognitive ability (Harding, 2015). Similarly, paternal occupation prestige, as a proxy for educational level and intelligence, was linked to improved cognitive functioning, with every 10-unit increase in father's occupational prestige resulting in increased children's cognitive performance by 2.0 points at seven years and 1.1 points at 11 to 13 years (Tong, 2007). Parental intelligence and educational level have been associated with a greater likelihood of engaging in cognitive stimulation of their children, fostering an intellectual environment, and a greater affection and interest in the child's schooling, all of which have been significantly associated with childhood reading ability (Byford, 2012). Harding proposes that parental education expands a parents' capacity to access human, cultural, and social capital, which is then used to promote their child's cognitive development (2015).

Maternal Mental Health: Several studies have examined the relationship between maternal mental health that has been measured at various time points (prenatal and postpartum) and childhood cognition (Kurstijens, 2013; Niederhofer, 2004). Commonly, the impact of prenatal mental health has been primarily studied through the effects on birth outcomes (Orr, 1995; Matte, 2001; Breslau et al. 1996). Prevalence of low birth weight and preterm delivery increased from 9.5% to 14.1% in mothers scoring in the top 10% on the CES-D depression scale (Orr, 1995). In a study cohort study by Matte et. al, mean IQ increased monotonically with birthweight in both sexes across the range of birth weight (2001). This association stayed true after adjusting for maternal age, race, education, birth order, and socioeconomic status, with birth weight in boys, but not girls, directly associating with differences in IQ by 0.50 points with a 100 g difference in birth weight (Matte et al, 2001). Antenal psychological distress has also been reported to result in more significant mental distress in subsequent children at six years old, which was negatively associated with school grades (Niederhofer, 2004).

Postpartum depression (up to 18 months after birth) and the associated cognitive outcomes in the first seven years of life have been examined in several prospective longitudinal studies (Grace, 2003). In one of these studies, Murrey found no relationship between maternal depression at any time point and cognitive development, even within known vulnerable groups at five years old (Murrey, 1996). Similarly, at six years old, neither timing (postpartum or chronic), recency, severity, number of episodes, nor the duration of the depression episodes, at any point post-partum, influenced cognitive development in the first seven years of life (Kurstjens, 2001). However, a child's experience of maternal insensitivity early in life did predict poorer cognitive outcomes. It was mediated by postpartum depression at 18 months, suggesting that maternal depression may work through an indirect pathway such as the quality of home environment (Murrey, 1996).

Maternal depression in middle childhood was analyzed in two prospective cohorts by Brennan et al. (2000) and Kurstjens (2001). Brennan et al. found that vocabulary development scores were not significantly related to the timing of depression, but it was significantly associated with severity and chronicity; importantly, the variance in vocabulary scores attributable to maternal depression was close to zero (2000). This minimal attributable impact was reinforced by Kurstjens, who reported no variation in cognitive ability for children with mothers who had an episode of depression within the last year (2001). However, low scores on the K-ABC cognitive assessment were found for boys with chronically depressed mothers in low SES households or born at neonatal risk suggesting that children in already vulnerable circumstances may be more impacted by depressed mothers (Kurstjens, 2001).

Maternal Body Composition (BMI): Maternal nutrition before and during pregnancy is identified as an important, influential factor for offspring health (Ramakrishnan, 2012). Obesity or undernutrition during pregnancy can influence a child's nutritional status, as well as cognitive functioning later in life (Li et al., 2018; Alvarez-Bueno, 2017). In a longitudinal study conducted by Li and colleagues, low maternal weight at pre-pregnancy was associated with an increased odds of a child being underweight and thin, 2.02 and 2.79, respectfully, and to have a decreased verbal comprehension index by 2.70 points (Li et al., 2018). Similarly, evidence from four systematic reviews reported a negative influence of pre-pregnancy and pregnancy obesity on offspring's neurocognitive development spanning childhood (Alvarez-Bueno, 2017; Adane, 2016; Van Lieshout, 2011; Van Lieshout, 2013). The association between BMI and children's IQ appears to follow an inverted u-shaped relationship, with a maternal BMI of 20 kg/m^2 having the highest child IQ score at seven years (Huang, 2014). During pregnancy, accelerated gestational weight gain in obese mothers was found to mediate the negative association with cognitive outcomes; however, in mothers with undernutrition, gestational weight gain improved a child's nutritional status later in life but was not related to intellectual development (Huang, 2014; Li et al., 2018). Although maternal BMI, high or low, has been inversely associated with the IQ of a child, a similar association with paternal BMI has been found in a cohort study by Biddal (2014). The impact observed by maternal BMI not be a specific pregnancy-related adiposity effect, and should be carefully analyzed with other know factors of childhood intelligence (Bliddal, 2014).

Maternal Micronutrient Status: Micronutrients are critical to brain development and growth, with iron, in particular, reported to influence early fetal brain development (Georgieff, 2008) Other micronutrients such as vitamin B-6, B-12, and zinc are also considered to play a role in childhood cognitive development (Stephenson et al., 2018). A mothers' availability of nutrients for a developing fetus depends on her dietary intake, nutrient stores, and other contesting requirements, and when depleted, before or during pregnancy, this may be detrimental to supporting the developing fetus and positive birth outcomes (Cetin, 2010). Before conception, low maternal hemoglobin concentrations in mothers was associated with a two-fold increased odds of adverse birth outcomes such a low birth weight or an infant being small for gestational age (Young, 2019). However, much less is known about preconception maternal hemoglobin concentrations and long-term development outcomes, specifically middle childhood cognitive development.

Prenatal anemia was associated with a significantly lower IQ in four and seven-year-old children whose mothers had moderate or mild anemia versus those with normal non-anemic (92.3 and 94.7 versus 100.6) (Drassinower, 2016). Similar to preconception, limited research has been conducted over the association of low maternal hemoglobin concentrations during pregnancy and cognitive function in middle childhood.

Two studies in Nepal and Indonesia reported the impact of micronutrient supplementation during gestation and cognitive ability in middle childhood (Christian, 2010; Prado et al., 2017). The study in Nepal found working memory, inhibitory control, and fine motor functioning in seven to nine-year-old children to be positively associated with prenatal iron/folic acid supplementation in an area where iron deficiency was prevalent (Christian, 2010). Likewise, in Indonesia, children of mothers given multiple micronutrients scored higher in procedural memory than those given iron and folic acid, equivalent to the increase in scores seen from half a year of schooling; simultaneously, children of anemic mothers in the multiple micronutrient group scored higher in general intellectual ability, similar to an increase seen from 1 year of schooling (Prado et al., 2017). A positive association with micronutrient supplementation and an overall positive effect size between the group from 0.00 - 0.18 SD was observed in the study (Prado et al., 2017). Socioenvironmental status was significantly reported within the analysis in Indonesia, suggesting a larger and more consistent impact by factors such as home environment and maternal depression in cognitive function at 9 –12 years old that should be included within the analysis of cognitive functioning (Prado et al., 2017).

Childhood Determinants

Birth Outcomes: Several systematic reviews have synthesized studies assessing the impact of children born preterm and low birth weight on cognitive ability later in childhood. Reviews show a negative association between these birth outcomes and children's cognitive development (Moreira, 2014; Linsel, 2015; Kerr-Wilson, 2012). Intelligence scores were found to be 11.94 points lower among children born preterm, with a statistically significant linear association between the gestational age range suggesting a dose-response relationship (Kerr-Wilson, 2012). Similarly, children who are born small for gestational age were at increased risk for delays in growth and cognitive ability (Sudfeld, 2015). As a child ages, one systematic review found the effect of low birth weight and pre-term birth, which were predictive of global cognitive impairment in children younger than five, to no longer be significant predictors later in childhood (Linsell, 2015). Parental education was the only factor that continued to significantly predict intelligence signifying a growing influence of environmental factors on intelligence as a child enters middle childhood (Linsell, 2015).

Childhood Body Composition: Previous research has suggested a negative association between a child's nutritional status, as reported by anthropometric measurements, and cognitive development. Evidence of the effect of wasting and head circumference is unclear and inconclusive, but stunting in the first two years has been associated with delays in cognitive ability at 5 – 11 years (Sudfield, 2015; Alamo-Junquera et al., 2015). A meta-analysis of observational studies within low to middle-income countries found each unit increase in height for age z-score for children ≤ two years old to be positively associated with a 0.22 standard deviation increase in cognition at 5 to 11 years after multivariate adjustment (Sudfield, 2015). The timeframe in which stunting occurs was analyzed by multiple studies to determine the long-term impact. Early on-set persistent (first stunted at 1–6 months and persisting at 60 months) stunting was found to significantly associate with cognitive intelligence of 5-year-old children even in a fully adjusted model considering home quality, exclusive breastfeeding, maternal education, and income. Neither early-onset non-persistent (first stunted at 1–6 months and not stunted at 60 months), late-onset non-persistent (first stunted at 7–24 months and not stunted at 60 months), nor late-onset non-persistent (first stunted at 7–24 months and persisting at 60 months) stunting were found to significantly associate with a child's intelligence at five years (Alam, 2020). Since the persistence of stunting appears to be key to deteriorated cognitive ability later in childhood, programs focused on alleviation early in childhood have been suggested. Risk factors such as family income, maternal height, and childbirth weight have been found to be protective against stunting (Alam, 2020). Programs focused on socioeconomic position, maternal health, as well as the child's nutrition, have been suggested to combat both pre-natal and intergenerational forces that impact a children's growth and ultimately cognitive ability (Alam, 2020).

Child Pre-School/Day Care: Early care for children outside of the household is commonly distinguished as daycare (0-2 years) and childcare (3-5 years). Both are influential extra-familiar determinants (Margherita Fort, 2016). The influence of daycare (0-2 years) on middle childhood cognitive function has been less frequently studied when compared to childcare (3-5). The available research has been inconsistent and dependent on the economic status of the household (Margherita Fort, 2016; Drange and Havnes, 2015). Margherita Fort reported that an additional month of daycare between 0-2 years was shown to decrease IQ by 0.6 points, but was significant in girls, but not boys (2016). A one-on-one interaction from an adult at home, in a quality home environment, was found to be superior in supporting cognitive development than the shared interaction between the child and care-worker that is typical of daycare settings (Fort, 2016). However, children from low-income homes, with parents who have completed minimal education or with immigrant status, have shown to benefit from daycare attendance (Felfe and Lalive, 2014; Drange and Havnes, 2015).

The impact of childcare on children three to five years old has been extensively researched in the United States, with an overall increased improvement in pre-academic abilities seen in children who attend early education programs, but this influence on cognitive function faded as time persisted (Duncan and Magnuson, 2013). Both low (Puma et al., 2012) and high-income children have been found to benefit from childcare (3-5 y), with the benefits likely to outweigh the costs for middle to high-income children (Havnes, 2015).

Infant Breastfeeding: Breastfeeding has been related to improved performance in children's cognitive development (Kramer, 2008; Horta, 2015). A meta-analysis of 17 studies, reporting estimates on the association between breastfeeding and performance in various intelligence tests, found there to be a positive association between the two with an average gain of 3.44 IQ points in children who were breastfed versus those who were not was reported. Previously distinguished residual confounders such as maternal IQ, home environment, and SES status were controlled for in most if not all of the included studies or the review; however, even after controlling for these variables, the relationship between breastfeeding and childhood IQ persisted. (Horta, 2015). Further support from a large randomized control trial reported an association between exclusive breastfeeding duration and cognitive development (Kramer, 2008).

The exclusivity and duration of breastfeeding has also been related to higher verbal and nonverbal IQ scores in seven-year-old children, with the effect size of 0.80 per month of exclusive breastfeeding translating to five verbal IQ points in almost six months (Belfort, 2013). The duration of breastfeeding past six months proved to benefit language development in middle childhood positively, but when breastfeeding up to two years and longer was systematically reviewed by Delgado, no effect on cognitive ability scores from extended breastfeeding in eight-year-old children was found (Whitehouse, 2011; Delgado, 2013).

Child Dietary Intake: The majority of studies reporting on nutrition and cognitive development have focused on early life micronutrient levels. Observational studies frequently report that micronutrients play an essential role in cognitive development; however, intervention trials of single micronutrients have been less consistent in reporting a significant influence on cognitive ability (Nyaradi et al., 2013). The intake of specific food groups, dietary patterns, or diet diversity in early and middle childhood has been less frequently researched with weak results (Nyaradi et al., 2013). Research has found that diets containing high levels of processed food, high fat, and refined sugars have been associated with lower scores in verbal ability. Commonly, after adjusting for confounders such as maternal IQ, folic acid supplements, and alcohol use during pregnancy, this relationship was attenuated (Leventakou, 2016; Northsonte et al., 2012). The study of dietary patterns rather than individual foods has begun to be studied, providing insight into the intercorrelations between differing foods. Northstone examined the dietary patterns of 'processed' (high fat and sugar content), 'traditional' (meat, poultry, potato, vegetable) and 'health-conscious' (salad, rice, pasta, fish, fruit) childhood diets at numerous time points from three to eight. Findings showed that in a fully adjusted model, higher intakes of processed food at three years old was negatively associated with lower IQ scores at eight years old, while the influence of consuming this diet at a lower frequency at eight years old did not influence IQ at the same age. A 'health-conscious' diet at eight was found to associate with IQ leading to a 1.20-point increase in IQ even within the fully adjusted model (2012). The influence of diet patterns beginning in early childhood through middle childhood appear to minimally associate with intelligence score at 8.5 years old (Northstone, 2012).

Study Population: Vietnam

Beginning in the mid-1980s, when Vietnam was considered one of the world's poorest nations, drastic improvement began leading to the establishment of Vietnam as a low-middle-income nation (World Bank Overview, 2019). Between 2002 and 2018, poverty rates declined sharply from over 70% to below 6% (US$3.2/day PPP), and GDP per capita increased by 2.5 times, standing over US$2,500 in 2018 (World Bank Overview, 2019). The current study occurred specifically in the Thai Nguyen province, where eight different ethnic groups reside, with 70% of the 1 million residents living in rural areas. The majority of the population works as farmers, and the primary language is Vietnamese (Nguyen et al., 2012).

Despite drastic improvements in poverty and overall welfare, malnutrition is still present in women and young children in Vietnam. The Vietnamese South East Asian Nutrition Survey (SEANUTS) reported a prevalence of stunting (15.6%) and underweight (22.2%) for school-aged children aged six to eleven, more commonly in rural than urban areas (Nyguen, 2013). Progressively since the turn of the century, the double burden of undernutrition and obesity has added to the complexity of malnutrition in Vietnam. Almost 29% of the urban children were either overweight or obese in contrast with 4% of the overweight children and 1·6% of the obese children in rural areas, opposite to what was found for undernutrition (Nyguen, 2013). Analysis of diet quality found that most children (6-11y) were not consuming the recommended dietary allowance for Vietnam. A minimal percent of children were found to have low Hb (11-14%) and Vitamin A (5-10%) concentrations; however, vitamin D deficiency was found in almost half the children in the study (Nyguen, 2013). About 18% of women of reproductive age were classified as having low BMI (BMI <18.5), and 8.2% were classified with BMI > 25 (NIH, MOH, UNICEF, 2012). Low birth weight has also been observed in 14% of newborns in Vietnam (Khan, 2007).

Primary schools within Vietnam have scored high in coverage and learning outcomes, as shown by impressively high scores on the Program for International Student Assessment (PISA) in 2012 and 2015 (World Bank Overview, 2019). Research on childhood intelligence has been developed in Vietnam through various studies. The most prominently used data source being the Young Lives cohort, an international study spanning 15 years, used to analyze the developing nature of childhood poverty in Ethiopia, India (Andhra Pradesh), Peru, and Vietnam (Barnett, 2013). From the Young Life cohort, several studies focused on early childhood nutrition as distinguished by height-age-z-score (HAZ), weight-age-z-score (WAZ), and weight-height-z-score (WHZ), and its influence on cognitive development (Georgiadia, 2016; Georgiadia, 2017; Hoang, 2019; Sanchez, 2017). Early height has been associated with cognitive and non-cognitive scores with the significance of this relationship mediated through growth in subsequent years (Sanchez, 2017; Georgiadia, 2016; Georgiadia, 2017). The influence of socio-economic status, as well as maternal mental health, were also investigated for an association with childhood intelligence utilizing the Young Lives cohort. Results reported that poor maternal mental health and low SES significantly associated with lower scores on the Peabody Picture Vocabulary Test (PPVT) within adjusted models (Bennett, 2016; Boo 2016; Reynolds, 2017). A few studies were conducted utilizing data other than the Young Lives cohort, but similarly reported on the relationship between stunting and cognitive function; however, adding to the findings, Duc demonstrated that after controlling for length in preterm infants the relationship between height and intelligence was not significant at age five (Duc, 2011). Research within Vietnam investigating determinants of cognition has been a recent development within the last decade, with several gaps still to be studied, including ones focused on within the current study.

Current Gaps Within Research

Considering gaps within Vietnam research first, the commonly used Young Lives data has limitations translating to the studies utilizing this prospective longitudinal study. Since the longitudinal study used a non-representative population, which purposeful biases towards impoverished areas, it is difficult to accurately generalize to the Vietnamese population as a whole (Boo, 2016). Furthermore, the data does not include information on a child's home environment, which has previously shown to influence cognitive development even from the slightest change in the environment (Fishbein, 2019). As such, the frequently used Young Life cohort is limited in its ability to assess childhood development in Vietnam. Research that will utilize an unbiased population and include known determinants, such as quality of home environment, are needed.

Vietnam has ample research on the impact of nutrition in terms of stunting or undernutrition, as measured by anthropometric measurements, but little is known about the relationship between food diversity or quality and cognitive development. Since Northstone found that a child's diet at 8.5 years impacted cognitive assessment at that time, the inclusion of diet quality/diversity within research on cognitive development at middle childhood would be influential (2012). Furthermore, studies quantifying the influence and relationship between and by determinants other than nutrition on cognitive development could be especially beneficial in an evolving context such as Vietnam where increasing GDA per capita could mean a change in predominant determinants of cognition.

Globally, the study of cognitive development in middle childhood has been frequently studied with a continuous gap reported as confounding within the analysis. In an attempt to control for as much confounding as possible, data used in determining factors involved in cognitive development should include information from the household environment, caregiver characteristics, and childhood attributes. Few studies reviewed in this literature review had the availability of this amount of data needed to accurately control for key confounders from these three domains.

To takes steps towards filling these gaps, the current study used high-quality data with the inclusion of influential factors, home environment and diet diversity, to provide insight that had previously been missing in cognitive development research in Vietnam. Overall, this research provided understanding into what associates with cognitive ability in Vietnamese children at 6 years and how nutritional status influenced cognitive development.

Chapter 2: Manuscript

Contribution of the Student

The publication of this manuscript will include multiple authors including key investigators from the PRECONCEPT Study team. All data that were used were collected by the field team based at the Thai Nguyen University of Pharmacy and Medicine under the leadership of Dr. Phoung Nguyen. After which, personal contributions include data analysis, table/figure development, and the writing of the manuscript. Dr. Ramakrishnan (Thesis Chair) and Dr. Young (Committee Member) have contributed to the design of the original study, data analysis plans and reviewing and editing the manuscript. The intended journal of publication is Maternal and Child Nutrition.

Factors Influencing Cognitive Intelligence Among Children 6-7 Years Old in Vietnam

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Section 1: Introduction

The intelligence of a child is a significant direct and indirect determinant of health outcomes and quality of life in adulthood and is considered an indicator of human capital (Feinstein & Duckworth, 2006). In light of this, globally, countries are aspiring towards societies in which every child has the opportunity to complete primary or basic education at a minimum (UNICEF, 2012). As the number of children attending school increases, however, it is evident that many children are not prepared, leading to repeated grades, high drop out and failure rates, and a lack of learning (UNICEF, 2012). Consequently, a major question that must be addressed is what determinants cause some children to enter school with the cognitive ability needed to achieve success while other children struggle.

A household environment, specifically the socioeconomic status, has been shown to account for a large amount of intellectual variance in children (Smith, 1997). Children who live below the poverty threshold are 1.3 times more likely to experience developmental delays and learning disabilities, and those in extreme poverty are at risk for scoring 6-13 points lower on standardized tests of IQ (Brooks-Gunn, 1997; Smith, 1997). The pathways through which socioeconomic status is suggested to operate include a child's health and nutrition, the quality of home environment, and parental mental health (Brooks-Gunn, 1997). The increasing quality of a home environment moderately contributes to higher executive functioning and verbal intelligence scores, accounting for up to 16% of the variance in IQ measurements (Fishbein, 2019; Luster, et al. 1992). Mothers' IQ or level of education has been reported to mediate this relationship, as mothers with a higher level of education have been found to provide a more supportive environment for their school-aged children (Belsky, 2010). Household factors such food security, ethnicity classification, and family structure have been found to have crude relationships with children’s cognitive ability; however, these associates were often attenuated by household socioeconomic status, quality of home environment, and maternal characteristics (Belsky, 2010; Carlson, 2001; Smith, 2016; Brooks-Gunn, 1996)

A mother's impact on a child’s health and cognitive ability begins prior to conception, primarily through nutritional status. The availability of nutrients for a developing fetus depends on a mother’s dietary intake, nutrient stores, and other contesting requirements. When these are depleted, before or during pregnancy, this may be detrimental to supporting the developing fetus and positive birth outcomes (Cetin, 2010). While micronutrients such as iron, B-6, B-12, and zinc have been considered critical to brain development and growth, very little is known about the impact of preconception and prenatal micronutrient deficiencies and its influence on long term cognitive functioning (Georgieff, 2008, Stephenson et al., 2018). A mother’s body composition during pregnancy has also been found to follow an inverted u-shaped relationship as it associates with childhood cognitive ability, with a maternal BMI of 20 kg/m^2 having the highest child IQ score at seven years (Huang, 2014).

Poor mental health prenatal, postpartum, or chronic has shown a low to moderate influence on cognitive ability in middle childhood, with the greatest impact seen through birth outcomes and in preexisting vulnerable groups (Orr, 1995; Matte, 2001; Kurstjens, 2011). Although an impact may not be seen directly between mental health and cognitive ability, a child’s experience of maternal insensitivity early in life was found to predict poorer cognitive outcomes, and this association was mediated by postpartum depression seen through the first 18 months of life (Murrey, 1996). Similarly, increased parental intelligence and educational level have been associated with a greater likelihood of engaging in cognitive stimulation with children, fostering an intellectual environment, and a greater affection and interest in the child's schooling, all of which have been significantly associated with childhood reading ability (Byford, 2012)

Childhood experiences beginning with birth outcomes, including being born preterm or with low birth weight, have been linked to delayed cognitive development (Moreira, 2014; Linsel, 2015; Wilson, 2011). Preterm birth has been found to decrease intelligence by 11.94 points, with a possible dose-response relationship dependent on the gestational age range (Wilson, 2011). Similarly, children determined to be small for gestational age at birth have been associated with delays in future growth and cognitive ability, and children with delayed growth within the first two years of life have also been reported to experience a decrease in cognition at 5 to 11 years (Sudfield, 2015).

A child’s early care, both daycare (0-2) and childcare (3-5) has been positively associated with cognitive development specifically in low-income contexts and in environments with parents who have completed minimal education or with an immigrant status (Felfe and Lalive, 2014; Drange and Havnes, 2015). A nutritionally adequate diet, beginning with early and exclusive breastfeeding, had shown an average gain of 3.44 IQ points in children when mothers initiated breastfeeding early, and up to 5% increase if breastfeeding extended to 6 months postpartum (Horta, 2015; Belfort, 2013). As children persist into middle childhood, the influence of diet as it pertains to intake of specific food groups, dietary patterns, or diet quality in early and middle childhood has been less frequently researched with weak results (Nyaradi et al., 2013). In Vietnam, nutrition-focused studies as they relate to cognitive outcomes have previously focused on the anthropometric measurements of children, leaving the influence of diet quality and diversity unknown.

Between 2002 and 2018, poverty rates declined sharply in Vietnam from over 70% to below 6%, drastically evolving the status of the country from one of the world's poorest nations to a low-middle-income nation (Overview, 2019). Primary schools within Vietnam have scored high in coverage and learning outcomes, as shown by impressively high scores on the Program for International Student Assessment (PISA) in 2012 and 2015 (Overview, 2019). However, research assessing factors influencing these children's cognitive ability is limited and lacks the inclusion of key known determinants such as home environment or the child's dietary diversity (Fishbein, 2019, Northstone, 2012). Despite drastic improvements in poverty and overall welfare, malnutrition is still present in women and young children in Vietnam, with the Vietnamese South East Asian Nutrition Survey reporting a prevalence of 22.7% stunting and 11.7% underweight in children six to eleven (Chaparro, 2014). Studies in Vietnam have also not had the depth of data capturing the household environment, caregiver characteristics, and childhood attributes to support the analysis of cognitive development while adjusting for appropriate confounders. Examining the different influential factors on cognitive ability with high-quality data, while including diet diversity and home learning environment, would provide insight into the evolving context in which children in Vietnam are developing. The objectives of this study were to answer two questions: (a) What best predicts Vietnamese cognitive ability at 6-7 years old?; (b) How does diet diversity influence cognitive development?

Section 2: Methods

Data Source and Study Population

This study used data that were collected as part of a randomized controlled trial (RCT), PRECONCEPT, which evaluated the effects of preconceptional micronutrient supplementation on maternal and child health outcomes (Nguyen et al., 2012). Four districts of Thai Nguyen province in northeast Vietnam served as the population for the RCT (Nguyen et al., 2012). The PRECONCEPT parent study was approved by the Ethical Committee of Institute of Social and Medicine Studies in Vietnam (May 31st, 2011) and Emory University's Institutional Review Board in Atlanta, Georgia, USA (July 26th, 2011) (Nguyen et al., 2012). Written informed consent was obtained from all participants. Women of reproductive age (n= 5011) were randomized into three groups a) 2,800 µg folic acid (FA, control); b) 60 mg iron and 2, 800 µg of folic acid (IFA); or c) multiple micronutrients (MM) with the same amount of iron and folic acid as the previous group (Nguyen et al., 2012). Women were prospectively followed, and upon pregnancy confirmation (n = 1,813), participants stopped the intervention and began daily prenatal supplements (Nguyen et al., 2012). Exclusion criteria for the study included women who were pregnant at the time of recruitment, consumed iron, folic acid, or other micronutrients within the last two months, were severely anemic (Hb < 7g/L), or had a history of chronic hematological diseases or high-risk pregnancies (Nguyen et al., 2012).

In the second phase, all singleton live births (n=1,599) were followed up through age two years (n=1,461) and measures of child growth and development were obtained at various time points along with measurements of infant and young child feeding practices, child morbidity, maternal health, and home quality (Nguyen, 2017). Most recently, in the current third phase of the prospective study, roughly 86% (n=500) of the eligible cohort (children who have turned six at this point) have been contacted and will be leveraged for this study. Data were collected from primary caregivers (two-thirds mothers and the rest fathers, grandparents or relatives) and children.

Outcome Instrument: Wechsler Abbreviated Scale of Intelligence (WASI)

The Vietnamese version of the *Wechsler Intelligence Scale for Children®—Fourth Edition* (WISC–IV®) was used to assess cognitive functioning at 6-7 years for the current study. This assessment has been validated and adapted in the Vietnamese context and takes 70-90 minutes to administer (Dang. et al, 2012). The WISC-IV consists of 10 subtests (Vocabulary, Similarities, Comprehension, Block Design, Picture Concepts, Matrix Reasoning, Digit Span, Letter-Number Sequencing, Coding, and Symbol search). These are summed into four indices, namely the Verbal Comprehension Index (VCI, a measure of crystallized abilities,), Perceptual Reasoning Index (PRI, a measure of inductive and quantitative reasoning), Working Memory Index (WMI, a measure of children's ability to memorize new information), Processing Speed Index (PSI, a measure of the speed of information processing that includes children's abilities to focus attention and quickly scan, discriminate and sequentially order visual information) as well as a Full-Scale IQ (FSIQ).

Results were scored beginning within each of the 10 subsets by calculating a raw subset score from the summation of all item scores. Each raw subset score was then scaled by the child's age. The scaled scores of the subtests are then summed for Verbal Comprehension score (Similarities, Vocabulary, and Comprehension), Perceptual Reasoning score (Block Design, Picture Concepts, and Matrix Reasoning), Working Memory score (Digit Span and Letter Number Sequencing), Processing Speed score (Coding and Symbol Search), and Full-Scale IQ score (all 10 subset scores). Finally, the composite indices were calculated for each score. The FSIQ scores normally range from lowest at 40 to highest at 160 points.

Exposure Variables

In the current study, household environment, caregiver characteristics, and child attributes were assessed in relation to cognitive function. Assessments of socioeconomic status, quality of home environment, maternal mental health, maternal intelligence, small for gestational size, and breastfeeding practices were captured in the first and second phases of the PRECONCEPT control trial and utilized in the current study. At the household level, SES was measured at baseline using a Vietnam adapted questionnaire, which included questions about household ownership, housing quality, access to services, and household assets. Principle component analysis was utilized, and the first component score derived was divided into tertiles to represent household SES (Gwatkin et al., 2007; Vyas, 2006). At 12 months postpartum, the quality of the learning environment at home was measured using the HOME Inventory (Bradley and Caldwell, 1988). The assessment measured the quality and quantity of the social, emotional, and cognitive support available to a child in the home environment. Scores ranged from 0 – 45, with a higher quality home environment scoring higher in the assessment (Bradley and Caldwell, 1988). Maternal mental health was also assessed with the Center for Epidemiologic Studies Depression Scale (CES-D) and used to create a score that ranged from 0 to 13. A dichotomous variable that classified women reporting any signs or not was used. Lastly, child attributes, including sex, SGA, and breastfeeding were obtained from the first and second phases of PRECONCEPT. SGA was defined as a birth weight below the 10^{th} percentile for gestational age based on the multicounty INTERGROWTH-21^{st} Project (Villar et al., 2014), and breastfeeding was measured at 3, 6, 9, and 12 months.

In the most recent data collection at 6 – 7 years, household size was evaluated with a cutoff of four or more members. Height and weight measurements were obtained in duplicate for all mothers and used to calculate average body mass index (BMI, kg/m^2) based on which mothers were classified as underweight (<18.5), normal (18.5-23), and overweight (≥23) (WHO, 2004). Child height and weight measurements followed the same protocol as mothers and were converted to height-for-age Z-scores (HAZ), weight-for-age z-scores (WAZ) and BMI-Z scores using the 2006 WHO child growth references (WHO, 2010). Stunting and underweight were defined at HAZ and WAZ < -2, respectfully, while overweight and obesity were defined as BMIZ > 1 and > 2, respectfully. Food insecurity was evaluated using FANTA/USAID's Household Food Insecurity Access Scale (HFIAS). HFIAS questions use a 30-recall-day period and provide information on food insecurity at the household level with specific emphasis on access-related characteristics (Coates, 2007). The HFIAS category variables were developed (food secure, and mild, moderately, and severely food insecure) and then translated to a dichotomous variable representing food secure or insecure categories. Child diet diversity was assessed through a 24-hour open recall, which reported on the food and beverages consumed in the previous 24-hours. Food consumption was categorized into 10 groups: 1) starchy staple foods; 2) beans and peas; 3) nuts and seeds; 4) dairy products (milk, yogurt, and cheese); 5) fleshy foods; 6) eggs; 7) dark and green vegetables; 8) vitamin-A rich fruits and vegetables; 9) other vegetables; 10) other fruits. Diet diversity was measured by the number of animal sourced foods consumed and represented as low quality (0-1 animal sourced foods consumed), medium quality (2 animal sourced foods consumed) and high quality (3-4 animal sourced foods consumed). The overall health status of the child was evaluated by any hospital visits within the last year, and the child's wellness within the last two weeks, specifically if they showed any symptoms of illness (Fever, Pneumonia/Sever Cough, Convulsions, Skin Disease, Anemia, Malnutrition, Flu, Diarrhea, or other).

Statistical Analysis

Descriptive analyses were used to report the characteristics of the study population. The bivariate relationships between categorical exposure variables were evaluated through chi-squared analyses, and when necessary, the Fisher Exact test was used when subgroups groups were less than five. Two-sample t-tests were utilized for continuous demographics, and significance was reported from the two-tailed p-value. Following the completion of descriptive analyses, linear regression models were evaluated to identify exposures that best predicted cognitive ability and the influence of diet diversity. First, a bivariate unadjusted analysis was completed between exposure variables and all cognitive indices (FSIQ, PRI, PSI, WMI, VSI). Next, predictive models were built for each cognitive index with the same exposures, chosen from the unadjusted bivariate analysis and represented variables which significantly associated with all five indices (socioeconomic status, home, maternal education, child stunting status). Models for each cognitive index were then individually fit, and the best fit models were selected based on the significance of the t values, with consideration of the beta coefficients and parity. Lastly, hierarchical regression was systematically completed for full scale IQ involving variables from the set exposure models and diet diversity.

Section 3: Results

Characteristics of Participants

Participant characteristics are presented in **Table 2** for a sample of 467 children and caregivers. Study analysis included all children who had cognitive development data at age 6-7 years, capturing roughly half the population and serving as a mid-data collection analysis. Loss to follow up to this point occurred due to migration (n=33), lack of interest (n=44), and the death of the child (n=4).

Table 2 shows the baseline characteristics of children, maternal caregivers, and the household environment. Approximately 53% of study participants were classified as a minority, and 40% of those individuals reside in a low SES household with a significantly lower home quality. The quality of home environment increased by two points on the HOME scale with a single level increase in SES status.

The majority of mothers had obtained a middle school education (51.8%). As maternal education levels increased, the socioeconomic status of the household also increased, with 79.1% of those who achieved college or higher degrees classified as high SES and 70.6% of those who only completed elementary education classified as low SES (**Figure 1**). Daycare attendance was observed in 32.1% of children and was significantly more common in households with a higher socioeconomic status and with a mother who had a higher level of education.

The presence of food insecurity was higher among children within a low SES household (61.0%), for those whose mothers had only completed middle school education, and in children experiencing a lower quality home environment. The prevalence of stunting was significantly higher among children whose mothers only achieved middle school educations (65.1%), lived within households characterized as low SES (58.1%), had medium diet diversity (46.5%), and were categorized minority ethnic group (72.1%) **(Figure 2)**.

The prevalence of thinness in children observed the same pattern as stunting, but thin children frequently experienced a lower quality home environment as well. Increased diet diversity was found in children who were breastfed and in households with a higher quality home environment. Similarly, a child's consumption of diverse foods increased as socioeconomic status increased, with 64.4% of those in high SES consuming 3-4 animal products, while only 33.8% of those in a low SES household had the same diverse consumption **(Figure 3)**.

Cognitive Assessment and Unadjusted Analysis

Figure 4 shows the index score for full-scale IQ (FSIQ), and the four indices within the FSIQ score (Perceptual Reasoning Index, Working Memory Index, Verbal Comprehension Index, Processing Speed Index). Working memory had the highest score, and verbal comprehension had the lowest score, with FSIQ reporting a mean score of 88.4.

The results of the bivariate analysis show that ethnicity, household SES **(Figure 5)**, maternal education **(Figure 6)**, quality of home environment **(Figure 8)**, child diet diversity **(Figure 7),** child stature and weight for age were significantly and positively associated with FSIQ.

Multivariate Analysis

Table 3 reports sex and age-adjusted models with set predictors for all five cognitive indices. A higher level of socioeconomic status had significant positive associations with all indices except working memory (Low – Ref, Med 1.3, 95% CI: -1.3,3.8, High –0.1, 95% CI: -3.1, 2.9). Acquiring an education at the college or higher level was significantly associated with a 6.3-point increase in FSIQ and an 8.4-point increase in working memory when compared to an elementary education. Stunting was significantly and negatively associated with all indices, except for perceptual reasoning, whereas the effects of the quality of home environment remained significant only for FSIQ (0.3, 95% CI: 0.0-0.6) and VCI (0.4, 95% CI: 0.1, 0.7).

Table 4 reports individually fit models, sex and age-adjusted, for all five cognitive indices. In every model excluding the PRI model, stunting significantly decreased cognitive scores by 5.1, 5.5, 3.8, and 4.9-point for FSIQ, VCI, WMI, and PSI, respectfully. Diet Diversity was only significantly associated with perceptual reasoning, with a 5.5-point increase in score when compare in low diversity.

Table 5 shows the crude association of key predictors and the hierarchical regression models. All factors remain significant when sex and age are adjusted for, revealing limited contributions from these demographic characteristics. When a child's status of stunting was added to the model it was a significant negative predictor of FSIQ (5.2, 95% CI: -8.8, 1.5). Household and maternal factors minimally decreased in effect but remained significant within this model. When diet diversity was added to the model, it did not significantly contribute to the model, but home quality dropped from significance (0.3, 95% CI: -0.0, 0.6). In the last model, stunting status contribution remained significant and diet diversity, and home environment quality remained insignificant.

Section 4: Discussion

General Cognitive Ability

This cross-sectional analysis assessed the influence of a household environment, maternal characteristics, and child attributes on cognitive ability in Vietnamese children 6 –7 years old. Overall, children's full-scale IQ significantly associated with socioeconomic status, home quality, maternal education, and childhood growth status. Working memory, verbal comprehension, and processing speed were all associated with variations of the factors that significantly influence FSIQ. However, perceptual reasoning was significantly associated with socioeconomic status as well as diet diversity. While these exposure variables are independently associate with cognitive outcomes, they also associate amongst each other. Children within the study who lived in a higher socioeconomic context were more likely to have mothers who reached a higher educational level and to have experienced a better-quality home environment. Childhood stunting and low diet diversity had a higher prevalence in children whose mothers did not complete high school and who lived in a low socioeconomic household.

Socioeconomic status was associated with all cognitive indices except working memory. Previous research has reported a similar independent positive association between household socioeconomic status and child's IQ (Luster, 1992). The pervasive influence of socioeconomic status has been reported to attenuate the effect of other exposures such as family structure, ethnicity, and even poor birth outcomes (Carlson, 2001; Smith, 2016; Linsell, 2015). The current study found socioeconomic positioning to associate with several other factors including ethnicity, quality of home environment, maternal education level, child day care attendance, child size for gestational age, and child nutritional status (food security, diet diversity, growth status). Previous research has shown the influence of socioeconomic status on cognitive development to increase as a child ages from early to middle childhood (Luster, 1992). One suggested explanation for the expansive influence of SES was the factor acting as a proxy for childhood education quality, since middle childhood signifies a time when children are beginning formal education (Luster, 1992). Alternatively, previous research has suggested that socioeconomic status could be accounting for a portion of home learning environment that is not being accounted for in the HOME assessment (Luster, 1992). Since quality of home environment provides minimal variance within the current analysis and only daycare (0-3 years) attendance is assessed rather than pre-school quality (+3 years), these assumptions are plausible in explaining some of the variance accounted for by socioeconomic status.

In the current study, maternal education was associated with full-scale IQ and working memory in children. In this population, the majority of mothers completed a middle school education (51.8%). Any education above primary school was significantly and positively associated with working memory index, as scores doubled for children whose mothers completed college or higher (8.79 points [3.6,14.0]). Full-scale IQ positively increased (middle school: 1.80 points [-2.4,6.0] and high school: 2.02 points [-2.6, 6.6]) as maternal education increased, but this association was not significant unless a mother completed college or higher (6.33 points [1.0, 11.7]). Previous research has reported maternal education to have a stronger association with general cognitive intelligence; one study reported a 9.2 point and 15.4-point increase in general cognitive intelligence for those who completed secondary school and university, respectfully (Gonzalez, et al., 2020). The limited effect seen by maternal education in this study may be attributed to an indirect influence through the home environment quality. The current study found that as maternal education increased the quality of home environment also increased. Similarly, other studies reported that mothers with a higher level of education often cultivated a better home environment that facilitated a greater reading level and overall cognitive ability in children (Byford, 2012; Harding, 2015).

Home learning environment was significantly associated with both full-scale IQ and verbal comprehension scores. As household, maternal, and child factors improved, home environment quality also improved. However, the variance in any cognitive index by home quality was minimal in comparison to socioeconomic status and maternal education, contradicting previous research that has suggested these factors may function through quality of home environment (Byford, 2012; Harding, 2015; Luster, 1992). One possible explanation for this may be that home environment was mediated by these exposures, as seen by Coon, who found Family Environment Scales to be as highly correlated with parent IQ as with children IQ (Coon, 1990).

Factors including marital status, household size, maternal mental health, infant breastfeeding, size for gestational age, daycare attendance, and childhood obesity were not found to associate with intelligence scores. Within the population assessed for this study, an overwhelming majority of mothers were married (97%) and lacked significant signs of depression (2%); as such, it is difficult to analyze any true influence from these exposures. Similarly, children who were overweight or obese only accounted for 9% of the population. Household size did not provide any significant variance in childhood cognitive ability, nor does it associate with other exposures. While previous research has shown the presence of grandparents and older siblings to influence cognitive development, the measurement of household size in this study could be insufficiently capturing the influence of family structure through the simplified dichotomous variable. The lack of cognitive variance observed by children who were born small for gestational age or by those who were not exclusive breastfed has been observed in previous studies in children past the age of five (Linsell, 2015; Michaelsen, 2009). In the current study, it is again important to note that SGA was only accounted for in 12% of the population, which could have impacted the association. However, the growing influence of environmental factors on intelligence as a child enters into middle childhood has been reported to attenuate the effect of infant breastfeeding and birth outcomes (Linsell, 2015; Michaelsen, 2009). Child daycare was also found to have an insignificant association with childhood intelligence, contradictory to previous research that reported a significant effect (Fort, 2016; Felfe and Lalive, 2014; Drange and Havnes, 2015). While a direct association with cognitive ability was not present in the current study, daycare attendance was associated with socioeconomic status. Children living in a higher socioeconomic position were more likely to attend a daycare. The impact on cognitive ability may be represented within socioeconomic status rather than daycare attendance.

Role of nutrition on Cognitive Ability

Childhood nutritional status at 6 -7 years of age is assessed in the current study through diet diversity, food security, and anthropometric measurements. Full-scale IQ was not associated with food security, diet diversity, or by a child being overweight or obese; however, a child's growth status and thinness showed significant variation in FSIQ. While diet diversity was not associated with FSIQ, it was associated with perceptual reasoning. The perceptual reasoning index accounts for a child's ability to accurately interpret, organize, and think with visual information (Dowell, 2011). It measures non-verbal reasoning skills that focus on fluid intelligence (Dowell, 2011). Children in the current study who consumed a diet with high diversity reported perceptual reasoning scores 5.5-points (C.I.: 1.4, 9.6) greater than those who consumed diets with low diet diversity. Previous research supports the consumption of animal products to combat Vitamin B-12 deficiency also known as cobalamin deficiency (Herrmann, 2012). While children were not directly assessed for Vitamin B-12 levels in the current study, cobalamin deficiency has been found to lower performance on tests measuring fluid intelligence, spatial ability, and short-term memory similar to that observed by children consuming low-diversity diets (Louwman, 2000). Women within this study were also assessed for Vitamin B-12 levels at baseline, and the PRECONCEPT cohort as a whole had low levels of Vitamin B-12 and consumed diets with minimal animal sourced foods (Nguyen, 2015). As such, a diet with minimal diversity in animal product consumption could represent a Vitamin B-12 deficiency in children and consequently deteriorated perceptual reasoning abilities.

Household food insecurity was not significantly associated with cognitive ability within this study; however, children who lived in a higher socioeconomic environment with a caregiver who graduated high school were more likely to be food secure. Food security was also more common in a quality home learning environment, and children who were food secure were more likely to consume diverse diets. Contradicting the results found in this study, a systematic review found a dose-response relationship between food security and academic performance (Shankar, 2017). The conflicting results of this study and previous research may be explained by the associations between food insecurity and the other exposures. A study by Belsky found food insecure households, as a whole, to be less sensitive to a child's needs, finding that food insecurity could influence cognitive ability by facilitating a poor home learning environment (Belsky, 2010). Socioeconomic status could represent the variation in cognitive ability rather than food security as well. Previous research has shown income to attenuate the association between food insecurity and cognitive ability at age 12 (Belsky, 2010). Alternatively, seasonality is another important factor that may affect the observed association of household food insecurity. The strength of the association between food insecurity and cognitive ability may change with seasonal variations. This cross-sectional study, however, could not capture these potential variations within the association between food insecurity and cognitive ability due to seasonal effects.

Stunting and thinness were prevalent in 9% and 14% of children within the current study, respectfully. Both factors crudely associated with all cognitive indices within WISC, except for an insignificant association between thinness and perceptual reasoning. After adjusting for socioeconomic status, quality of home learning environment, and stunting, the association between thinness and cognitive ability was attenuated. Stunting was attenuated by socioeconomic status and diet diversity when associated with perceptual reasoning, but continued to be significant for all other cognitive indices. Stunted children were found to have a significant decrease in cognitive scores, observing a 5.2, 5.4, 3.6, and 4.9-point decrease in fully adjusted models for FSIQ, VCI, WMI, and PSI, respectfully. Previous research has reported childhood growth impairment in the first two years of childhood to influence future growth and cognitive development (Sudfield, 2015; Alamo-Junquera et al., 2015). The presence of stunting within children in the PRECONCEPT cohort at two years of age was reported as 22% (Young, 2018). Assessing children at six years of age in the current study, the prevalence of stunting decreased to 9%. One explanation for this variance in growth impairment between the two time points is the attenuation of early growth impairment through direct nutritional improvement in a child, and the second is the improvement of environmental stimulation (Alam, 2020; Sudfield, 2015). Children within this study were found to have a higher prevalence of stunting if their mothers did not complete high school and if they resided in a low socioeconomic household. While this study was limited by temporal constructs, the significant impact of stunting observed at 6-7 years of age could be due to the current nutritional and environmental status of the child or because of previous patterns observed in early childhood. Further research is needed to assess the patterns and critical periods of stunting as it influences cognitive ability through middle childhood.

Strengths and Limitations

Major strengths of this study included the use of high-quality data that provides information from the household, caregiver, and child level. This depth of data allows for a broader understanding of possible determinants, including how they associate with cognition and each other. The current analysis also included child home quality and diet diversity, which were not previously used in research in Vietnam. WISC is also utilized to provide information on general intelligence, as well as other cognitive indices that are key to cognitive ability in middle childhood, specifically in a Vietnamese population (Dang. et al, 2012).

While this analysis allowed for the quick assessment of multiple exposures at one time point, it was also limited by its lack of temporality resulting in an inability to interpret causality or the direction of associations between exposure factors and cognitive ability. Potential biases include non-response bias and recall bias. Since the study functioned as at the midpoint of data collection, the data captured earlier in data collection, and utilized for this study, could have been systematically different than data collected in the latter half. Furthermore, loss to follow-up due to migration, lack of interest, and death of a child could have also caused non-response bias.

Future Research

Findings from this study reported the significant impact of socioeconomic status, quality of home environment, maternal education, and child nutritional status on cognitive intelligence in middle childhood. Given the exploratory nature of this study, further investigation into factors related to cognitive development and their root causes is necessary. The significant influence of growth retardation as measured in middle childhood is time bound to a single point in this study;

however, there is a need to examine the timing and persistence of stunting to understand patterns and critical periods. Research examining patterns of stunting has previously been assessed up to age five, with both timing and persistence of stunting found to be significant, but little is known about these patterns into middle childhood (Sudfield, 2015). Similarly, the influence of nutritional intake on childhood growth and development should be analyzed to determine critical periods, patterns, and diets throughout early and middle childhood.

Chapter 3: Conclusion and Public Health Recommendations

Conclusions

This cross-sectional study analyzed data from the PRECONCEPT cohort to evaluate the influence of children's household environment, caretaker characteristics, and personal attributes on cognitive ability at 6-7 years. General full-scale IQ was primarily assessed along with working memory, verbal comprehension, processing speed, and perceptual reasoning. A child's full-scale IQ was positively associated with socioeconomic status, quality of home environment, and maternal education. Child nutritional status at 6-7 years, as measured by diet diversity and child growth, was also positively associated with measures of cognitive ability even after adjusting for maternal and household characteristics for perceptual reasoning and full-scale IQ, respectfully.

Adding to previous research completed in Vietnam, the current study demonstrates the importance of home quality and diet diversity in middle childhood. Although home quality provides minimal variance in IQ, the influence on full-scale IQ is consistent. Quality of home environment, as defined by intellectual home environment, parental aspiration, and cognitive stimulation, has been positively and independently associated with offspring childhood cognitive ability (Byford, 2010). While home environment quality, socioeconomic position, and maternal IQ have been found to have independent associations with childhood cognitive functioning, the degree of this effect and the interrelated influence of these exposures is less clear (Tong, 2007; Luster, et al., 1992). However, it is clear that a child's household environment, as characterized by both household and maternal characteristics, appears to have the greatest impact on a child's cognitive ability.

Prior nutritional research in Vietnam, as related to cognitive development, primarily focused on anthropometric measurements to assess impaired growth. As such, the effect of diet diversity, specifically the consumption of animal products, on childhood intelligence was unknown. In the current study, diet diversity is significantly and positively associated with full-scale IQ, perceptual reasoning, and verbal comprehension. However, these effects remained significant for only perceptual reasoning, reporting a 5.5-point variation in scores between high and low diet diversity, after accounting for the effects of maternal and other household characteristics. Perceptual reasoning accounts for a child's ability to interpret, organize, and think through visual information and is key to development during middle childhood (Dowell, 2011). Cobalamin deficiency, also known as vitamin B -12 deficiency, is commonly present in those who have limited consumption of animal products and has been linked to decreased fluid intelligence, spatial ability, and short-term memory (Herrmann, 2012; Louwman, 2000). Mothers within this study were also assessed for Vitamin B-12 intake at baseline, and the PRECONCEPT cohort as a whole had low Vitamin B-12 levels (Nguyen, 2015). The absence of biomarkers for Vitamin B-12 plus the possible alternative influence from bacteria and parasites can make it difficult to independently relate Vitamin B-12 deficiency to poor animal source intake. However, the presence of low levels of Vitamin B-12 in mothers and a low frequency of animal sourced product consumption in both mothers and children make it a plausible mechanism by which diet diversity associates with cognitive ability.

Nutritional status, as assessed by childhood growth, was associated with every cognitive index within WISC except for perceptual reasoning. The current study demonstrated this association at a single time-point in middle childhood, but previous research also reports an association between early life growth retardation and long-term cognition (Sudfield, 2015;

Alamo-Junquera et al., 2015). Future research would benefit from time sensitive analysis to understand the influence of childhood nutrition beginning in preconception through middle childhood. The use of approaches such as path analysis would provide insight on the relative contributions of different time periods before, during and beyond the first 1000 days of life on child cognition ability.

Public Health Implications

Since 2002, Vietnam has seen a drastic improvement in economic status, observing a sharp decline in poverty rates from 70% to below 6%, and in 2012 and 2015, primary schools in Vietnam scored high in both coverage and learning outcomes in primary school (World Bank Overview, 2019). However, 7 million children still live in a poor household (UNICEF, 2012). One outcome from this study was the persistent association between a child's household environment and caregiver education with cognitive ability. As such, interventions directed towards improving development in children should take into consideration the pervasive influence of a child's household environment and include strategies that address systematic disparities, such as poverty and hunger, in alignment with the United Nations Sustainable Development Goals (United Nations, 2015). As the Vietnam government or other public health organizations continue to work towards improving childhood growth and development, the continued improvement of socioeconomic status (income, education, occupation) within the population should be a part of interventions. Children who reside in households of low socioeconomic status should be the primary targets within these interventions. As households increase in income and parental education levels, this could facilitate improved growth and cognitive development.

Despite the improvements in poverty and overall welfare in Vietnam, malnutrition is still present in women and young children (Nguyen, 2013). Previous research has focused on nutritional status as it pertains to growth or weight status, which is significant and supported by findings within this study, but consideration of diet quality and diversity should also be integrated into research and nutritional programs. Mothers and children within the PRECONCEPT study have both reported low diet diversity as it pertains to animal source consumption, and subsequent children have had decreased perceptual reasoning in comparison to children with higher diet diversity. Nutritional programs within Vietnam should include education on the importance of childhood consumption of a diverse diet and initiatives should be developed when necessary to assist in making these resources available. One avenue in which this could occur would be through the school system, since middle childhood marks the time point when children begin formal education. This could be an opportunity for the government to systematically support the nutritional status of children in Vietnam.

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Tables and Figures

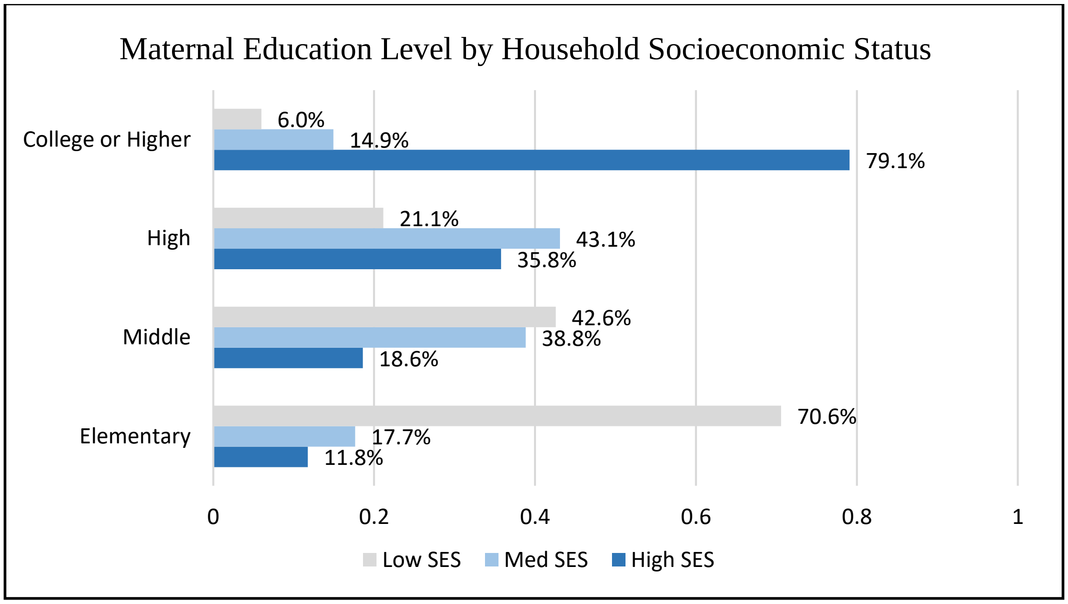

Figure 1: Maternal education level by household socioeconomic status

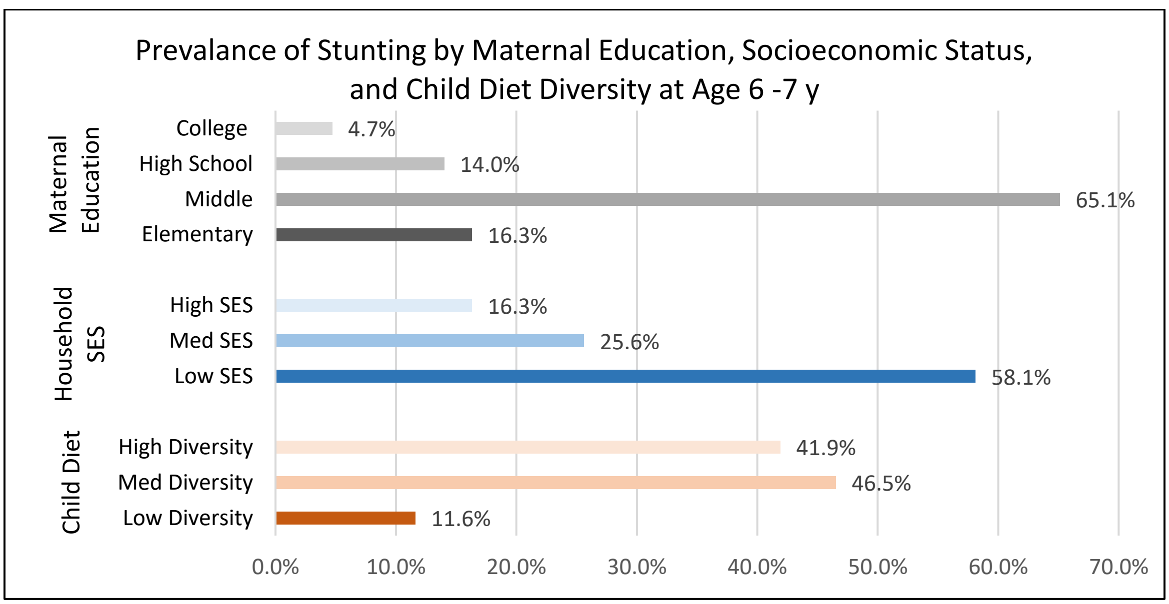

Figure 2: Prevalence of stunting stratified by maternal education, socioeconomic status, and child diet diversity

Table 2: Descriptive Statistics for Household, Maternal, and Childhood Determinants			
Variable	**n (467)**	**Mean, SD**	**Percent**
Household Determinants			
Ethnicity[a]			
Kinh	221	---	47.3
Others	246	---	52.7
Household Size[d]			
≤ Four People	273	---	58.5
> Four People	194	---	41.5
Household SES[a]			
Low	157	---	33.7
Medium	163	---	35.0
High	146	---	31.3
Food Insecurity[d]	59		12.7
Family Environment (HOME)[c]	455	28.05 (3.95)	---
Maternal Determinants			
Marital Status (Married)[d]	454	---	97.2
Mental Health (Depression)[a]	324		71.1
Body Mass Index[d]			
Underweight (<18.5)	23	---	7.1
Normal (18.5 - 23.5)	210	---	65.2
Overweight (>23.5)	89	---	27.6
Maternal Education[a]			
Elementary School	34	---	7.3
Middle School	242	---	51.8
High School	124	---	26.6
College or Higher	67	---	14.4
Child Determinants			
Gender (Male)[d]	238	---	51.3
Age at Time of WISC Survey[d]	467	6.43 (0.21)	---
SGA at Birth[b]	54	---	12.4
Exclusive Breastfeeding[c]	247	---	59.8
Day Care Attendance (0-3y)[d]	150	---	32.1
Currently Healthy (Last 2 Weeks)[d]	246	---	53.1
Hospitalized in the Last Year[d]	61	---	13.1
Anthropometric Measurements[d]			
Stunting	43	---	9.3
Undernutrion	63	---	13.6
Overweight	29	---	6.3
Dietary Diversity of Animal Product Consumption[d]			
Low Diversity (0-1)	65	---	14.0
Medium Diversity (2)	178	---	38.20
High Diversity (3-4)	223	---	47.9

Data Reported : [a] Baseline Preconception; [b] Child's Birth; [c] 12 Months Postpartum; [d] 6 - 7 y
Missing Data: Household SES (1); Food Insecurity (3); HOME Environment (12); Maternal Mental Health (11); Maternal BMI (145); Child Gender (3); SGA at Birth (33); Early Breast Feeding (56); Exclusive Breastfeeding (54); Child Current Health (4); Hospitalization of Child (2); Child Anthropometric Measurements (3); Child Diet Diversity (1)

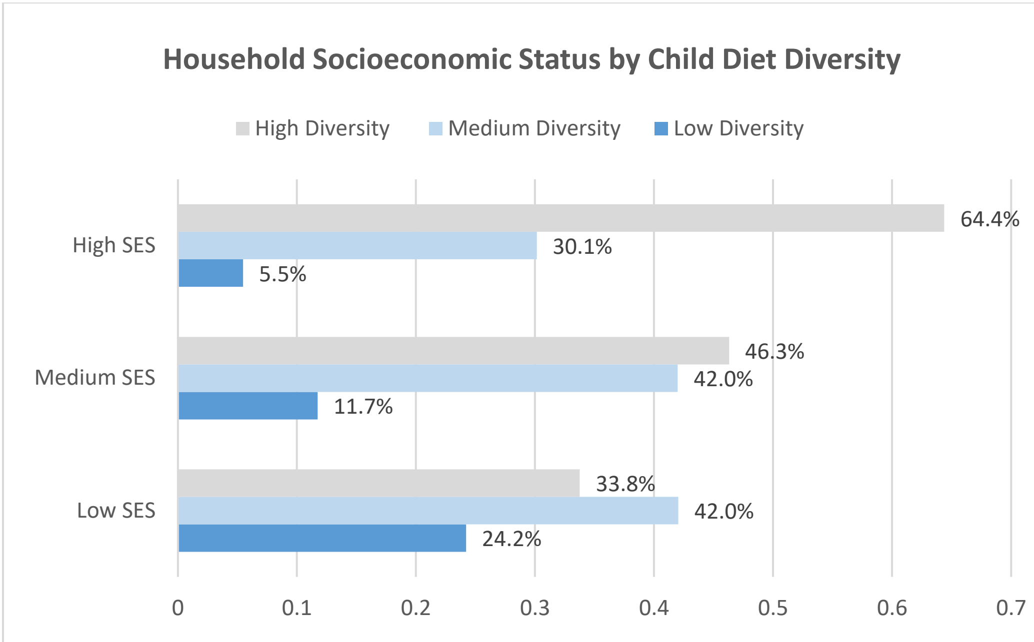

Figure 3: Household socioeconomic status stratified by child diet diversity

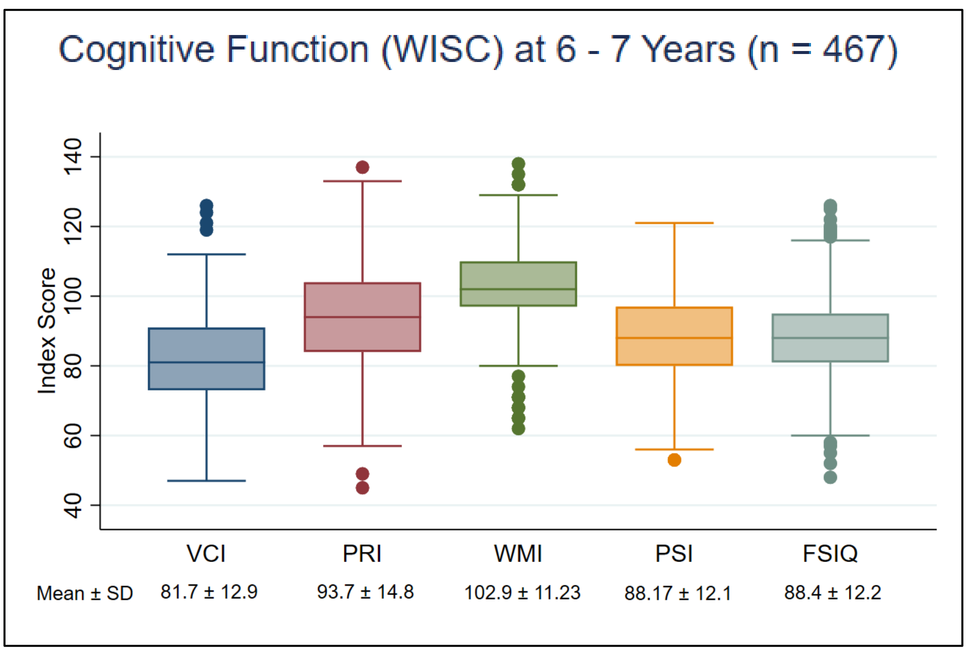

Figure 4: Box-whisker plot for all five cognitive indices

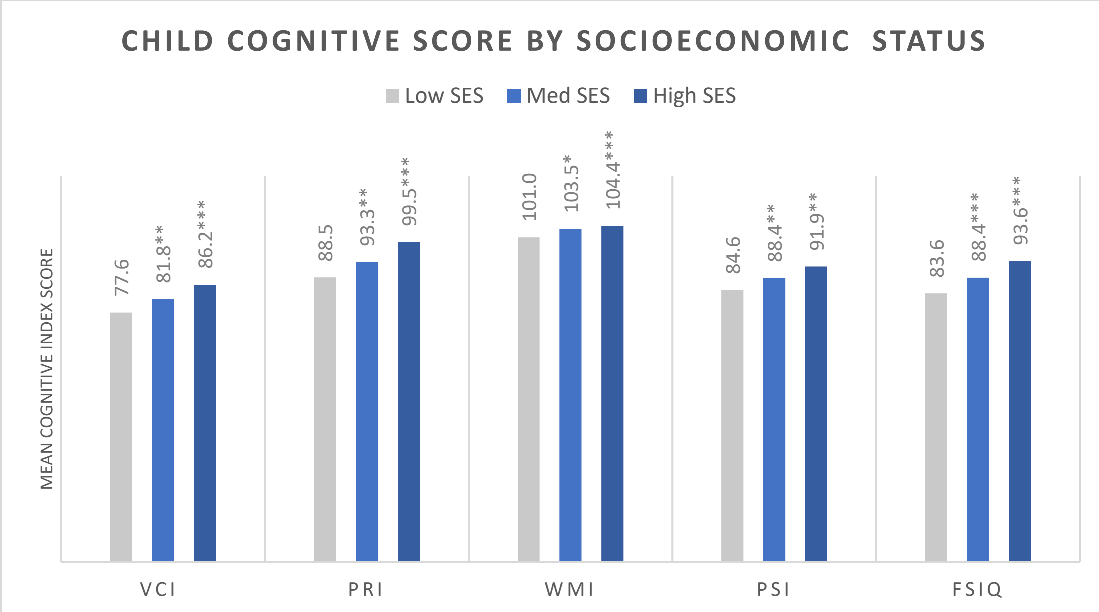

Figure 5: Bivariate analysis of socioeconomic status and all cognitive indices with means reported
*p <.05 **p<.01 ***p<.001

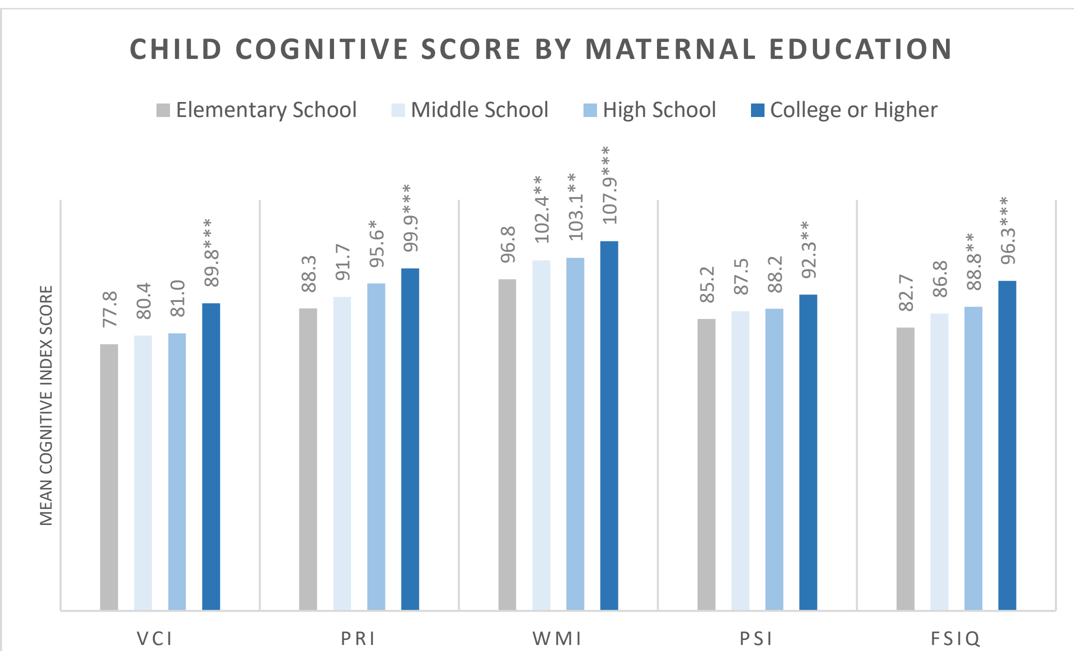

Figure 6: Bivariate analysis of Maternal Education and all cognitive indices with means reported
*p <.05 **p<.01 ***p<.001

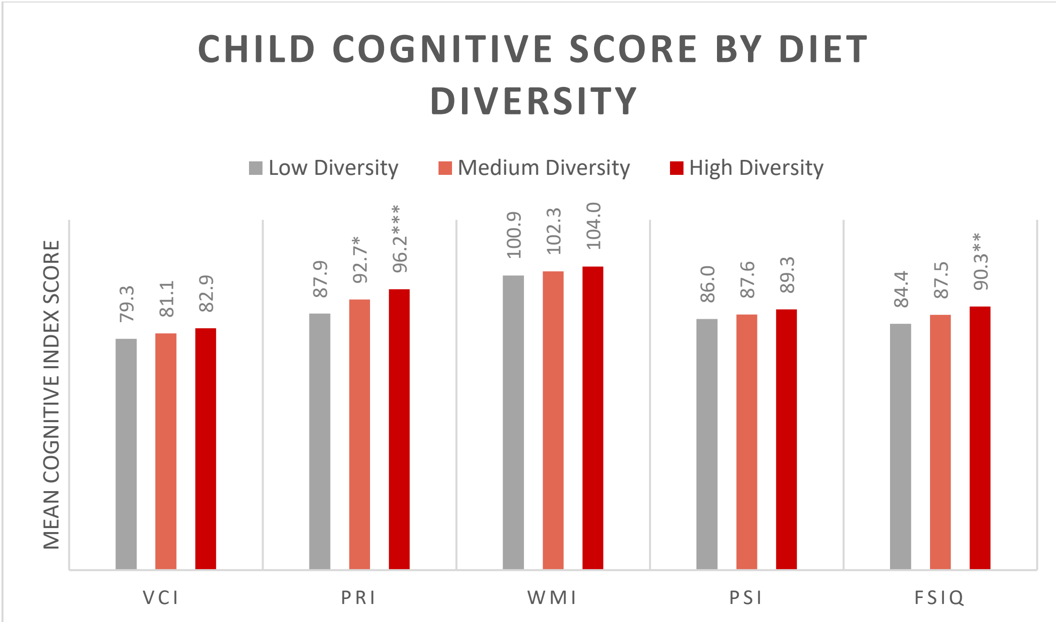

Figure 7: Bivariate analysis of Diet Diversity and all cognitive indices with means reported
*p <.05 **p<.01 ***p<.001

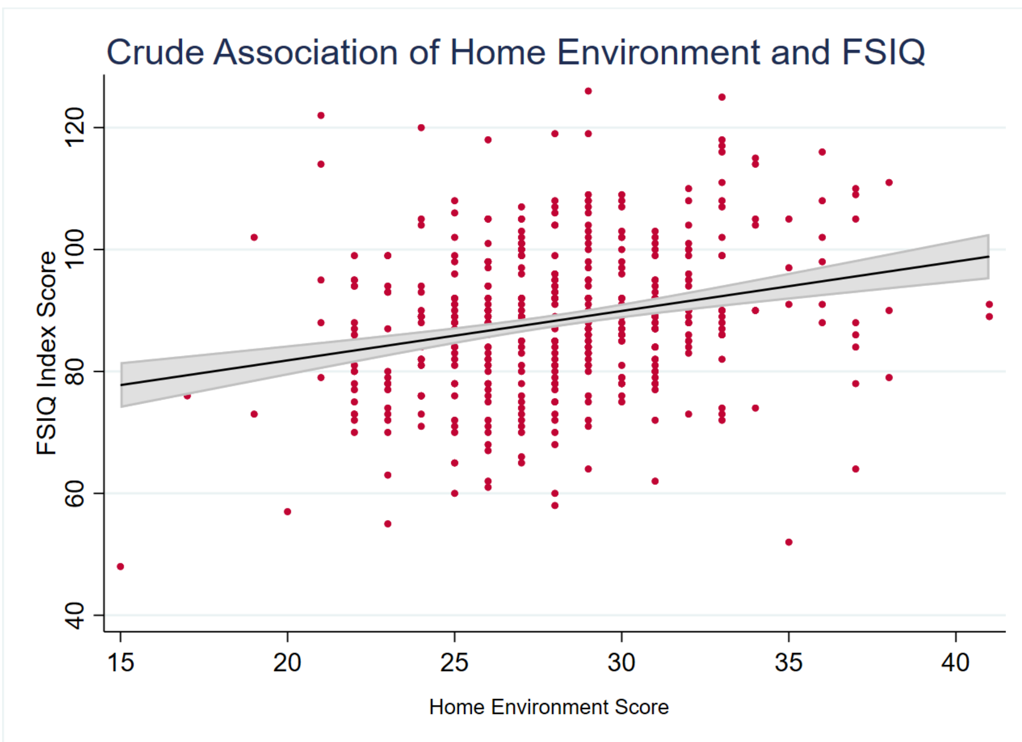

Figure 8: Bivariate analysis of Home Environment Scale score and all cognitive indices
*p <.05 **p<.01 ***p<.001

Table 3: Multivariate prediction models with set predictors for the five measurement of cognition

	FSIQ Model[a]	PRI Model[a]	VCI Model[a]	WMI Model[a]	PSI Model[a]
Socioeconomic Status					
Low	**Ref.**	**Ref.**	**Ref.**	**Ref.**	**Ref.**
Medium	3.29 (0.6, 5.9)	3.53 (0.2, 6.8)	2.66 (-0.2, 5.5)	1.29 (-1.3, 3.8)	2.87 (0.2, 5.6)
High	5.69 (2.6, 8.8)	8.06 (4.2, 11.9)	4.02 (0.7, 7.4)	-0.01 (-3.0, 3.0)	**5.27 (2.1, 8.5)**
Maternal Education					
Elementary School	**Ref.**	**Ref.**	**Ref.**	**Ref.**	**Ref.**
Middle School	1.80 (-2.4, 6.0)	1.22 (-4.1, 6.5)	0.49 (-4.1, 5.1)	4.68 (0.6, 8.8)	0.27 (-4.1, 4.6)
High School	2.02 (-2.6, 6.6)	3.19 (-2.6, 9.0)	-0.49 (-5.5, 4.5)	4.77 (0.3, 9.2)	-0.34 (-5.1, 4.4)
College or Higher	6.33 (1.0, 11.7)	3.22 (-3.5, 10.0)	5.41 (-0.4, 11.2)	8.79 (3.6, 13.99)	2.03 (-3.5, 7.6)
Child Undernutrition					
Stunted	-5.17 (-8.8, -1.5)	-2.32 (-6.9, 2.3)	-5.4 (-9.3, -1.4)	-3.60 (-7.1, -0.1)	-4.92 (-8.7, -1.2)
Not Stunted	**Ref.**	**Ref.**	**Ref.**	**Ref.**	**Ref.**
Home Environment	0.34 (0.0, 0.6)	0.27 (-0.1, 0.7)	0.12 (0.1, 0.7)	0.22 (-0.1, 0.5)	0.17 (-0.1, 0.5)
r squared	0.1457	0.0962	0.1175	0.0642	0.0784
adjusted r squared	0.1282	0.0778	0.0995	0.0451	0.0596

[a]Model adjust for age and gender
FSIQ – Full Scale IQ, PRI – Perceptual Reasoning Index, WMI – Working Memory Index, VCI – Verbal Comprehension Index, PSI – Processing Speed Index

Table 4: Individually fit predictive models for all cognitive indices (WISC) for children 6 -7 years old

	FSIQ Model[a]	PRI Model[a]	VCI Model[a]	WMI Model[a]	PSI Model[a]
Socioeconomic Status					
Low	**Ref.**	**Ref.**	**Ref.**	**Ref.**	**Ref.**
Medium	3.29 (0.6, 5.9)	4.1 (1.0, 7.3)	2.48 (-0.3, 5.3)	---	3.32 (0.7, 5.9)
High	5.69 (2.6, 8.8)	9.56 (6.2, 12.9)	5.05 (1.9, 8.2)	---	6.68 (4.0, 9.4)
Home Environment	0.34 (0.0, 0.6)	--	0.52 (0.2, 0.8)	--	--
Maternal Education					
Elementary School	**Ref.**	**Ref.**	**Ref.**	**Ref.**	**Ref.**
Middle School	1.80 (-2.4, 6.0)	---	---	5.15 (2.2, 9.1)	---
High School	2.02 (-2.6, 6.6)	---	---	5.58 (1.4, 9.8)	---
College or Higher	6.33 (1.0, 11.7)	---	---	9.89 (5.3, 14.5)	---
Child Undernutrition					
Stunted	-5.17 (-8.8, -1.5)	---	-5.5 (-9.5, -1.6)	-3.78 (-7.3, -0.3)	-4.87 (-8.6, -1.1)
Not Stunted	**Ref.**	**Ref.**	**Ref.**	**Ref.**	**Ref.**
Diet Diversity					
Low	**Ref.**	**Ref.**	**Ref.**	**Ref.**	**Ref.**
Medium	---	3.53 (-0.5, 7.6)	---	---	---
High	---	5.47 (1.4, 9.6)	---	---	---
r squared	0.1457	0.102	0.1008	0.0557	0.0732
adjusted r squared	0.1282	0.0901	0.0886	0.0433	0.0631

[a]Model adjust for age and gender
FSIQ – Full Scale IQ, PRI – Perceptual Reasoning Index, WMI – Working Memory Index, VCI – Verbal Comprehension Index, PSI – Processing Speed Index

Table 5: Multivariate linear regression models for full Scale IQ of children 6 – 7 years old

	Crude Model	Model 1	Model 2	Model 3	Model 4	Model 5
Socioeconomic Status						
Low	**Ref.**	**Ref.**	**Ref.**	**Ref.**	**Ref.**	**Ref.**
Medium	4.85 (2.32, 7.38)	4.84 (2.30, 7.37)	3.67 (1.01, 6.32)	3.29 (0.64, 5.94)	3.53 (0.86, 6.21)	3.12 (0.45, 5.79)
High	9.97 (7.37, 12.57)	9.71 (7.09, 12.33)	6.07 (2.96, 9.18)	5.69 (2.59, 8.79)	5.72 (2.55, 8.89)	5.30 (2.15, 8.46)
Home Environment	0.81 (0.54, 1.09)	0.78 (0.50, 1.06)	0.34 (0.03, 0.65)	0.34 (0.03, 0.65)	0.31 (-.001, 0.63)	0.31 (-0.01, 0.62)
Maternal Education						
Elementary School	**Ref.**	**Ref.**	**Ref.**	**Ref.**	**Ref.**	**Ref.**
Middle School	4.07 (-0.13, 8.27)	3.97 (-0.25, 8.19)	2.20 (-2.06, 6.46)	1.80 (-2.43, 6.04)	1.84 (-2.47, 6.15)	1.41 (-2.87, 5.70)
High School	6.07 (1.63, 10.51	6.00 (1.55, 10.46)	2.67 (-1.95, 7.29)	2.02 (-2.59, 6.63)	2.33 (-2.35, 7.01)	1.65 (-3.01, 6.31)
College or Higher	13.61 (8.78, 18.43)	13.17 (8.31, 18.02)	7.03 (1.63, 12.43)	6.33 (0.95, 11.72)	6.69 (1.24, 12.13)	5.96 (0.53, 11.38)
Child Undernutrition						
Not Stunted	**Ref.**	**Ref.**	**Ref.**	**Ref.**	**Ref.**	**Ref.**
Stunted	-7.50 (-11.25, -3.75)	-7.46 (-11.23, -3.69)	---	-5.17 (-8.82, -1.51)	---	-5.29 (-8.5, -1.62)
Child Diet Diversity						
Low Diversity	**Ref.**	**Ref.**	**Ref.**	**Ref.**	**Ref.**	**Ref.**
Med Diversity	3.12 (-0.31, 6.54)	3.08 (-0.34, 6.51)	---	---	0.97 (-2.40, 4.34)	1.29 (-2.06, 4.64)
High Diversity	5.93 (2.60, 9.26)	5.88 (2.54, 9.22)	---	---	1.96 (-1.45, 5.38)	2.25 (-1.14, 5.64)

Crude Model – Bivariate Analysis
Model 1 – Crude Model + Child Age + Child Sex
Model 2 – Model 1 + Household SES Status + Home Environment + Maternal Education
Model 3 – Model 2 + Child Stunting Status
Model 4 – Model 2 + Child Diet Diversity
Model 5 – Model 2 + Child Stunting Status + Child Diet Diversity

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Table 6: Bivariate analysis of descriptive variables and all cognitive indices

Variable	Population	n	VCI	PRI	WMI	PSI	FSIQ
Sex	Male	238	-1.3	-0.9	0.3	0.2	-0.6
Ethnicity	Kinh	221	-2.4*	-3.5*	-1.4	-1.1	-2.8*
Marital Status	Married	454	5.2	3.7	-1.6	-1.0	2.5
Household size	<= 4 Members	273	-0.3	0.4	-0.5	-0.7	-0.3
Household SES Status	Low	157	REF	REF	REF	REF	REF
	Medium	163	4.2**	4.8**	2.6*	3.8**	4.9***
	High	146	8.6***	11.1***	3.5**	7.1***	10.0***
Food Insecurity	Food Insecure	59	-3.1	-2.7	-2.4	-1.9	-3.2
Maternal Mental Health	Any Signs of Depression	324	-1.3	-0.3	0.2	1.2	-0.2
Maternal Education	Elementary School	34	REF	REF	REF	REF	REF
	Middle School	242	2.6	3.4	5.6**	2.3	4.1
	High School	124	3.2	7.2*	6.3**	3.0	6.1**
	College or Higher	67	12.0***	11.6***	11.1***	7.1**	13.6***
Maternal BMI	Underweight	23	REF	REF	REF	REF	REF
	Normal	210	0.7	3.0	1.6	-2.2	1.2
	Overweight	89	0.1	-2.3	1.5	-2.8	-1.1
Child Attends Day Care	Yes	150	1.2	0.6	2.2	1.7	1.7
Hospitalized in the Last Year	Yes	61	-1.3	-2.4	-3.3*	-0.5	-2.3
Currently Healthy	Yes	246	0.9	3.8**	1.5	0.2	2.0
Early Breastfeeding	Yes	223	1.0	0.03	0.9	0.04	0.6
Exclusive Breastfeeding	Yes	247	1.2	0.6	1.0	2.3	1.5
SGA at Birth	Yes	54	-3.3	-3.7	-1.0	-1.6	-3.2
Diversity of Child Animal Source Consumption	Low Diversity (0-1)	65	REF	REF	REF	REF	REF
	Medium Diversity (2)	178	1.9	5.1*	1.4	1.6	3.1
	High Diversity (3-4)	223	3.6*	8.6***	3.1	3.3	5.9**
Stunting	Yes	43	-7.3***	-5.1*	-4.8**	-6.2**	-7.5***
Undernutrition	Yes	63	-4.1*	-1.3	-3.6*	-3.8*	-3.9*
Overweight	Yes	29	2.1	-0.6	0.7	-1.4	1.6
Child Age		467	-2.4	0.8	1.3	2.3	0.4
HOME Environment		455	0.8***	0.8***	0.5**	0.5***	0.8***

*p<0.05 **p<0.01 **p<0.001

FSIQ – Full Scale IQ, PRI – Perceptual Reasoning Index, WMI – Working Memory Index, VCI – Verbal Comprehension Index, PSI – Processing Speed Index

Table 7: Characteristics of household, caregiver, and child by household ethnicity, household socioeconomic status, and child gestational size

Determinant	Population	By Ethnicity Kinh	By Ethnicity Other	By Socio-Economic Status Low	By Socio-Economic Status Medium	By Socio-Economic Status High	By SGA at Birth Small	By SGA at Birth Not Small
		% or mean ± SD		% or mean ± SD			% or mean ± SD	
Sex	Male	53.2	49.6	53.5	51.5	48.3	48.2	52.1
Ethnicity	Kinh	---	---	37.6	48.5	56.9**	35.2	49.2
Marital Status[bc]	Married	97.7	96.8	97.5	98.2	95.9	98.2	97.1
Household size	<= 4 Members	43.0	40.2	63.1	55.8	56.9	64.8	57.4
Household SES Status	Low	26.7	40.0**	---	---	---	50.0	31.4*
	Medium	35.8	34.3	---	---	---	25.9	36.7
	High	37.6	25.7	---	---	---	24.1	31.9
Food Insecurity	Food Insecure	10.0	15.2	23.2	11.1	3.4***	13.2	13.0
Maternal Mental Health[b]	Depressed	70.5	71.6	73.5	69.8	70.4	74.5	70.1
Maternal Education[cd]	Elementary School	5.4	8.9	15.3	3.7	2.7***	9.3	6.8
	Middle School	52.9	50.8	65.6	57.7	30.8	50.0	52.4
	High School	27.2	26.0	16.6	32.5	30.1	31.5	26.8
	College or Higher	14.5	14.2	2.6	6.1	36.3	9.3	14.0
Maternal BMI	Underweight	9.0	5.4	4.8	6.5	10.2	12.2	6.6
	Normal	63.9	66.5	71.4	61.1	32.4	65.9	64.6
	Overweight	27.1	28.1	23.8	32.4	26.9	22.0	28.8
Child Attends Day Care	Yes	29.9	34.1	25.5	27.6	44.5**	24.1	32.1
Hospitalized in the Last Year	Yes	11.3	14.8	13.6	15.3	10.3	9.4	13.7
Currently Healthy	Yes	58.6	48.2*	44.0	52.5	63.5	64.8	44.2**
Early Breastfeeding	Yes	51.3	56.9	57.6	54.0	50.4	42.0	55.8
Exclusive Breastfeeding	Yes	55.4	63.6	62.4	62.7	53.7	68.0	59.1
SGA at Birth	Yes	9.2	15.4	18.5	9.2	9.7*	---	---
Diversity of Child Animal Source Consumption[c]	Low Diversity (0-1)	14.0	13.9	24.2	11.7	5.5***	7.4	15.8
	Med Diversity (2)	36.2	40.0	42.0	42.0	30.1	44.4	37.2
	High Diversity (3-4)	49.8	46.1	33.8	46.3	64.4	48.2	47.0
Stunting	Yes	5.5	12.7**	15.9	6.8	4.9**	14.8	8.2
Undernutrition	Yes	11.4	15.6	19.1	13.5	7.7*	24.1	11.8*
Child Age		6.4 ± .2	6.4 ± .2	6.4±.2	6.4±.2	6.4±.2	6.5±.2	6.4±.2
HOME Environment		28.9 ± 3.7	27.3 ± 4.0***	26.0±3.2	28.1±3.8	30.3±3.7***	27.7±3.6	28.0±3.9

*p < .05 **p< .01 ***p<.001

[a] Fisher test used in proportion analysis with ethnicity chi^2

[b] Fisher test used in proportion analysis with SES chi^2

[c] Fisher test used in proportion analysis with SGA chi^2

[d] Fisher test not run for SES due to limited numbers

Table 8: Characteristics of household, caregiver, and child by household food insecurity, maternal education, and caregiver present during 6 – 7 y assessment

		By Food Insecurity		By Maternal Education				Caregiver	
		Insecure	Secure	Elementary	Middle	High	College or Higher	Mother	Other
Determinant	Population	% or mean ± SD		% or mean ± SD				% or mean ± SD	
Sex	Male	58.6	50.1	50.0	52.7	49.2	50.8	51.3	51.4
Ethnicity	Kinh	37.3	49.1	35.3	48.4	48.4	47.8	47.8	46.2
Marital Status[ab]	Married	98.3	97.3	97.1	97.1	98.4	95.5	98.1	95.2
Household size	<= 4 Members	59.3	58.5	58.8	58.3	55.7	64.2	60.9	53.1
Household SES Status[b]	Low	61.0	29.5***	70.6	42.6	21.1	6.0***	32.7	35.9
	Medium	30.5	35.6	17.7	38.8	43.1	14.9	33.6	37.9
	High	8.5	34.9	11.8	18.6	35.8	79.1	33.6	26.2
Food Insecurity[b]	Food Insecure	---	---	23.5	15.1	8.9	6.0*	12.5	13.3
Maternal Mental Health	Depressed	80.0	69.6	62.5	72.9	71.5	67.7	69.1	75.2
Maternal Education[a]	Elementary School	13.6	6.4*	---	---	---	---	7.8	6.2
	Middle School	61.0	50.1	---	---	---	---	48.8	58.6
	High School	18.6	27.9	---	---	---	---	27.0	25.5
	College or Higher	6.8	15.6	---	---	---	---	16.5	9.7
Maternal BMI[bc]	Underweight	12.5	6.4	0.0	8.9	6.9	5.7	6.9	100.0
	Normal	67.5	64.8	68.0	63.7	67.8	64.2	65.4	0.0
	Overweight	20.0	28.8	32.0	27.4	25.3	30.2	27.7	0.0
Child Attends Day Care	Yes	30.5	32.4	20.6	27.3	31.5	56.7***	35.1	25.5*
Hospitalized in the Last Year[b]	Yes	10.2	13.4	11.8	15.4	9.7	11.9	11.9	15.9
Currently Healthy	Yes	54.2	45.6	67.7	49.0	42.3	37.3*	48.3	43.8
Early Breastfeeding	Yes	63.3	52.9	46.9	54.4	54.0	58.8	55.3	51.9
Exclusive Breastfeeding	Yes	56.9	60.2	56.3	62.0	59.7	52.9	58.0	63.9
SGA at Birth	Yes	12.5	12.3	16.1	12.0	14.3	8.6	13.8	9.6
Diversity of Child Animal Source Consumption[b]	Low Diversity (0-1)	30.5	11.1***	32.4	15.3	11.4	4.5***	12.5	17.2
	Medium Diversity (2)	45.8	37.1	55.9	38.8	35.0	32.8	38.6	37.2
	High Diversity (3-4)	23.7	51.7	11.8	45.9	53.7	62.7	48.9	45.5
Stunting[b]	Yes	12.1	8.9	20.6	11.6	4.8	3.1**	8.4	11.1
Undernutrition[b]	Yes	15.5	13.4	29.4	16.6	8.1	4.6**	13.4	13.9
Overweight[ab]	Yes	5.2	6.5	8.8	4.2	10.5	4.6	6.6	5.6
Child Age		6.4 ±.2	6.43±.2	6.4 ±.2	6.4 ±.2	6.4 ±.2	6.4 ±.2	6.4±.2	6.4±.2
HOME Environment		26.8±4.4	28.3 ± 3.9*	25.2 ±3.3	27.4 ±3.6	28.4 ±3.7	31.60 ±3.4***	28.4±3.9	27.2±3.9**

*p < .05 **p< .01 ***p<.001
a Fisher test used in proportion analysis with food insecurity chi2
b Fisher test used in proportion analysis with maternal education level chi2
c Fisher test used in proportion analysis with caregiver level chi2

Table 9: Characteristics of household, caregiver, and child by child nutritional status and child diet diversity

		By Child Nutritional Status		By Diversity of Child Animal Source Consumption			By Child Nutritional Status	
Determinant	Population	<-2 HAZ	≥ -2 HAZ	Low Diversity	Med Diversity	High Diversity	<-2 WAZ	≥ -2 WAZ
		% or mean ± SD		% or mean ± SD			% or mean ± SD	
Sex	Male	62.8	50.1	44.6	51.4	53.4	50.8	51.4
Ethnicity	Kinh	27.9	49.4**	47.7	44.9	49.3	96.8	97.3
Marital Status[abc]	Married	97.7	97.2	93.9	98.3	97.3	39.7	48.6
Household size	<= 4 Members	60.5	58.4	55.4	59.6	58.3	63.5	57.9
Household SES Status	Low	58.1	31.4**	58.5	37.1	23.9***	47.6	31.8*
	Medium	25.6	36.2	29.2	38.2	33.8	34.9	35.3
	High	16.3	32.4	12.3	24.7	42.3	17.5	33.0
Food Insecurity	Food Insecure	16.3	12.2	28.6	15.3	6.3***	14.3	12.3
Maternal Mental Health	Depressed	69.8	71.3	75.0	70.9	69.9	67.7	71.7
Maternal Education[abc]	Elementary School	16.3	6.4**	16.9	10.7	1.8***	15.9	6.0**
	Middle School	65.1	50.6	56.9	52.8	49.8	63.5	50.1
	High School	14.0	28.0	21.5	24.2	30.0	15.9	28.4
	College or Higher	4.7	15.0	4.6	12.4	18.8	4.8	15.5
Maternal BMI[b]	Underweight	14.8	6.5	7.5	4.0	9.0	11.6	6.5
	Normal	63.0	65.2	60.0	66.4	66.0	65.1	65.0
	Overweight	22.2	28.3	32.5	29.6	25.0	23.3	28.5
Child Attends Day Care	Yes	25.6	32.8	23.1	33.7	33.2	28.6	32.7
Hospitalized in the Last Year	Yes	11.6	13.4	21.5	11.9	11.7	14.5	13.0
Currently Healthy	Yes	54.8	46.2	56.3	48.6	42.5	66.7	43.8**
Early Breastfeeding	Yes	52.5	54.5	55.4	53.7	54.7	53.3	54.4
Exclusive Breastfeeding	Yes	50.0	60.7	55.2	54.4	67.4*	65.0	58.7
SGA at Birth[b]	Yes	20.5	11.7	6.3	14.6	12.8	22.4	10.9*
Diversity of Child Animal Source Consumption	Low Diversity (0-1)	11.6	14.3	---	---	---	12.7	14.3
	Medium Diversity (2)	46.5	37.4	---	---	---	38.1	38.3
	High Diversity (3-4)	41.9	48.3	---	---	---	49.2	47.5
Stunting	Yes	---	---	7.7	11.3	8.1	46.0	3.5***
Undernutrition	Yes	67.4	8.1***	12.3	13.6	14.0	---	---
Overweight[c]	Yes	0.0	6.9	7.7	7.9	4.5	0.0	7.2*
Child Age		6.4±.2	6.4±.2	6.4±.2	6.4±.2	6.4±.2	6.4±.2	6.4±.2
HOME Environment		27.1±3.8	28.1±3.9	25.6±3.9	28.0±4.2	28.9±3.4***	26.9±3.6	28.2±4.0*

*p < .05 **p< .01 ***p<.001

[a] Fisher test used in proportion analysis with the entity of HAZ chi^2

[b] Fisher test used in proportion analysis with the diet diversity chi^2

[c] Fisher test used in proportion analysis with the WAZ chi^2