The Associations between Adiposity, Cognitive Function, and Achievement in Children

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Abstract

Although obesity has been related to measures of academic achievement and cognition in children, the influence of fat distribution, specifically visceral adiposity, on select aspects of achievement and cognitive function remains poorly characterized among preadolescent children. **Purpose:** The aim of this study was to evaluate the relation of adiposity, particularly visceral adipose tissue, on achievement and cognitive function among children. **Methods:** Children with obesity (ages 7-9 years old, N= 55, 35 females) completed cognitive and academic tests. Normal weight children (N= 55, 35 females) were matched to this group on demographic characteristics and aerobic fitness. Covariate analyses included age, Brief Intellectual Ability (BIA), SES, and fat free VO$_2$ (VO$_2$ peak adjusted for lean mass; ml/kg lean/min). Adiposity (i.e., whole body percent fat, subcutaneous abdominal adipose tissue (SAAT), and visceral adipose tissue (VAT)) was assessed using dual energy X-ray absorptiometry. **Results:** The results of this study revealed that, relative to their normal weight counterparts, children with obesity had significantly lower performance on tests of reading and math. Analyses revealed that among children with obesity, %Fat and SAAT were not related to cognitive abilities. However, higher VAT was associated with poorer intellectual abilities, $p's \leq 0.04$; and cognitive performance (i.e. Thinking Ability and Cognitive Efficiency), $p's \leq 0.04$. However, among normal weight children, VAT was positively associated with intellectual abilities and cognitive efficiency. **Conclusion:** In conclusion, the results suggest that VAT was selectively and negatively related with cognition among children with obesity. Along with the dangerous metabolic nature of VAT, its detrimental relationship with obese children’s intellectual and cognitive functioning is concerning.

**Key Words:** obesity; visceral adipose tissue; cognitive ability; academic performance
Introduction

Childhood obesity has become one of the most serious public health concerns in the United States and around the world, with 35.5% of children in the United States now considered overweight or obese (1). Even during childhood, there are negative consequences of obesity such as metabolic and cardiovascular dysfunction (2), and recent research suggests that obesity may also influence cognitive function (3). Specifically, children with obesity have been shown to exhibit decreased cognitive abilities in terms of executive function, attention, short term memory, global functioning, visual spatial skills, and verbal abilities (3). Thus, it is not surprising that a negative association exists between academic achievement and weight status as measured by body mass index (BMI) (4).

One of the major limitations of the existent knowledge is the reliance on BMI as the primary measure of obesity. Although BMI has a dominant role in obesity research, it neglects the important influence of body composition as well as fat deposition. Dual energy x-ray absorptiometry (DXA) provides more experimental rigor in the measurement of obesity and affords the ability to characterize different areas, types, compartments, and distributions of fat. Fat can be divided into a variety of compartments, two of which are: subcutaneous and visceral adipose tissue. Subcutaneous abdominal adipose fat (SAAT) is the fat present directly underneath skin in the abdominal area. SAAT is not only a physical buffer for the body, it is also where excess energy is stored (5). In adults, roughly 80% of all body fat is stored as SAAT (6–8). When the storage capacity of SAAT is exceeded, or the body is not able to make more fat cells, fat begins to accumulate in other locations such as the viscera. Visceral fat (VAT) is stored within the abdominal cavity, around vital organs including the liver, pancreas, and intestines. Additionally, increased VAT is related to a high risk of metabolic disease, as it produces inflammatory cytokines and hormones (9). SAAT and VAT variables are calculated from a 5cm
wide section placed across the entire abdomen just above the iliac crest at a level approximately coinciding with the 4th lumbar vertebrae. The total abdominal adipose tissue is measured from this region and VAT was estimated by using an automated algorithm that models SAAT at the fourth lumbar vertebra and subtracts it from the regional abdominal adipose tissue (10). This estimate of VAT correlates (r = 0.92, p < 0.01 with computed tomography (CT) values of VAT.

Given that VAT has been mechanistically implicated in metabolic dysregulation, the implications of excess VAT for cognitive function have received increasing scrutiny in recent years. In a sample of over 900 adolescents (12-18 years old), greater amounts of VAT were associated with lower performance on a series of executive function tasks, independent of a number of other key demographic confounders (11). In children, higher amounts of central adiposity have been associated with lower math, reading, and spelling performance even after controlling for IQ (12). Furthermore, in a sample of sedentary, overweight children, fatness was negatively related to cognition, behavior, and academic achievement (13). Despite the few studies that have investigated this relationship, there is much to be learned about how specific types of adipose tissues, namely VAT, relate to cognitive performance during childhood. Understanding the impact of VAT on cognitive function in childhood is particularly important given the rise and prominence of childhood obesity as a public health concern across the globe.

Accordingly, this study aimed to investigate the implications of whole body and central adiposity (i.e., VAT and SAAT) for academic achievement and cognitive abilities among normal weight and obese children. Our central hypothesis was that SAAT would not be related to cognitive performance in either normal weight or obese children, but VAT would be negatively associated with cognitive performance and that these relations will be particularly evident among children with obesity.
Methods

Participants and Laboratory Procedure

The results of this study are based on cross-sectional analysis of baseline data collected from a sample of prepubertal children (N=243) who were recruited to participate in the FITKids2 randomized controlled trial (NCT01619826). All participants provided written assent and their legal guardians provided written informed consent in accordance with the Institutional Review Board of the University of Illinois at Urbana-Champaign. Exclusionary criteria for the study included being outside of the age range (8-10 years old), medical diagnosis of Attention Deficit Disorder, currently taking medications for neurological disorders, specialized education due to educational or attentional disorders, being more than one standard deviation below normal on the measure of Brief Intellectual Ability (BIA), and not completing either the aerobic fitness test or the body composition (DXA) scans. After these inclusion criteria were applied, 55 children with obesity were identified based on BMI-for-age-percentile cut-offs from the CDC (BMI ≥ 95th%) (14), and 55 normal weight children (BMI between the 5th% and 85th%) were matched to this group based on key demographic variables (age, sex, BIA, SES, and fat free VO2 max (ml/kg lean/min)). The matched group of normal weight children was also specifically identified as individuals whose VAT values did not overlap with the range of VAT among the children with obesity. This approach was purposeful in order to examine the unique contribution of VAT within each weight category, and as such, the range of VAT measures did not overlap for normal weight children and children with obesity. This allowed for the examination of groups that were both physiologically and clinically distinct.

Guardians completed questionnaires regarding their child’s health history and demographics. Socioeconomic status (SES) was determined from these questionnaires using a trichotomous index (15). Participants completed the Woodcock Johnson III (WJ III) to assess a
range of cognitive abilities. Participants also completed the Kaufman Test of Educational Abilities (KTEA2) to assess academic achievement. Administration of the WJ III and KTEA2 was conducted individually. All authors as well as all individuals administering these tests met publishers’ test user qualification requirements. When these cognitive and academic tests were complete, participants performed an exercise test to assess aerobic fitness and a DXA scan to assess body composition.

**Cognitive Measures**

Children completed subtests from the WJ III Tests of Cognitive Abilities (WJ III) (16) to assess cognitive abilities. Tests of Brief Intellectual Ability (BIA) and General Intellectual Ability (GIA) were used, and BIA was also used to screen for below normal intelligence (more than 1 standard deviation below the norm). In addition, seven individual tests (Verbal Comprehension, Visual-Auditory Learning, Spatial Relations, Sound Blending, Concept Formation, Visual Matching, and Numbers Reversed) were administered. Combinations of these individual tests form clusters which can be used for interpretive purposes, and these clusters represent general categories of broad cognitive abilities. Cognitive performance clusters (Verbal Ability, Thinking Ability, and Cognitive Efficiency) were computed using the manufacturer’s software. The software provides measures of standard scores as well as percentiles for each participant.

Subtests of the KTEA2 were administered to assess academic achievement in the content areas of math, reading, and spelling. The math test contained 72 items that systematically sampled numeration, the basic operations, fractions, decimals, algebra, roots and exponents, signed numbers, binomials, and factorial expansion with increasing complexity. The reading test assessed knowledge of high frequency words which children learn early on, from those that can be sounded out phonetically and continued to words that were difficult to pronounce. Finally, the
spelling test was based on consideration of the developmental sequence of spelling skills. Both the WJ III and the KTEA2 are one-on-one assessments involving a skilled tester and a child participant, which have been age normed. Standard scores were calculated for each participant. Both examinations are based on a standard score with a mean of 100 and a standard deviation of 15. Age normed standard scores by weight category are presented in Figure 1.

**Cardiorespiratory Fitness Testing**

Participants completed a VO₂max test on a motorized treadmill while indirect calorimetry measurements were collected (Parvo Medics True Max 2400, Sandy, UT) using a modified Balke protocol. Participants ran at a constant speed with incremental grade inclines of 2.5% every two minutes until volitional fatigue (17). Average oxygen uptake (VO₂) and respiratory exchange ratio (RER) were assessed every 20 seconds, and participants wore a Polar heart rate (HR) monitor (Model A1, Polar Electro, Finland) during the test. Every two minutes, ratings of perceived exertion (RPE) were taken using the children’s OMNI scale (18). Relative VO₂max (ml/kg/min) was evidenced by achieving two of the following four criteria: a) a plateau in oxygen consumption corresponding to an increase of less than 2 ml/kg/min despite an increase in workload; b) RER ≥ 1.0 (19); c) a peak HR ≥ 185 beats per minute (bpm) and a HR plateau (17,20); and/or d) RPE ≥ 8 (18). To reduce the collinearity between whole body adiposity and aerobic fitness, fat free VO₂max (ml/kg lean/min) was calculated using an individual’s absolute VO₂max and lean mass. This measure has greater validity than relative VO₂max when comparing aerobic fitness in children of different body sizes (21).

**Body Composition Assessment**

Standing height and weight measurements were completed with participants wearing light weight clothing and no shoes. Height and weight were measured using a stadiometer (Seca; model 240) and a Tanita WB-300 Plus digital scale (Tanita, Tokyo, Japan), respectively. Body
mass index (BMI) was calculated by dividing body mass (kg) by height (m) squared. Whole body and regional soft tissue were measured by DXA using a Hologic Discovery bone densitometer (software version 12.7.3; Hologic, Bedford, MA). DXA is a valid and accurate measure of body composition in children (22). VAT area was estimated by using an automated algorithm that models subcutaneous abdominal adipose tissue (SAAT) at the fourth lumbar vertebra and subtracts it from the regional abdominal adipose tissue (10). This estimate of VAT correlates with MRI measured VAT in adolescents (r=0.71, \( p<0.001 \))(23). In children, CT and DXA measured VAT are correlated (r=0.62, \( p<0.01 \)) (24,25). Importantly, these relationships were strongest among obese children (25). In addition, MRI and DXA measured VAT were also highly correlated (r=0.9, \( p<0.01 \)) in 7-9 year old children (24).

Statistical Analysis

All statistical analyses were performed with SPSS 24 (IBM, Armonk, New York). First, Pearson correlations were conducted to assess bivariate relationships between adiposity and cognitive measures across all participants. Then, because we were specifically interested in the unique relationships within each weight category, Pearson correlations were performed within each weight category. Differences between normal weight children and children with obesity in demographic and cognitive function measures were assessed using independent samples \( t \)-tests using a family-wise alpha threshold for all tests set at \( p=0.05 \). Differences between groups were post hoc corrected using Bonferroni correction for the academic achievement tests (\( p \leq 0.017 \)).

Results

Participant demographics are presented in Table 1 (mean ± SE throughout). Children with obesity and normal weight children were matched based on key demographic variables and did not differ in age, BIA, SES, or fat free VO\( _2 \), confirming efficacy of the participant matching procedure. Confirming accurate group creation, normal weight children had less VAT (100.14 ±
5.63cm$^3$) (range: 19.41, 164.67 cm$^3$) than children with obesity (351.64 ± 16.19cm$^3$) (range 165.54, 660.23 cm$^3$), $t$(108)=14.69, $p<0.001$. As expected, obese and normal weight children also differed in the body composition variables of %Fat and SAAT.

Cognitive cluster performance and academic achievement differences between children with obesity and normal weight children are presented in Figure 1. Normal weight children (113.55 ± 1.78) performed better than children with obesity (108.05 ± 1.63) on the Thinking Ability cluster, $t$(108)=2.27, $p=0.025$, Cohen’s $d=0.43$. The Cognitive Efficiency cluster and Verbal Ability cluster were not different between groups, $t's$(108)$\leq 0.84$, $p's\geq 0.40$. There were differences in academic achievement between normal weight children and children with obesity (see Figure 1). Normal weight children (111.60 ± 1.56) performed significantly better than their obese peers (105.65 ±1.47) in reading, $t$(108)=2.78, $p=0.006$, Cohen’s $d=0.53$. Similar effects were seen in mathematics, $t$(108)=3.0, $p=0.003$, Cohen’s $d=0.57$, with normal weight children (107.20 ± 2.38) performing better than children with obesity (98.91 ± 1.40).

Results of the bivariate correlations across all participants and by weight category are presented in Table 2 and Figure 2. Across all children, VAT was negatively related to measures of cognitive abilities (Brief Intellectual Ability, $r=-0.19$, $p=0.04$; General Intellectual Ability, $r=-0.22$, $p=0.02$, Thinking Ability, $r=-0.25$, $p=0.01$), and Academic Achievement (Reading, $r=-0.22$, $p=0.02$; Spelling, $r=-0.21$, $p=0.03$). SAAT was also negatively related to measures of cognitive abilities (Brief Intellectual Ability, $r=-0.23$, $p=0.02$; General Intellectual Ability, $r=-0.22$, $p=0.02$, Thinking Ability, $r=-0.23$, $p=0.01$), and Academic Achievement (Reading, $r=-0.24$, $p=0.01$; Mathematics, $r=-0.25$, $p=0.01$). In addition, %Fat was negatively related to Academic Achievement (Reading, $r=-0.23$, $p=0.02$; Mathematics, $r=-0.23$, $p=0.02$). Interestingly, among normal weight children, VAT was positively related to measures of IQ (Brief Intellectual Ability, $r = 0.31$, $p = 0.02$; General Intellectual Ability, $r = 0.33$, $p = 0.01$);
cognitive cluster performance (Cognitive Efficiency, $r = 0.28$, $p = 0.04$); and reading ($r = 0.34$, $p = 0.01$), suggesting that in normal weight children, higher VAT is related to higher cognitive and academic performance across a number of domains. Specifically, among children with obesity, VAT was negatively correlated with measures of cognitive abilities (Brief Intellectual Ability, $r=-0.30$, $p=0.03$; General Intellectual Ability, $r=-0.36$, $p=0.007$); and cognitive cluster performance (Thinking Ability, $r=-0.30$, $p=0.03$; Cognitive Efficiency, $r=-0.33$, $p=0.015$), suggesting that in children with obesity, higher VAT is related to worse cognitive performance. These effects were not present for either weight category for other measures of adiposity including %Fat and SAAT. There were no demographic variables that were significantly related to cognitive performance.

**Discussion**

In this investigation, cognitive differences between normal weight children and children with obesity were assessed. A particularly valuable aspect of the current study was the matching on fitness levels between obese and normal weight children, as these variables are usually confounded. Novel to this study was the focus on fat distribution within each weight category. The findings highlight the importance of examining the role of different types of adipose tissue within different weight categories, and add to past research suggesting that obesity during childhood is related to poorer academic achievement, thinking ability, and cognitive performance (4,12,26). Furthermore, a specific type of adipose tissue, VAT, may serve as a particularly pathogenic adiposity depot site with implications for children’s cognitive abilities. These findings are important to consider as VAT begins to accumulate in early childhood (27).

This is the first study to not only compare matched samples based on weight category, but also to define groups based on VAT. Children in the normal weight group were specifically selected to have less VAT than the group of children with obesity. This allowed for a better
understanding of the differential roles of weight status as well as VAT on cognitive health in children. Children with obesity performed significantly worse than their normal weight counterparts on tests of reading and mathematics. This finding corroborates recent studies indicating that weight status is negatively associated with academic achievement (4,12,28,29). In addition, children with obesity performed significantly worse than their normal weight peers on the cognitive cluster of thinking ability, which represents thinking processes such as visual-spatial thinking, fluid reasoning, long term retrieval, and others. The Thinking Ability cluster indicates an individual’s ability to process non-language based information in short term memory, and this information requires additional processing to be understood. Thus, Thinking Ability is critical for cognitive function since it is engaged when information in short term memory cannot be processed automatically (30). This is consonant with previous studies whereby children with obesity demonstrated impairments in cognitive processes (3,31). In addition, unlike most previous studies, children in this study were carefully matched based on demographic variables as well as fitness, highlighting the role that weight status has in cognition during childhood. Further, differences between children with obesity and normal weight children were of moderate effect sizes (between 0.43-0.57).

Interestingly, VAT independently and selectively correlated in opposite directions between normal weight children and children with obesity. Specifically, in normal weight children, higher VAT was related to better cognitive performance, whereas in children with obesity, increases in VAT were related to poorer cognitive performance. Neither %Fat or SAAT predicted performance in normal weight or children with obesity, emphasizing the critical nature of VAT. This corroborates prior research suggesting that VAT is a clinically relevant type of body fat, independent of total body fat (32,33). While the positive associations between VAT and cognition in normal weight children were unexpected, some amount of VAT serves a
physiological function in supporting and protecting the internal organs. These findings highlight how important it is to consider the amount of VAT an individual has in addition to their weight category.

In a large study of adolescents, as VAT was negatively correlated with performance on a Stroop task of inhibition (11). In addition, prior studies have used waist circumference as a surrogate measure of central adiposity, and in both adolescents and young adults greater waist circumference has been associated with worse performance on tasks of executive function (34). Furthermore, although it is not uncommon for there to be sex differences in VAT as well as cognition, the present sample did not demonstrate sex differences along these variables. This is in contrast to Schwartz et al., which found that sex moderated the association between VAT and cognition, whereby the associations were mainly present in females. One potential reason for these differences is age, as Schwartz et al. included adolescents between 12-18 years old, and the present study included children between 8-9 years old. Accordingly, pubertal timing (among other maturational factors) may moderate the sex-VAT relationship.

These findings emphasize the critical nature of VAT in children with obesity, which is not entirely surprising as VAT is particularly metabolically dangerous, and therefore may especially detrimental to cognitive health. This corroborates prior research suggesting that VAT is a clinically relevant type of body fat, independent of total body fat (33). These findings suggest that specific types of adipose tissue may be important to consider, above and beyond the cumulative amount of adipose tissue, relative to its influence on cognition. It is also worth noting that there was no association between aerobic fitness and cognition or academic achievement in this sample, and these findings are in disagreement with many prior findings (4,35). This is likely because our samples of normal weight children and children with obesity were relatively homogeneous, exhibiting very low fitness. Furthermore, these prior findings were primarily
concerned with fitness, and thus did not adjust for lean body mass. Thus, there was an insufficient range of fitness to examine differences in cognition and achievement.

These findings highlight how important it is to consider the amount of VAT an individual has in addition to their weight category, and future work should account for both constructs. When excessive VAT begins to accumulate, various negative health consequences may result. There are a number of reasons why VAT may be so influential to cognitive outcomes. Specifically, VAT is sensitive to lipolytic impulse, resulting in an increased rate of lipolysis as well as increased amounts of plasma free fatty acids, which are then drained through venous blood directly into the hepatic portal circulation (36). This system leads directly to the liver, contributing to insulin resistance, fat deposition, and other metabolic complications. Although the present study did not measure metabolic markers, previous studies in obese children suggest that VAT is positively associated with dyslipidemia and insulin resistance (27). Insulin receptors are present in the hippocampus and the cerebral cortex, and obese, insulin resistant children have less efficient brain function than their obese non-insulin resistant peers (37).

Another potential mechanism linking obesity and cognition is inflammation. Children with obesity show higher levels of pro-inflammatory cytokines, which are activated by adipose tissue as an inflammatory response (38). Particular cytokines disrupt neural circuitry involved in cognition and memory, such that elevated plasma levels are associated with impaired processing speed and executive function (39).

While the results of this study are interesting, they are not without limitation. Although recent advances in software technology permit the estimation of VAT using DXA (40), its application to developing children requires caution as the strength of the correlation between DXA generated estimates and CT and MRI-derived visceral fat range between moderate to strong (i.e. 0.62-0.90). Additionally, the directionality of the relationship between obesity and
cognition is unknown, but it may not be unidirectional, such that initially poorer cognitive control may lead to increased adiposity, and this increase may continue to negatively impact cognitive control (3). Finally, due to sample size and a focus on the extreme weight group, overweight children were not included in this analyses. It remains unknown as to how this group of children performs relative to their NW and OB peers.

These results have critical public health relevance, with 17% of today’s youth being obese. The rates of obesity in children are triple to that of recent history, with the greatest increases in the highest BMI percentiles (1). Furthermore, obesity in childhood predicts future poor health outcomes, including risk for mortality (41). The results from this study suggest a detrimental effect of VAT, particularly in obese children, in terms of demanding cognitive tasks. Thus, these findings add to a body of research indicating the negative impact of VAT on aspects of cognition in children with obesity.

Acknowledgments

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References


FIGURE CAPTIONS

Figure 1. BIA, GIA, Cognitive Clusters, and Academic Achievement in Children with Obesity and Normal weight children (Mean ± SE).

Figure 2. Bivariate correlations for VAT and Brief Intellectual Ability, General Intellectual Ability, Thinking Ability, and Cognitive Efficiency. Children with obesity are presented in grey and normal weight children are presented in black.
Figure 2
**Table 1. Participant Characteristics.**

<table>
<thead>
<tr>
<th></th>
<th>Normal weight</th>
<th>Obese</th>
<th>p-values</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>55 (35 females)</td>
<td>55 (35 females)</td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>8.63 ± 0.07</td>
<td>8.72 ± 0.07</td>
<td>0.36</td>
</tr>
<tr>
<td>BIA</td>
<td>107.75 ± 1.81</td>
<td>103.67 ± 1.63</td>
<td>0.10</td>
</tr>
<tr>
<td>SES</td>
<td>1.91 ± 0.11</td>
<td>1.63 ± 0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>( \text{VO}_2 \text{ FF} \text{ (ml/ kg lean/ min)} )</td>
<td>58.52 ± 0.99</td>
<td>57.70 ± 0.92</td>
<td>0.50</td>
</tr>
<tr>
<td>VAT* (cm(^3))</td>
<td>99.47 ± 5.69</td>
<td>351.65 ± 16.19</td>
<td>≤ 0.001</td>
</tr>
<tr>
<td>SAAT* (cm(^3))</td>
<td>531.39 ± 33.00</td>
<td>1605.37 ± 67.34</td>
<td>≤ 0.001</td>
</tr>
<tr>
<td>%Fat*</td>
<td>26.59 ± 0.60</td>
<td>40.43 ± 0.56</td>
<td>≤ 0.001</td>
</tr>
</tbody>
</table>

Note: data are presented as mean ± SE; SES = socioeconomic status; \( \text{VO}_2 \text{ FF} \) = fat free maximal oxygen volume; VAT = visceral adipose tissue; SAAT = subcutaneous abdominal adipose tissue; \*p ≤ 0.05
Table 2. Correlations between demographics, fitness, adiposity, and cognition.

<table>
<thead>
<tr>
<th></th>
<th>Age</th>
<th>Sex</th>
<th>SES</th>
<th>FF VO&lt;sub&gt;2max&lt;/sub&gt;</th>
<th>%Fat</th>
<th>VAT</th>
<th>SAAT</th>
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<tbody>
<tr>
<td>Brief Intellectual Ability</td>
<td>-0.19</td>
<td>0.02</td>
<td>0.17</td>
<td>0.06</td>
<td>-0.14</td>
<td>-.19&lt;sup&gt;*&lt;/sup&gt;</td>
<td>-.23&lt;sup&gt;**&lt;/sup&gt;</td>
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<tr>
<td>General Intellectual Ability</td>
<td>-0.12</td>
<td>-0.01</td>
<td>0.18</td>
<td>0.07</td>
<td>-0.13</td>
<td>-.22</td>
<td>-.22&lt;sup&gt;**&lt;/sup&gt;</td>
</tr>
<tr>
<td>Verbal Ability</td>
<td>-0.12</td>
<td>0.02</td>
<td>.21&lt;sup&gt;*&lt;/sup&gt;</td>
<td>0.04</td>
<td>-0.11</td>
<td>-.11</td>
<td>-0.19</td>
</tr>
<tr>
<td>Thinking Ability</td>
<td>-0.17</td>
<td>-0.06</td>
<td>0.12</td>
<td>0.09</td>
<td>-0.13</td>
<td>-.25&lt;sup&gt;**&lt;/sup&gt;</td>
<td>-.23&lt;sup&gt;**&lt;/sup&gt;</td>
</tr>
<tr>
<td>Cognitive Efficiency</td>
<td>0.01</td>
<td>0.01</td>
<td>.22&lt;sup&gt;*&lt;/sup&gt;</td>
<td>0.03</td>
<td>-0.04</td>
<td>-0.14</td>
<td>-0.08</td>
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<tr>
<td>Reading</td>
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<td>0.07</td>
<td>0.11</td>
<td>0.02</td>
<td>-.23&lt;sup&gt;**&lt;/sup&gt;</td>
<td>-.22</td>
<td>-.24&lt;sup&gt;**&lt;/sup&gt;</td>
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<tr>
<td>Mathematics</td>
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<td>0.12</td>
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<td>0.05</td>
<td>-.23&lt;sup&gt;**&lt;/sup&gt;</td>
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<td>-.25&lt;sup&gt;**&lt;/sup&gt;</td>
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<td>Spelling</td>
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<td>-0.14</td>
<td>-.21&lt;sup&gt;*&lt;/sup&gt;</td>
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Normal weight Children

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Children with Obesity

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*p ≤ 0.05, **p ≤ 0.001