

# OBESITY, VISCERAL ADIPOSE TISSUE, AND COGNITION IN CHILDHOOD

BY

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DISSERTATION

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## **Abstract**

There is an increasing prevalence of physical inactivity during childhood, concurrent with a rise in obesity rates, which are associated with a myriad of health complications. In addition to weight status, central adipose tissue is particularly dangerous, with visceral adipose tissue being linked to higher risks of metabolic diseases and cardiovascular complications. However, the relationship between central adiposity and brain health and cognition during childhood, and the influence of a physical activity on these relationships, is unknown. Accordingly, the aim of this investigation was to examine baseline behavioral and neuroelectric differences between healthy weight children and obese children, as well as the effect of a 9-month physical activity intervention on changes in body composition and cognition in preadolescent children. Obese children participating in a randomized controlled trial were matched with healthy weight children participating in the same intervention. Following a 9-month physical activity intervention, children who participated in the intervention showed improved body composition, whereas those children in the waitlist-control condition, particularly obese children, gained central adipose tissue. Furthermore, obese children in the intervention showed greater changes in a cognitively demanding task, which were further related to changes in visceral adipose tissue. Beneficial changes in body composition were related to an increased capacity to allocate attentional resources and faster cognitive processing, particularly in obese intervention children. These findings highlight the benefits of physical activity, both in terms of body composition and cognitive health, particularly for obese children.

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## **Chapter 1**

### **Introduction**

For the first time in history, today's children are expected to live less healthy and shorter lives than their parents (Fontaine, Redden, Wang, Westfall, & Allison, 2003; Layden et al., 2005), with approximately 2.8 million deaths per year attributed to being overweight or obese (World Health Organization, 2010). Childhood obesity has become one of the most serious public health concerns in the United States and around the world, with nearly 25 million children overweight or obese. Obesity is characterized by an excess accumulation of adipose tissue resulting in health complications including psychosocial (poor self-esteem, depression, etc.), neurological, pulmonary (sleep apnea, asthma, etc.), gastrointestinal, renal, musculoskeletal, endocrine (type 2 diabetes), and cardiovascular function (dyslipidemia, hypertension, etc.) (Cara B Ebbeling, Dorota B Pawlak & Daring, 2002). Body mass index (BMI), weight in kilograms divided by height in meters squared ( $\text{kg}/\text{m}^2$ ), is typically used to determine weight status. In children, a BMI above the 95<sup>th</sup> percentile is considered obese. Although BMI does not directly measure body fat, other measures such as Dual Energy X Ray Absorptiometry (DXA) are more sensitive, and therefore considered a more precise and useful tool. One reason is because DXA allows for the distinction between subcutaneous and visceral adipose tissue. Subcutaneous adipose tissue is primarily stored under the skin, and visceral adipose tissue is stored in the abdominal cavity around vital organs. Unsurprisingly, visceral adipose tissue is more dangerous and related to metabolic complications such as insulin resistance and cardiovascular complications (J.-P. Després et al., 2008; M. I. Goran, Bergman, & Gower, 2001; Gower, Nagy, & Goran, 1999).

Not only is obesity associated with poorer physical health, it has also been related to poorer cognitive health, with disproportionately larger effects observed for tasks requiring

cognitive control. Cognitive control refers to a group of higher order mental operations implicated in the regulation of goal directed behaviors mediated by the prefrontal cortex and associated networks (Botvinick, Braver, & Barch, 2001; Meyer, David E & Kieras, 1997; E. K. E. Miller & Cohen, 2001; Norman & Shallice, 1986). Cognitive control follows a protracted developmental course (Lamm, Zelazo, & Lewis, 2006; Zelazo & Müller, 2002) and is made up of the core cognitive processes: inhibition, working memory, and cognitive flexibility (Diamond, 2006). Inhibition refers to the ability to suppress irrelevant task information in the environment, and to inhibit a prepotent or impulsive response (Diamond, 2006). During childhood, inhibition is particularly critical since it involves prolonged attention and control of one's actions (Diamond, 2006). Working memory involves holding information in one's mind and mentally manipulating it (Baddeley & Hitch, 1994; Smith & Jonides, 2003). On the other hand, cognitive flexibility involves changing perspectives both spatially and interpersonally. These aspects of cognitive control provide the foundation for academic achievement as well as learning during childhood, such that children often have to inhibit irrelevant stimuli in their environment, and process and store diverse types of information during academic lessons. Clearly, effective learning is critical for successful academic achievement. Thus, if children have less optimal levels of cognitive control, they may struggle to learn, and have lower achievement, which may have deleterious effects across the lifespan. Children who perform poorly on working memory tasks perform below standards on tests of English, math, and science (Elliott, Figg, Bennett, Resing, & Stringer, 2003; Gathercole, Pickering, Knight, & Stegmann, 2004; Gathercole & Pickering, 2000). Inhibitory control has also been implicated in both reading (De Beni, Palladino, Pazzaglia, & Cornoldi, 1998; Gernsbacher, 1993) and mathematics (Espy et al., 2004; St Clair-Thompson & Gathercole, 2006a). In general, cognitive control is heavily implicated in

academic achievement (Diamond, 2006). Furthermore, a negative relationship exists between academic achievement and BMI (Castelli, Hillman, Buck, & Erwin, 2007; Datar & Sturm, 2006; Donnelly et al., 2009; Kamijo, Khan, et al., 2012), and higher amounts of central adiposity have also been associated with lower math, reading, and spelling scores even after controlling for IQ (Kamijo, Khan, et al., 2012).

These negative associations between obesity and academic achievement are in concert with the relationship between obesity and cognition. Research suggests that childhood obesity is related to poorer cognition, ranging from behavioral measures to differences in brain structure and function. Among children, obesity, as measured by BMI, has been shown to be associated with impairments in cognitive processes involving inhibition, working memory, cognitive flexibility, attention, and memory (Castelli et al., 2007; Kamijo et al., 2014; Kamijo, Khan, et al., 2012; Li, Dai, Jackson, & Zhang, 2008; E. Smith, Hay, Campbell, & Trollor, 2011). Children with extreme obesity, a BMI greater than the 99<sup>th</sup> percentile, exhibit significantly worse performance on tests of attention, mental flexibility, and verbal ability (Lokken, Boeka, Austin, Gunstad, & Harmon, 2009). Inhibition is sensitive to obesity, with obese children performing worse than healthy weight children, specifically on the most challenging aspects of tasks (Reyes, Peirano, Peigneux, Lozoff, & Algarin, 2015). Additionally, elevated visceral adipose tissue has been linked to reduced neurocognitive functioning (Schwartz et al., 2013). Although there is a great deal of variability in the methods used to measure cognitive control and obesity, specific aspects of cognitive control may be related to body composition. Collectively, these findings present converging support for the conclusion that cognitive control is impaired with obesity.

A more detailed understanding of cognitive control may be afforded using sophisticated, non-invasive, brain measures known as event-related potentials (ERPs). ERPs are neuroelectric



activity resulting from, or preparing for, a stimulus or response, and they offer excellent temporal resolution relative to other neuroimaging tools. One ERP component of particular interest is the P3, which is a positive going waveform occurring approximately 300-800 ms after a stimulus occurs (Herrmann & Knight, 2001). P3 amplitude is related to the allocation of attentional resources (Polich & Heine, 1996; Polich, 1987), and its latency reflects the speed at which classification and evaluation of a stimulus occurs (Duncan-Johnson, 1981; Verleger, 1997).

Of concern, obesity has been shown to influence the structure and function of the brain. The relationship between obesity and cognitive control extends to neuroelectric measures, such that obese children, relative to healthy weight children, exhibit smaller P3 amplitude, and longer P3 latency on inhibitory control tasks (i.e., Go/NoGo and flanker tasks) (Kamijo, Pontifex, et al., 2012; Reyes et al., 2015). Insulin may play a role in these differences, as obese children who were also insulin resistant showed the smallest P3 amplitudes and slower P3 latency compared to non-insulin resistant obese children, as well as healthy weight children. Another ERP component of interest is the error related negativity, a negative going component that occurs following errors of commission, which reflects the action monitoring system (Falkenstein, Hohnsbein, Hoormann, & Blanke, 1991; Gehring, Goss, Coles, Meyer, & Donchin, 1993). Obese children have also shown smaller ERN amplitude relative to healthy weight children, reflecting less effective action monitoring (Cserjesi, Molnar, Luminet, & Lenard, 2007; Kamijo et al., 2014). Taken together, obese children may have decreased inhibitory control as evidenced by reductions in the allocation of attentional resources and the speed at which stimuli are processed. However, the relationship between visceral and central adipose tissue on the neuroelectric underpinnings of cognitive control has not been examined in children, to date.

Although childhood obesity is a major physical and mental health concern, there have been few interventions that have resulted in changes in obesity status. These interventions are particularly challenging in children as they continue to grow and develop. Behavioral interventions targeting physical activity have shown some positive outcomes (Atkinson et al., 2001; Gortmaker et al., 1999; Metcalf, Henley, & Wilkin, 2012). However, a recent systematic review revealed that many of these interventions had small to negligible increases in physical activity in children (on average, only about 4 minutes more of walking or running per day) (Metcalf et al., 2012). Thus, it is not surprising that many physical interventions in children have been unsuccessful in improving BMI or body fat (Kamath et al., 2008; Metcalf et al., 2012; Summerbell CD, Waters E, Edmunds L, Kelly SAM, Brown T, 2005). Conversely, in a 9 month physical activity intervention aimed at improving aerobic fitness, children improved body composition, with modest decreases in total and central adiposity compared to the control group who saw unfavorable changes in body composition. The improvements in the intervention group were observed in both healthy weight and overweight/obese children (N. a Khan et al., 2014). Additional research has shown that increases in moderate to vigorous physical activity over the long term may improve BMI in overweight or obese children (Trinh, Campbell, Ukoumunne, Gerner, & Wake, 2013). These findings also advocate for the recommended guidelines of 60 min/day of MVPA to reduce adiposity.

Interestingly, investigations into the effects of long term chronic physical activity on behavioral indices of cognitive control in children who are obese are extremely limited. Research in children, regardless of weight status, suggests that 9 months of a physical activity intervention (previously mentioned) results in increased aerobic fitness and maintenance of BMI; and enhanced task performance and brain function during tasks requiring greater amounts of

cognitive control (C. H. Hillman et al., 2014). In a different intervention, with only obese children, researchers did not observe changes in fitness or BMI, but they still observed improvements in cognitive processes (Davis et al., 2007) and changes in brain function, suggesting that physical activity may modulate neural circuitry involved in cognitive control. Such findings suggest that chronic physical activity interventions may be cognitively beneficial to obese children, regardless of changes in weight status.

Although the physical consequences of obesity are well understood, and evidence from previous research supports the influence of obesity on cognition, the influence of specific types of adiposity (implicated in obesity) such as visceral and central adiposity on particular facets of cognitive development are not yet understood. To date, no single study has examined the relationship between physical activity interventions, sensitive measures of adiposity, and cognitive processes as measured by ERPs. Additional research is needed to understand both the cross sectional associations between specific measures of obesity and cognitive control processes, as well as the changes that occur after a physical activity intervention. Thus, the central goal of the present study is to combine sophisticated cognitive measures (behavior and ERPs) with externally valid measures of aerobic fitness (VO<sub>2</sub>max) and dual energy X-ray absorptiometry (DXA) to characterize the role of body composition (fat distribution-VAT, %Fat, and central adiposity) on cognitive health in prepubertal children.

### **Rationale and Study Purpose**

The purpose of this study was twofold. First, to understand the cross sectional relationship between particular measures of adiposity, specifically central and visceral adipose tissue, on cognitive control, using an inhibition task with various levels of conflict, and academic achievement in 8-9 year old children. Second, to determine the role of a 9-month physical

activity intervention, or 9 months of typical (control/non-intervened) development, on changes in the previously described relationship. These changes over 9 months are critical to understand because if the development of cognitive control is delayed due to obesity, it may have a long term impact on cognition, learning, and scholastic outcomes. Accordingly, obese children may have the most to gain from a physical activity intervention in terms of improved fitness, body composition, cognition, and academic achievement. Given that obesity onset often occurs during childhood, at the same time that rapid brain development is occurring, the associated changes with obesity and the brain is of importance to brain maturation and development. Thus, a more detailed understanding of how obesity affects the development of cognitive control is needed.

### **Aims and Hypotheses**

Aim 1: To examine the influence of whole body fat, visceral fat, and total abdominal adipose fat on brain function, cognition, and achievement in preadolescent children. Furthermore, to examine the differences of the adiposity measures on the various neural and cognitive outcomes in children of different weight categories (i.e., healthy weight and obese).

Hypothesis 1: Obese children are hypothesized to perform more poorly (i.e., lower response accuracy with no differences in reaction time) than healthy weight children on flanker task conditions requiring greater amounts of cognitive control (i.e., incompatible and incongruent conditions). In addition, it is hypothesized that with increasing VAT, obese children would have smaller P3 amplitude on the flanker task, with the largest differences for task conditions requiring greater amounts of cognitive control. This relationship between VAT and P3 amplitude is not expected in healthy weight children. No differences in P3 latency are predicted between obese and healthy weight children, or in relation to VAT. Obese children are also predicted to have lower academic achievement scores than their healthy weight peers, with the greatest

differences on mathematics and reading tests, and VAT is predicted to mediate this relationship in obese children.

Aim 2: To examine changes in whole body, visceral fat, and total abdominal adipose tissue during a 9-month school year with associated changes in brain function, cognition, and achievement.

Hypothesis 2: Following a 9 month intervention, all children are predicted to show cognitive improvements given typical developmental trajectories. Obese children in the physical activity intervention are predicted to show decreases in VAT, whereas obese children in the control group are predicted to increase in VAT over 9 months. Furthermore, it is predicted that the obese children in a physical activity intervention will show greater improvements in response accuracy, and increases in P3 amplitude, relative to obese children in the control. Changes in VAT among obese children are also predicted to correlate with changes in P3 amplitude. Thus, the current investigation provides additional insight into the role of visceral and central fat on cognition, and that obese children enrolled in a physical activity intervention not only become physically healthier, they also show improvements in cognitive health.

## Chapter 2

### Review of Literature

To better understand why adiposity may be related to cognitive control it is necessary to review the existing literature on adiposity, cognitive control, academic achievement, and neuroelectric indices of cognition. First, an overview of the main constructs: childhood obesity, cognition, and ERPs will be discussed to provide a background and framework for their significance. Next, the literature discussing the relations of these constructs to one will be reviewed. Finally, the beneficial influence of physical activity interventions on these constructs is examined to provide justification for the present investigation.

#### *Obesity and Visceral Adipose Tissue*

Obesity is an accumulation of excess adipose tissue that may impair health (Caterson & Gill, 2002). Adipose tissue within the body has various functions. It is the body's primary energy store (Wabitsch, 2002), and well as a large endocrine organ, distributing peptides, cytokines, and proteins into circulation (Rajala & Scherer, 2003). Early onset obesity (such as during childhood) results in adipose cells that experience hypertrophy (increase in volume and size) and hyperplasia (increase cell division and replication) (Hirsch & Batchelor, 1976). The time just before puberty is when maximum proliferation and differentiation of adipose cells occurs. In addition, children show a higher proportion of smaller fat cells than adults, indicating that more new adipose cells are formed during childhood. As adipose cells enlarge they begin to secrete more pro inflammatory cytokines (including TNF alpha, IL6), less anti-inflammatory peptides (such as adiponectin) (Matsuzawa, Funahashi, & Nakamura, 1999), and draw macrophages to the adipose tissue- initiating low grade chronic inflammation (Weisberg et al., 2003; Xu et al.,

2003). Thus, obesity is oftentimes associated with subclinical chronic inflammation (Kathryn, Wellen, & Gokhan, 2003; Weisberg et al., 2003).

Obesity is thought to be the result of an imbalance between energy intake and energy expenditure (Lustig, 2001). However, obesity is a complex disorder that is affected by many interrelated genetic, non-genetic, environmental, and behavioral elements. The most common technique to measure obesity is Body Mass Index (BMI), which is computed by measuring weight in kilograms, and dividing it by height measured in meters ( $\text{kg}/\text{m}^2$ ) with higher values indicating higher body fatness. In children, BMI is age and sex specific, and it is typically expressed as a percentile, which identifies a child's BMI relative to other children in the United States. Individuals with a BMI below the 5<sup>th</sup> percentile are considered underweight, those between the 5<sup>th</sup> and 85<sup>th</sup> percentile are considered normal or healthy weight, those between the 85<sup>th</sup> and 95<sup>th</sup> percentile are considered overweight, and those with a BMI at or above the 95<sup>th</sup> percentile are considered obese (Kuczmarski et al., 2002). However, BMI does not directly measure body fat, but rather total body weight. A more accurate alternative to BMI for measuring body composition is Dual Energy X Ray Absorptiometry (DXA). DXA utilizes low-dose X rays to determine bone mineral tissues as well as soft tissues. These tissues are then divided into lean and fat mass through calibration techniques.

One valuable advantage of DXA is the ability to look at different areas, types, compartments, and distributions of fat. This is important because not all fat is the same, different fat compartments carry different metabolic risks. Fat can be divided into two specific compartments: subcutaneous and visceral adipose tissue. The distribution of subcutaneous and visceral is controlled by hormones (Björntorp, 1997). Subcutaneous fat (SAT) is the fat present directly underneath skin. SAT is not only a physical buffer for the body, it is also where excess

energy in the form of triglycerides is stored (Freedland, 2004). Roughly 80% of all body fat is stored as SAT (Berthomieu & Menasche, 1983; Wajchenberg, 2000). When the storage capacity of SAT 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 fat that is stored within the abdominal cavity, around vital organs including the liver, pancreas, and intestines; and increased VAT is related to a high risk of metabolic disease. VAT is a metabolically active endocrine tissue that produces inflammatory cytokines and hormones (Chaldakov, Stankulov, Hristova, & Ghenev, 2003; KERSHAW & FLIER, 2004; Landin et al., 1990) therefore inflammatory cells are more prevalent in VAT than SAT (Bruun, Lihn, Pedersen, & Richelsen, 2005; Curat et al., 2006). Thus, compared to SAT, VAT is more metabolically and lipolytically active, has greater lipid turnover, and higher fat uptake (Votruba & Jensen, 2007; Wajchenberg, 2000); thus, VAT has a greater influence in the development of insulin resistance (Rondinone, 2006). High VAT may also cause increases in central adiposity, leading to an altered metabolic and inflammatory state, increased insulin resistance, and cardiovascular disease (J.-P. Després et al., 2008; M. I. Goran et al., 2001; Gower et al., 1999). VAT is more dangerous than SAT, potentially due to the drainage of each adipose tissue type. While SAT drains through systemic veins, VAT drains directly to the liver through the portal vein. Drainage into the portal vein allows the free fatty acids and adipokines to act on the liver and affect metabolism. Interestingly, VAT is more sensitive to all forms of weight reduction than SAT (Armellini et al., 1991).

Based on these health complications, early identification and treatment of obesity is critical. Researchers have revealed that children who were overweight at age 5 had a 4 times higher incidence rate of obesity at age 14 compared to those who were normal weight (Cunningham, Kramer, & Narayan, 2014). This is particularly alarming because childhood



obesity can negatively affect nearly every organ system in the body, and has been shown to have various negative medical consequences. These include insulin resistance, type 2 diabetes, hypertension, dyslipidemia, and fatty liver disease (S R Daniels, 2009; Gesta, Tseng, & Kahn, 2007; Park, Falconer, Viner, & Kinra, 2012). VAT is also dangerous in childhood, such that in obese children, increased VAT is related to insulin complications (Bacha, Saad, Gungor, Janosky, & Arslanian, 2003; Cruz, Bergman, & Goran, 2002). Adding to the concern, over the last 30 years in the United States, childhood obesity has tripled, such that 35.5% of preadolescent children are now considered overweight or obese (Ogden, Carrol, Kit, & Flegal, 2012; Ogden, Flegal, Carroll, & Johnson, 2002). This is a growing concern because the prevalence rates of excess weight are increasing rapid, approximately 0.5% per year in the United States.

The onset of obesity tends to occur during childhood, which is a critical period for developing lifelong obesity (Stephen R. Daniels et al., 2005). This is troubling because children who were overweight or obese, and who became overweight or obese adults, had increased risks of type 2 diabetes, hypertension, dyslipidemia, and carotid artery atherosclerosis relative to individuals who were never obese, as well as obese children who became healthy weight adults (Juonala et al., 2011). However, if they became non-obese adults, these risks were similar to individuals who were never obese. In addition to the health consequences associated with obesity, Gortmaker et al. (1993) (Gortmaker, Must, Perrin, Sobol, Arthur, & Dietz, 1993) revealed that obese adolescent women were more likely to become adults with lower educational attainment, earn less money, experience higher rates of poverty, and have lower likelihood of marriage compared with lean adolescent women.

### *Cognitive Control*

Executive function, is mediated by the prefrontal cortex (E. K. E. Miller & Cohen, 2001) and involves the ability to plan, initiate, and perform activities that make up goal directed behavior, self-monitoring, and self-control. The development of executive function begins in childhood and continues through adolescence, overlapping with the growth and development of the frontal lobe (Gogtay et al., 2004; Sternberg, 1983; Welsh, Friedman, & Spieker, 2006). The neural organization and functional connectivity among brain regions changes and develops over childhood and adolescence. Executive function is a higher order cognitive process that oversees cognitive function, one aspect of which is cognitive control. Cognitive control facilitates goal directed behavior involved in perception, memory, and action, and is fundamental for normal cognition (Chajczyk, 1981; Cohen, Servan-Schreiber, & McClelland, 1992). Like executive function, cognitive control also follows a very protracted developmental course (Lamm et al., 2006; Zelazo & Müller, 2002) and is mediated by a neural network that connects the prefrontal cortex and the striatum (Casey et al., 1997; Durston et al., 2002; Koechlin, Ody, & Kouneiher, 2003; E. K. E. Miller & Cohen, 2001). This neural network is primarily comprised of the prefrontal cortex, the anterior cingulate cortex (ACC), and the basal ganglia (Bunge & Crone, 2009; Ridderinkhof, Van Den Wildenberg, Segalowitz, & Carter, 2004; Rueda et al., 2005). The development of cognitive control is also due to the maturation of fronto-striatal connectivity as measured by Diffusion Tensor Imaging (DTI), which detects changes in white matter microstructure based on properties of diffusion (Liston et al., 2006).

Cognitive control is made up of the core cognitive processes: working memory, cognitive flexibility, and inhibition (Diamond, 2006; Meyer, David E & Kieras, 1997; Norman & Shallice, 1986). Working memory is the ability to organize environments in a meaningful way to aid in reaching goals, as well as the ability to hold and manipulate information in one's mind.

Cognitive flexibility is the ability to switch attention and perspective. Inhibition refers to the ability to suppress irrelevant task information in the environment, and to inhibit a prepotent or impulsive response (Diamond, 2006). Inhibition can be measured using a variety of tasks, including Go/NoGo, flanker, stop signal, antisaccade, stroop, and many more. During these tasks, the inferior frontal gyrus and premotor regions show increased activation. The ventrolateral prefrontal cortex (VLPFC) also plays an important role in inhibition (Liston et al., 2006). Although each of these tasks are unique and may tap into different aspects of inhibition, they all require modulation of behavior. Improvements in inhibition continue through childhood and are evidenced by both inhibiting undesirable responses as well as correct responses.

In particular, the Eriksen flanker task (B. a. Eriksen & Eriksen, 1974) employs numerous levels of stimulus and response patterns requiring the modulation of inhibition for successful execution. The flanker task requires attentional inhibition, or the ability to attend to and focus on certain features while ignoring other features; as well as the inhibition of prepotent behavior responses (Diamond, 2013; Posner & DiGirolamo, 1998; Theeuwes, 2010). The flanker task requires an individual to distinguish a centrally presented stimulus from lateral flanking stimuli. Additional interference can be created by manipulating the congruency of the target and flanking stimuli, such that in the congruent condition, the target and flanking stimuli are the same, whereas in the incongruent condition, the target and the flanking stimuli require alternative behavioral responses. Responses to congruent trials are faster and more accurate than incongruent trials (C. W. Eriksen & Schultz, 1979). Incongruent trials require greater amounts of inhibitory/ interference control as the target and flanking stimuli activate multiple action schemas (Spencer & Coles, 1999). Additional amounts of inhibitory control are created by modifying the paradigm and layering an additional stimulus-response incompatible condition. In this condition,

the response mappings to the target stimuli are swapped, such that a target response previously requiring a left response now requires a right response, and a target response previously requiring a right response now requires a left (Friedman, Nessler, Cykowicz, & Horton, 2009; Pontifex et al., 2011). This additional task constraint requires cognitive inhibition, or interference control, to suppress the prepotent mental representations (Diamond, 2013). It is thought that this incompatible condition demands the greatest amount of inhibitory control as interference results from both the flanking stimuli and the initial response requirements (Friedman et al., 2009; Pontifex et al., 2011).

Children who have decreased inhibitory control abilities, such as trouble inhibiting a prepotent response and switching to a new response (as evidenced by slower performance on incongruent Stroop trials) have lower mathematical abilities (Bull & Scerif, 2010). Inhibition has been shown to be significantly associated with achievement in mathematics, English, and science, suggesting that inhibition supports general academic success (Bull, Johnston, & Roy, 1980; St Clair-Thompson & Gathercole, 2006b). In general, executive functions also contribute to academic achievement in mathematics, English, and science. Indeed, cognitive control is heavily implicated in academic achievement (Diamond, 2006).

#### *Childhood Obesity and Cognitive Control*

Various studies have demonstrated a link between adiposity, cognitive control, and brain development in children. For example, Kamiyo et al. (2012) utilized a Go/NoGo task, and after controlling for IQ, found no relationship between weight status and performance on the Go task, which only requires simple stimulus discrimination. However, weight status was negatively related with performance on the NoGo task, such that children with higher BMI exhibited poorer performance for the task that required greater amounts of inhibitory control. Additionally, BMI

and central adiposity were negatively related to academic achievement scores on the Wide Range Achievement Test (WRAT), again indicating that a higher BMI was associated with poorer scores (Kamijo et al., 2012). This finding corroborates recent studies indicating that weight status is negatively associated with academic achievement (Datar & Sturm, 2006). Previous studies have shown BMI to be negatively correlated with orbitofrontal cortex volume (Maayan, Hoogendoorn, Sweat, & Convit, 2011) as well as frontal, limbic (Alosco et al., 2014), and occipital volumes in children (Lange, 2012). However, the relationship between BMI and neurocognitive functioning may not be linear, such that a threshold may exist at which a certain BMI percentile puts an individual at a significantly higher risk of poorer neurocognitive functioning.

For example, children with a BMI equal to or greater than the 95<sup>th</sup> percentile, classified as obese, exhibit cognitive deficits as measured by neurocognitive tasks in executive function, attention, short term memory, global functioning, visual spatial skills, and verbal abilities (Liang, Matheson, Kaye, & Boutelle, 2014; E. Smith et al., 2011). Children with obesity have also been shown to perform worse on tests of inhibitory control (longer reaction times on the Stroop task) (Reyes et al., 2015), tests of cognitive flexibility and shifting (the Wisconsin Card sorting task), and tests of concentration and attention (the D2 attention task), despite similar intelligence and memory abilities (Cserjesi et al., 2007). Similar findings exist in adolescents, such that those who are overweight and obese perform worse on an inhibition and shifting digit test, as well as a flexibility test compared to their normal weight peers. Thus, adolescents with excess weight have poorer neuropsychological ability in measures of response inhibition, flexibility, and decision making (Verdejo-García et al., 2010). In addition, adolescents with extreme obesity, a BMI greater than the 99<sup>th</sup> percentile, had significantly worse performance than the norm on cognitive

tests of attention, mental flexibility, and verbal interference. Importantly, these effects were not due to emotional symptoms or sleep problems (Lokken et al., 2009). In a different study, after bifurcating children into healthy weight and obese groups, performance on compatible and incompatible flanker tasks was compared. There were no differences in performance between the groups on the compatible condition of the task, but on the incompatible condition obese children exhibited longer reaction times compared to their healthy weight counterparts. These results suggests that healthy weight children can effectively upregulate cognitive control as tasks become more difficult, but obese children are less able to modulate cognitive control in order to meet the increased task demands (Kamijo et al., 2014). In a sample of 2,519 children, an association was found between BMI percentile and cognitive impairments in visuospatial organization and general mental ability, and this remained even after adjusting for SES, sports participation, physical activity, TV viewing, blood pressure, and serum lipids. Of greater concern, overweight and obese children had double and triple the odds of poor performance on visuospatial organization and general mental ability compared to their healthy weight peers (Li et al., 2008).

In addition to BMI, a single study has reported that elevated VAT is linked to reduced neurocognitive functioning in childhood (Schwartz et al., 2013). In a sample of 983 adolescents, increased VAT as measured by magnetic resonance imaging (MRI) was associated with lower performance on measures of cognitive control (including processing speed, resistance to interference, cognitive flexibility), but not memory, and these findings was independent of the quantity of total body fat and confounders (age, puberty stage, and income). This relationship was moderated by sex such that the relationship was mainly present in females compared to male

participants (Schwartz et al., 2013). These results suggest that negative associations between obesity and cognition may be disproportionately related to visceral fat (Votruba & Jensen, 2007).

The relationship between obesity and cognition also extends longitudinally. In a sample of normal, overweight, and obese middle aged adults followed over 36 years, central adiposity was associated with an increased risk of dementia, independent of demographic factors, diabetes, cardiovascular comorbidities, and BMI (Whitmer et al., 2008). In children, a longitudinal study investigated the effects of maintaining a lean body on cortical development. Results revealed that lower BMI changes were associated with increased brain volume changes in certain cortical regions in the developing brain (such as the right posterior medial temporal lobe). These results suggest that maintaining a lean body during childhood may result in an increase in regional cortical volume (Hashimoto et al., 2015).

Based on previous research, it appears that aspects of cognitive control are related to body composition. However, there is a great deal of variability in the current literature. Studies have utilized different methodologies to examine cognitive control, and have controlled for different, potentially relevant variables. Further, studies have used different measures to test cognitive function, as well as body composition including BMI, DXA, and MRI. Some studies examined BMI continuously, whereas other studies categorized children based on their weight category. Moreover, very few studies controlled for aerobic fitness when examining the relationship between obesity and cognition. These measures are clearly related to one another, but at the same time, distinct from each other as well. Accordingly, Pontifex et al. (2014) sought to differentiate the roles of obesity and fitness on cognition in a sample of 204 children, who completed tests of cognitive flexibility and inhibition. They observed an association between aerobic fitness (measured via  $VO_{2max}$ ) and inhibition, such that lower levels of aerobic fitness

were related to poorer response accuracy for the flanker task. When fitness was accounted for, there was also a negative association of adiposity (measured via DXA) on inhibition in the most challenging conditions of the flanker task that required the greatest amount of inhibition. Furthermore, there was a negative association between adiposity and cognitive flexibility, in that greater amounts of adiposity were related to decreased accuracy on a switch task (Pontifex et al., 2014). These findings are intriguing as inhibition and cognitive flexibility appear to be distinct and distinguishable processes, but potentially share common neural structures (Miyake et al., 2000). In conclusion, the adverse effects of increased body mass on cognitive control include: inhibition (Kamijo, Khan, et al., 2012; Kamijo, Pontifex, et al., 2012), working memory, (Li et al., 2008) and cognitive flexibility (Cserjesi et al., 2007; Lokken et al., 2009), and these effects are distinguishable in preadolescent childhood.

#### *Event-Related Brain Potentials*

In addition to behavioral measures of cognitive control, it is also possible to measure brain activity using similar tasks and paradigms. In this capacity, event-related brain potentials (ERPs) are a useful tool to measure brain activity, such that they reflect central nervous system (CNS) processing of stimulus information. ERPs are the result of electroencephalogram (EEG) segments that have been averaged around a particular stimulus, and consist of a series of positive and negative voltage waves reflecting electrical activity in the brain. When neurotransmitters bind to receptors, the flow of ions across the cell membrane is changed, resulting in a post synaptic potential. When these post synaptic potentials occur at the same time across many neurons, they lead to electrical potentials that can be measured as voltages from the scalp. These voltages are collected on a moment by moment basis, reflecting the positive and negative peaks over the time course of the ERP, and reflect neural processes occurring in the brain. The



sequence of these waves indicates the flow of information through the brain, with the voltage (size) revealing brain activity occurring at the specific moment in time. Voltage changes reflect a single neural generator, and result in ERP components. The timing and magnitude of these components are measures of amplitude and latency, which can be recorded over the time when most of the action is occurring, from prior to the presentation of a stimulus until after a response to the stimulus is made (Bash, 2015; Lopez-Calderon & Luck, 2014).

Although there are many ERP components, of particular interest is the P3, which is a positive going component occurring approximately 300-800 ms after stimulus onset (Herrmann & Knight, 2001). The P3 is an index of cognitive processes (Donchin & Coles, 1988) including inhibition and working memory and is maximal in the parietal region (Polich, 2007). The P3 reflects context updating, specifically the processing of incoming information. Context updating occurs when an individual has a mental model of their environment (context) and this model is updated with novel stimuli, requiring the maintenance of working memory. Accordingly, the P3 reflects neuronal activity when the mental representations of previous events are revised. Thus, the P3 is involved in the processing of new information when attention is needed to update memory representations. Furthermore, the P3 reflects the allocation of attentional resources, specifically during tasks requiring inhibition and attentional focus (Polich, 2007).

The P3 amplitude is proportional to the amount of attentional resources applied to capture a specific stimulus or task, such that with more effort devoted to a given stimulus, P3 amplitude increases. Latency, on the other hand, is a measure of stimulus classification speed, which provides an index of processing time required before response generation. Shorter latencies reflect faster cognitive processing speed and thus superior cognitive performance (Polich & Herbst, 2000). P3 latency changes across the scalp, with the shortest latencies evident frontally

and the longest latencies evident in the parietal region. As children develop, P3 latency also decreases (Polich, 2007). The P3 is thought to be generated by neocortical generators in the prefrontal cortex, temporoparietal junction, temporal-parietal junction, primary auditory cortex, among others; thus, the midline electrodes tend to be the focus of P3 analyses (Friedman, 2003).

#### *Event Related Brain Potentials and Obesity*

The results of the previously mentioned behavioral studies suggest that weight status may be related to neural networks implicated in cognitive control, such that obese children may exhibit less effective functioning of the prefrontal cortex. ERPs can be used to more fully understand the relationship between obesity and brain function. The P3 is an ERP component that is influenced by a variety of internal and external factors, including circadian rhythm, body temperature, heart rate, food intake, activity time, exercise, fatigue, drugs, age, intelligence, handedness, personality, and genetics (Polich & Kok, 1995). Recently, the P3 and various other ERPs have been implicated in childhood obesity. For example, using a Go/NoGo task, obese children did not show the expected differential topographic P3 distributions between the Go and NoGo tasks, whereas healthy weight children exhibited a more anterior distribution for the NoGo P3 relative to the Go P3, suggesting an upregulation of cognitive control in healthy weight children (Kamijo, Pontifex, et al., 2012). This anteriorization of the NoGo P3 in healthy weight children is thought to reflect prefrontal inhibitory control (Fallgatter & Strik, 1999; Strik, Fallgatter, Brandeis, & Pascual-Marqui, 1998). A second study found that obese children exhibited more variable and smaller P3 amplitude, suggesting that obese children have decreased inhibitory abilities as well as difficulties in allocating attentional resources under more difficult task conditions. Thus, relative to the Go/NoGo task, obese children exhibit deficits in inhibitory control, as illustrated by both ERP and behavioral outcomes (Reyes et al., 2015).

Further research has suggested that insulin resistance may contribute to the observed relation of obesity on ERPs. Tascilar et al. used a target/non-target auditory task to better understand the interrelations of cognition, obesity, and insulin resistance in children. 50 obese children and 23 healthy weight children completed an auditory task eliciting a P3 and a collection of metabolic measures were obtained including fasting plasma glucose, serum triglyceride, total cholesterol, high density lipoprotein cholesterol, low density lipoprotein cholesterol, and fasting plasma insulin. Results revealed significant differences at the Cz electrode for P3 amplitude and latency between obese and healthy weight children, such that obese children showed reduced P3 amplitude and slower P3 latency. Furthermore, obese children who were also insulin resistant had decreased P3 amplitude and longer latency relative to those who were not insulin resistant. Importantly, there were no other differences between the groups in the metabolic measures or in BMI. This association between insulin resistance and P3 may be due to the fact that there is a high concentration of insulin receptors located throughout the brain, particularly in the cortex. Plasma insulin levels increase post prandial, leading to an increase in insulin levels in the cerebrospinal fluid. However, obese individuals with insulin resistance do not exhibit the same increases in insulin in cerebrospinal fluid. These differences in the level of insulin found in cerebrospinal fluid between those with and without insulin resistance may provide information into the mechanism underlying obesity and cognition (Tascilar et al., 2011).

In addition to differences in inhibition with increased adiposity, obese children also show decrements in mental flexibility. In a study that examined the relationship between response monitoring, cognitive control, and childhood obesity, children completed a Simon like interference task. This task is designed to produce a high number of errors to allow for measurement of the error related negativity (ERN); a response locked ERP observed following

errors of commission. The ERN is a negative going component that occurs following a mistake, and it is hypothesized to reflect the detection of conflict in the anterior cingulate cortex, (Botvinick et al., 2001; Yeung, Botvinick, & Cohen, 2004) with smaller ERNs reflecting less effective action monitoring. Following errors, obese children had smaller ERN amplitudes compared to healthy weight children (Cserjesi et al., 2007). Similar results were observed in a flanker task, such that obese children had smaller ERN amplitudes compared to healthy weight children on a modified flanker task, suggesting delayed development of the anterior cingulate cortex in obese children (Kamijo et al., 2014). Taken together, these results suggest that obese children may have decreased ability to modulate cognitive control, decreased efficiency in response monitoring, and greater impulsivity.

#### *The Role of Physical Activity on Obesity*

Clearly, childhood obesity is a serious health concern that warrants early intervention and treatment. However, interventions to stop weight gain and encourage weight loss in children are difficult and of limited success, requiring substantial resources, continuous follow up, and supervision (Cara B Ebbeling, Dorota B Pawlak & Daring, 2002). Various interventions aimed at preventing or treating childhood obesity incorporate a physical activity element (Metcalf et al., 2012). This is logical because more than 50% of 6-11 year olds do not meet the daily recommended 60 minutes/day of moderate to vigorous physical activity (Troiano et al., 2008). Furthermore, children who are obese engage in less moderate to vigorous physical than their healthy weight peers (Andersen, Crespo, Bartlett, Cheskin, & Pratt, 1998; Trost, Kerr, Ward, & Pate, 2001). However, a recent systematic review revealed that many of these interventions had negligible to small increases in physical activity in children (on average, only about 4 minutes) (Metcalf et al., 2012). This may explain why many physical activity interventions in children

have been unsuccessful in improving BMI or body fat (Kamath et al., 2008; Metcalf et al., 2012; Summerbell CD, Waters E, Edmunds L, Kelly SAM, Brown T, 2005). These interventions have been designed to improve health and decrease BMI, and while many are able to show changes in behavior (Atkinson et al., 2001; Gittelsohn et al., 1999; Going SB, Stone E, 2001; Gortmaker et al., 1999; JH & J, 2001; Lohman, S, & D, 2001; Luepker et al., 1996), only a few are able to significantly influence BMI (Atkinson et al., 2001; Gortmaker et al., 1999).

However, it is also important to remember that many of these interventions were originally implemented for different primary reasons, and included all children, regardless of whether they were normal, overweight, or obese. For example, a randomized controlled trial (RCT) in 8-9 year old children involved a 9 month physical activity intervention that met for 70 minutes every day after school. This intervention was aimed at improving physical fitness but children also improved body composition, with modest decreases in total and central adiposity. Importantly, these benefits were observed in both healthy weight and overweight participants. In contrast, the control group saw unfavorable changes in body composition. These findings advocate for the recommended guidelines of 60 min/day of MVPA to reduce adiposity (N. a Khan et al., 2014) and highlight the benefits of RCTs. RCTs are believed to be the best research practice as the treatment and control groups are randomly assigned and differ only in the variables of interest. There have been successful interventions that have focused specifically on overweight and obese children as well. For example, obese children enrolled in an intensive, multicomponent, 3 month intervention, including lectures, nutrition education, and physical activity, exhibited significant weight loss, reduced BMI, reduced body fat, increased physical activity, improved fitness, and reduced total and LDL cholesterol levels. This was in contrast to a control group of obese children who gained weight, increased body fat percentage, did not

change physical activity habits, and had smaller changes in fitness. These effects persisted for a year (Nemet et al., 2005). In order to better understand the long term role of physical activity in changing the BMI of obese children, Trinh et al. (2013) enrolled 258 overweight or obese children and followed them for 3 years. Results revealed that increases in moderate to vigorous physical activity over the long term improved BMI in overweight or obese children.

*The Effects of Physical Activity Interventions on Obesity, Cognition, & Event-Related Brain Potentials*

Although increasing BMI and obesity has been shown to be negatively related to cognition, the previously mentioned studies were primarily cross sectional in nature. Although cross sectional studies are relatively easy and inexpensive to conduct, they do not provide any long-term information regarding the causal nature of this relationship. Longitudinal studies and randomized controlled trials are particularly useful in characterizing how obesity interacts with cognition over time. Childhood obesity is a major public health concern and only a limited number of interventions have successfully improved the weight trajectories of obese children. In Odense, Denmark, a one year multicomponent intervention for overweight and obese 5<sup>th</sup> graders was implemented. This intervention resulted in a significant reduction in body fat, as well as improvements in visuospatial construction and non-verbal memory. There were no differences between the intervention group and the control group in Stroop interference, suggesting that the obesity intervention program may benefit specific aspects of cognitive function (Huang et al., 2015). Enhanced scholastic achievement has also been observed following school based interventions specifically targeting weight gain during development (Donnelly et al., 2009; Hollar, Lombardo, et al., 2010; Hollar, Messiah, et al., 2010)

In Georgia, a weight management RCT was conducted for children between 7-11 years old who were overweight or obese and physically inactive. The intervention was 13 weeks long and consisted of a control group, a low dose exercise group (20 minutes of exercise, 5 days a week), and a high dose exercise group (40 minutes, 5 days a week). Although there were no significant changes in BMI, or body composition after the intervention, there were cognitive changes. Participation in the high dose exercise program exhibited higher planning scores (as measured by the Cognitive Assessment System), which was 3.8 points higher than the control group (there were no differences in planning performance between the low and high dose groups). Furthermore, a dose-response relationship was observed between the amount level of exercise intervention (low or high) and mathematics achievement (measured using the Woodcock Johnson Tests of Achievement) (Davis et al., 2007). In addition to behavioral measures of cognition, researchers also completed functional magnetic resonance imaging (fMRI) scans before and after the intervention in a subsample of the children using an antisaccade task, which requires the inhibition of a prepotent response. The exercise group showed increased prefrontal cortex activity as well as decreased posterior parietal cortex activity (Davis et al., 2011). In a longer 8 month intervention, 43 overweight, inactive children were randomized to either a 40 minute aerobic exercise group or an active control group. After 8 months, changes in adiposity, fitness and cognition were not different between the exercise and active control groups. There were no significant correlations between changes in health variables (such as body fat and fitness) and changes in brain activation, nor were there any differences in changes in performance on the antisaccade and flanker tasks. However, the exercise intervention group showed decreased activation during the antisaccade task and increased activation during the incongruent flanker task at posttest relative to baseline. It should be noted that active control

attendance was 75%, which was significantly greater than attendance to the exercise intervention (i.e., 58%). However, attendance did not correlate with changes in brain activation. These results suggest that daily physical activity for children, even in the absence of fitness and body composition changes, may lead to increased efficiency, as well as increased flexible modulation of cognitive control (Krafft, Schwarz, et al., 2014).

### *Gaps in the Literature*

Research examining the relationship between obesity and cognitive function is in its infancy and findings have been variable. There are a number of potential reasons for the lack of consensus, but it is most likely due to widely divergent methodologies. Specifically, many studies have examined this relationship across large age ranges of childhood (6-18, etc). However, targeted age ranges would better account for neurological development that occurs over childhood, as well as changes in adiposity that occur through childhood, particularly peri- and post-puberty. Additionally, most researchers have measured adiposity using BMI. Although BMI is a good population based measure, it is only a surrogate measure of adiposity. There are other measures that provide more experimental rigor in the measurement of obesity. Further, measures of central adiposity, as well as the types of fat present, such as VAT, are of critical importance as individuals with increased central adiposity as well as VAT are at a greater risk for developing insulin resistance and metabolic syndrome (J.-P. Després et al., 2008). Few studies have controlled for the role of fitness when examining the relation between obesity and cognition. Inconsistencies in research also exist due to the variability in the aspects of cognition and tasks employed. Different tasks tap various aspects of cognitive control, and different cognitive outcomes may be particularly sensitive to the influence of obesity and visceral fat. Furthermore, no studies thus far have examined the neuroelectric underpinnings that may better



explain the relationship between visceral fat and cognition. These sensitive measures are of critical importance because they provide insights into the associated mechanisms, and the specific features of cognition most modifiable by obesity.

Moreover, many of the interventions designed to decrease obesity in childhood have low participation and attendance rates; and lack details regarding the intensity of the interventions. In numerous cases, the interventions fail to influence adiposity/weight gain in (already obese) children (no change in fitness, BMI, or measures of body composition between the intervention and control groups), and thus many would suggest that these interventions did not work. Therefore, the lack significance in the measured cognitive outcomes is not particularly surprising. Finally, the directionality of the relationship between obesity and cognition is also not known, but it may not be unidirectional, such that initial poorer cognitive control may lead to increased adiposity, and this increase may further negatively impact cognitive control.

#### *Rationale and Purpose*

Despite the growing body of research, the understanding of the relationship between obesity and cognition remains incomplete, particularly as it relates to preadolescent children. Therefore, this dissertation aim to examine the role of obesity on cognitive function from both a cross sectional perspective as well as from a longitudinal perspective (following a physical activity intervention). Even less is known in terms of measures of adiposity and neuroelectric measures. Thus, the present investigation provides insight into the relationship between detailed measures of body composition and cognitive control, and its relationship with a physical activity intervention over a 9 month school year.

As the impact of obesity on cognitive health in childhood remains largely unknown (Hildreth, Van Pelt, & Schwartz, 2012; Jeong, Nam, Son, Son, & Cho, 2005), the present

investigation utilizes sophisticated measures to better understand the relationship between obesity, VAT, central adiposity, and cognitive function in children 8 to 10 years old. A better understanding of this association is necessary because during this time, children are undergoing rapid development of executive functioning. Furthermore, the frontal lobe, which is critical for cognitive control (inhibition, working memory, and cognitive flexibility) undergoes substantial development during this time (Shaw et al., 2006). Therefore, a stressor such as obesity during this life stage may be particularly detrimental. Luckily, behavioral interventions may be able to counteract some of these stressors.

Therefore, we utilized a more sensitive and accurate measure of adiposity, dual-energy X-ray absorptiometry (DXA), to go beyond BMI and provide measures of whole body adiposity, central adiposity, and visceral fat as the functions and implications of these measures are unique. The implications of certain types and locations of fat is unknown, but of great significance. Another strength of this study is the ability to measure and control for the effects of aerobic fitness. Adiposity and fitness are interrelated constructs, however they are separate factors that may differentially influence cognitive health. In addition, we aim to extend previous research using valid and sophisticated cognitive tasks to understand this relationship. Behavioral performance on the tasks will be analyzed. The addition of functional neuroimaging (EEG/ERP) data allows the use of more specific measures, such that the brain activation patterns may differ between children of different weight categories, and as children gain adiposity.

The longitudinal aspect of this investigation allows for a unique opportunity to study the directionality of the relationship between adiposity and cognition. The longitudinal (i.e., 9 month) portion of this analysis will provide information regarding causality. As children's cognitive and neural development may be particularly sensitive to physical activity, in examining

changes after a 9 month physical activity intervention, we will determine which aspects of children's cognitive and neural development are most susceptible to interventions and changes in body composition, particularly visceral fat (Diamond, 2000; Charles H Hillman, Erickson, & Kramer, 2008; Kolb & Whishaw, 1998).

### *Hypothesis*

The first purpose of this investigation was to examine the influence of whole body fat, visceral fat, and total abdominal adipose fat on brain function, cognition, and achievement in preadolescent children. Furthermore, to examine the differences of the adiposity measures on the various neural and cognitive outcomes in children of different weight categories (i.e., healthy weight and obese). It is hypothesized that:

- a. Obese children are hypothesized to perform more poorly (i.e., lower response accuracy with no differences in reaction time) than healthy weight children on flanker task conditions requiring greater amounts of cognitive control (i.e., incompatible and incongruent conditions).
- b. In addition, it is hypothesized that with increasing VAT, obese children would have smaller P3 amplitude on the flanker task, with the largest differences for task conditions requiring greater amounts of cognitive control. This relationship between VAT and P3 amplitude is not expected in healthy weight children. This selective effect in obese children may imply that the harmful effects of visceral fat on the brain occur before clinical performance differences emerge.
- c. No differences in P3 latency are predicted between obese and healthy weight children, or in relation to VAT.

- d. Obese children are also predicted to have lower academic achievement scores than their healthy weight peers, with the greatest differences on mathematics and reading tests, and VAT is predicted to mediate this relationship in obese children.

The second purpose of this investigation is to examine changes in whole body, visceral fat, and total abdominal adipose tissue during a 9-month school year with associated changes in brain function, cognition, and achievement. It is hypothesized that:

- a. Following a 9 month intervention, all children are predicted to show cognitive improvements given typical developmental trajectories.
- b. Obese children in the physical activity intervention are predicted to show decreases in VAT, whereas obese children in the control group are predicted to increase in VAT over 9 months.
- c. Furthermore, it is predicted that the obese children in a physical activity intervention will show greater improvements in response accuracy, and increases in P3 amplitude, relative to obese children in the control.
- d. Changes in VAT among obese children are also predicted to correlate with changes in P3 amplitude. Thus, the current investigation provides additional insight into the role of visceral and central fat on cognition, and that obese children enrolled in a physical activity intervention not only become physically healthier, they also show improvements in cognitive health.

## Chapter 3

### Methodology

Aim 1: Cross Sectional Investigation: The relationship between adiposity and cognitive control in children was investigated using a sample of preadolescent children from the East Central Illinois area. Each participant underwent tests of aerobic fitness and body composition, academic achievement testing (WRAT, KTEA), and neuroelectric and behavioral assessment was collected during a modified flanker task.

#### *Participants and Recruitment*

A total of 407 preadolescent children between the ages of 8 and 10 years old were recruited to participate. Of these, 212 children were recruited to participate in FITKids, and 195 children were recruited to participate in FITKids2. All participants provided written assent and their legal guardians provided written informed consent in accordance with the Institutional Review Board of the University and Illinois at Urbana-Champaign.

All participants were administered the Kaufman Brief Intelligence Test (K-BIT; (AS., 1990) or the Woodcock Johnson (Woodcock, 1997) (subtests that make up the Brief Intelligence/ Intellectual Ability Score). Socioeconomic status (SES) was determined using a trichotomous index based on: participation in free or reduced-price lunch program at school, the highest level of education obtained by the mother and father, and number of parents who worked full time (Birnbaum et al., 2002).

#### *Exclusionary Criteria (at pre or posttest)*

Exclusionary criteria for the study included being outside of the age range (8-10 years old), pubertal timing greater than a score of 2 on the Tanner Staging Scale (Taylor et al., 2001), 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 intelligence measures, and not completing either the aerobic fitness test or the body composition (DXA) scans. After these inclusion criteria are applied, 382 children will be included, which consisted of 77 obese children who were matched to 77 healthy weight children based on treatment allocation and key demographic variables.

### *Cognitive Control Task*

Modified Flanker Task: Participants completed a modified version of the Eriksen flanker task (B. a. Eriksen & Eriksen, 1974) to assess inhibitory control. Congruent and incongruent trials require participants to respond based on the direction of the centrally presented stimuli (in this case, fish). Congruent trials consisted of an array of five fish facing the same direction, while incongruent trials consisted of the four flanking fish facing the opposite direction of the target (middle) fish. In addition, stimulus compatibility was manipulated, varying the amount inhibitory control needed to successfully execute the task. In the incompatible condition, the response mappings to each stimuli were reversed, such that when the centrally presented fish faces right, a left button response was required; and when the centrally presented fish faced left, a right button response was required. The incompatible condition required the regulation of interference from the flanking stimuli in addition to inhibition of the prepotent response (Friedman et al., 2009; Pontifex et al., 2011). After receiving task instructions, participants were afforded the opportunity to ask questions and practice the task prior to the start of testing. During 50 practice trials, the experimenter observed the participant to ensure they understand the task and responded correctly. For both compatible and incompatible conditions, participants were administered two blocks of 84 trials, consisting of equiprobable congruency and directionality. Stimuli were 2.5 cm tall fish presented focally for 250 ms on a blue background with a variable response window

of 1550 ms, 1750 ms, or 1950 ms based on the variable interstimulus interval of 1600, 1800, or 2000 ms. Total task time duration was approximately seven minutes. This task allowed for measures of response accuracy and speed.

### *Neuroelectric Assessment*

Electroencephalographic (EEG) activity was measured from 64 electrode sites arranged using the international 10-10 system with a Neuroscan Quik-cap (Compumedics, Charlotte, NC). During collection, data was referenced to a midline electrode placed at the midpoint between Cz and CPz, with AFz serving as the ground electrode. Inter-electrode impedance remained at <10 k $\Omega$  during data collection. Additional electrodes were placed above and below the left orbit and the outer left and right canthi to monitor electro-oculogram activity with bipolar recording. Continuous data were digitized at a sampling rate of 500Hz, amplified 500 times with a direct current to 70 Hz filter, and a 60-Hz notch filter using a Neuroscan Synamps2 Amplifier (Neuro, Inc. Charlotte, NC, United States of America). Offline EEG processing included: eye blink correction using an Independent Component Analysis (ICA), which identified vertical eye blinks. ICA components that met or exceeded a 0.35 correlation with measured vertical EOG channel were considered to be correlated with eye blinks and thus removed from the data. The data was re-referenced to average mastoids. Response-locked epochs from -200 to 1200 ms relative to response onset were created, and baseline corrected using -200 to -0 ms pre-stimulus interval. The data were filtered using a zero phase shift low pass filter at 30 Hz. Artifact detection involved a moving window peak-to-peak threshold of artifact rejection (“Artifact Detection,” n.d.). This function computed the peak-to-peak amplitude within a series of windows within each epoch, it then found the largest peak-to-peak amplitude from these windows for a given epoch of data, compared this to the largest value to the threshold values, and marked the

trial for rejection if the largest value exceeded the  $\pm 100\mu\text{V}$  threshold. Averaged ERP waveforms were created for the correct trials. Waveforms were averaged across compatibility and congruency. The stimulus locked ERP component, P3, was defined as the largest positive going peak within 300 and 600 ms latency window relative to response onset. Mean amplitude and fractional latency were the variables of interest for each component. Mean amplitude is thought to be superior to peak amplitude as it is computed by taking the average voltage over a specified measurement window. Specifically, a voltage is taken at each sample point in the time window and then the average of these voltages is computed. These voltage measures are taken at the same time points in all subjects, in all conditions, in all channels, making it an ideal measurement. To measure latency, fractional area latency was used, which employed area amplitude, and computed the area under the ERP waveform over a specific latency span and found the time point that divided that area into a predetermined fraction. This measure of latency is thought to be less sensitive to noise than peak latency.

### *Academic Achievement Testing*

Wide Range Achievement Test (WRAT): Participants in FITKids completed the WRAT-3 assessment tests for reading (the number of words pronounced correctly), spelling (the number of words spelled correctly), and mathematics (the number of mathematical computations completed correctly). The WRAT-3 is a paper and pencil based academic achievement assessment that has been age normed. The WRAT allowed for repeated administration through the use of two equivalent forms, making it a good option for a longitudinal study. Administration of the WRAT-3 was conducted individually by a trained experimenter.

KTEA academic achievement testing: Participants in FITKids2 completed the subtests of the Kaufman Tests of Educational Abilities to assess academic achievement in the content areas



of math computation, letter and word recognition, and spelling. The KTEA is a paper and pencil academic achievement assessment that has been age referenced. The KTEA allows for repeated administration through the use of two equivalent forms, making it a good option for a longitudinal study. Administration of the KTEA was conducted individually by trained experimenters with the duration of the assessment taking approximately 30 minutes. The following subtests were completed:

Reading/Word Recognition: assessed knowledge of high frequency words (from the Dolch lists), which children learn early on, from those that can be sounded out phonetically and continued to words that were difficult to pronounce

Spelling: based on consideration of the developmental sequence of spelling skills

Math Computation: contained 72 items that systematically sample numeration, the basic operations, fractions, decimals, algebra, roots and exponents, signed numbers, binomials, and factorial expansion. Items increased in complexity.

Both the WRAT and KTEA were based on a standard score with a mean of 100 and a standard deviation of 15. T tests were conducted between the WRAT and KTEA scores and there were no differences in performance on any of the tests between the WRAT and the KTEA, therefore they were combined to create general math, reading, and spelling scores.

### *Intelligence Assessment*

Children in FITKids were administered the Kaufman Brief Intelligence Test (K-BIT) to assess intelligence quotient. Children in FITKids2 completed the Woodcock-Johnson III Tests of Cognitive Abilities (WJ III) - Brief Intelligence Test to assess intelligence. The WJ is a paper and pencil based assessment of cognitive abilities that has been age normed. Standard scores were calculated for each participant. Both the K-BIT and WJIII were based on a standard score

with a mean of 100 and a standard deviation of 15. T tests were conducted between the K-BIT and WJ III scores and there were no differences in performance between the K-BIT and the WJIII, therefore they were combined to create a single intelligence score.

### *Cardiorespiratory Fitness Testing*

Participants completed a  $\text{VO}_2\text{max}$  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 (American College of Sports Medicine, 2014). Average oxygen uptake ( $\text{VO}_2$ ) 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 (Utter, Robertson, Nieman, & Kang, 2002). Relative  $\text{VO}_2\text{max}$  (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)  $\text{RER} \geq 1.0$  (Bar-Or, 1983); c) a peak  $\text{HR} \geq 185$  beats per minute (bpm) and a HR plateau (American College of Sports Medicine, 2014; Freedson PS, 1993); and/or d)  $\text{RPE} \geq 8$  (Utter et al., 2002). Age and gender matched percentile values were derived by using normative values (Shvartz & Reibold, 1990). In order to reduce the collinearity between whole body adiposity and aerobic fitness, fat free  $\text{VO}_2\text{max}$  (ml/kg lean/min) was calculated using an individual's absolute  $\text{VO}_2\text{max}$  and lean mass. This measure has greater validity than when comparing aerobic fitness in children of different body sizes (M. Goran, Fields, Hunter, Herd, & Weinsier, 2000).

### *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. Central adiposity variables were generated from a 5cm wide section placed across the entire abdomen just above the iliac crest at a level approximately coinciding with the 4<sup>th</sup> lumbar vertebrae. TAT (total abdominal adipose tissue) was the total adipose tissue in that area. VAT area was estimated by using an automated algorithm that models subcutaneous abdominal adipose tissue at the fourth lumbar vertebra and subtracts it from the regional abdominal adipose tissue (Micklesfield, Goedecke, Punyanitya, Wilson, & Kelly, 2012). This estimate of VAT correlates ( $r = 0.92$ ,  $p < 0.01$ ) with computed tomography (CT) values of VAT. Precision for DXA measurements of interest are ~1-1.5% in our laboratory.

### Aim 2: Change/ Longitudinal

#### *Procedure*

A total of 407 preadolescent children between the ages of 8 and 10 years old were recruited to participate. Of these, 212 children were recruited to participate in FITKids, and 195 children were recruited to participate in FITKids2. After inclusion criteria were applied, 382 children were included, which consisted of 77 obese children who were matched to 77 healthy weight children based on treatment allocation and key demographic variables. All of the above described tasks/measures were completed at baseline (before the start of the school year) and

following randomization into 9 month intervention/wait list control assignment. The intervention was held during the academic school year and occurred in 9 cohorts between 2009 and 2016.

The aim of the RCT intervention was to increase cardiorespiratory fitness using physical activity with the goal of improving cognitive and brain function in children. It is important to note that this study was advertised as an afterschool physical activity program, and not a weight loss program. The intervention group received a 2-hour intervention (5 days/week for 9 months) based on the Child and Adolescent Trial for Cardiovascular Health (CATCH) curriculum, which is an evidence based physical activity program that provides 70 minutes of moderate to vigorous physical activity in a non-competitive environment. Research staff were blinded to group assignment.

### **Statistical Analysis**

All statistical analyses were performed with SPSS 23 (IBM, Armonk, New York) using a family-wise alpha threshold for all tests set at  $p = 0.05$ .

#### *Baseline Analyses*

Demographic and fitness measures that were significantly different between healthy weight and obese children were included as covariates. Analyses of flanker task performance (response accuracy and reaction time) were conducted using multivariate repeated measures analyses of variance comparing healthy weight and obese children. The dependent variables of interest were assessed using separate 2 (Weight Status: healthy weight, obese) x 2 (Compatibility: compatible, incompatible) x 2 (Congruency: congruent, incongruent). Analyses of flanker task ERP variables (P3 amplitude and P3 latency) were conducted using multivariate repeated measures analyses of variance comparing healthy weight and obese children. The dependent variables of interest were assessed using separate 2 (Weight Status: healthy weight,

obese) x 2 (Compatibility: compatible, incompatible) x 2 (Congruency: congruent, incongruent) x 7 (Electrode Site: Fz, FCz, Cz, CPz, Pz, POz, Oz). Post hoc comparisons were conducted using Bonferroni corrected independent- and paired- sample t-test. All factors were treated as dependent variables and analyses with three or more within subject levels used the Wilks' Lambda statistic. Differences in academic achievement (reading, mathematics, and spelling) were assessed using t-tests between healthy weight and obese children.

Pearson correlations assessed bivariate relationships between adiposity and cognitive measures. Then, separate stepwise linear regressions were conducted across all participants and then separately within each BMI Group (healthy weight, obese) to determine if VAT was associated with the dependent variables of interest: academic achievement (Reading, Math, and Spelling), accuracy and reaction time on flanker tasks (compatible congruent, compatible incongruent, incompatible congruent, and incompatible incongruent), and ERP measures (P3 amplitude and latency). In the first step, the dependent variables were regressed on demographic variables (e.g., age, sex, IQ, VO<sub>2</sub> FF) determined to be significant. Step 2 included VAT, SAT, or TAT. The change in R<sup>2</sup> values between the steps was used to judge the independent contribution of these measures for explaining the variance in the dependent variables of interest beyond that of demographic variables.

#### *Longitudinal Analyses*

Longitudinal analyses mirrored the baseline multivariate approach, with the inclusion of a time factor (pre-test, post-test) and a group factor (intervention, control) to assess group wise differences over the course of 9 months.

In order to account for any baseline differences between BMI and treatment groups, change scores ( $\Delta$ ) were computed for the fitness, adiposity, academic achievement, flanker task

performance, and ERP measures by subtracting the pretest measure from the posttest measure. Demographic and fitness measures that were significantly different between healthy weight and obese children were included as covariates. Analyses of body composition ( $\Delta$ VAT,  $\Delta$ SAT,  $\Delta$ TAT) were conducted using multivariate repeated measures of variance comparing change in healthy weight and obese children. The dependent variables of interest were assessed using separate 2 (Weight status: healthy weight, obese) x 2 (Group: Intervention, control). Analyses of flanker task performance (response accuracy and reaction time) were conducted using multivariate repeated measures analyses of variance comparing changes in healthy weight and obese children. The dependent variables of interest were assessed using separate 2 (Weight Status: healthy weight, obese) x 2 (Group: Intervention, control) x 2 ( $\Delta$ Compatibility:  $\Delta$ compatible,  $\Delta$ incompatible) x 2 ( $\Delta$ Congruency:  $\Delta$ congruent,  $\Delta$ incongruent). Analyses of flanker task ERP variables (P3 amplitude and P3 latency) were conducted using multivariate repeated measures analyses of variance comparing healthy weight and obese children. The dependent variables of interest were assessed using separate 2 (Weight Status: healthy weight, obese) x 2 (Group: intervention, control) x 2 ( $\Delta$ Compatibility:  $\Delta$ compatible,  $\Delta$ incompatible) x 2 ( $\Delta$ Congruency:  $\Delta$ congruent,  $\Delta$ incongruent) x 7 ( $\Delta$ Electrode Site: Fz, FCz, Cz, CPz, Pz, POz, Oz). Analyses of changes in academic achievement variables (reading, mathematics, and spelling) were conducted using multivariate repeated measures analyses of variance comparing healthy weight and obese children. The dependent variables of interest were assessed using separate 2 (Weight Status: healthy weight, obese) x 2 (Group: intervention, control). Post hoc comparisons were conducted using Bonferroni corrected independent- and paired- sample t-test. All factors were treated as dependent variables and analyses with three or more within subject levels will use the Wilks' Lambda statistic.

A second analytical approach employed regression analyses to determine differences within and across groups. First, Pearson correlations were used to assess bivariate relationships between changes in adiposity and changes in cognitive measures. Next, separate stepwise linear regression within each intervention group (intervention vs control) by BMI Group were conducted to determine if changes in VAT, SAT, and TAT were associated with changes in the dependent variables of interest: academic achievement (Reading, Math, and Spelling), flanker task performance (accuracy and reaction time on compatible congruent, compatible incongruent, incompatible congruent, and incompatible incongruent), and ERP measures (P3 amplitude and latency). Analyses were conducted across all participants, and then separately for each BMI Group (healthy weight, obese) for each dependent variable. In the first step, the dependent variables were regressed on the demographic variables (e.g., age, sex, IQ, VO<sub>2</sub> FF). Step 2 assessed  $\Delta$ VAT,  $\Delta$ SAT, and  $\Delta$ TAT. The change in R<sup>2</sup> values between the steps was used to judge the independent contribution of these measures for explaining the variance in the dependent variables of interest beyond that of demographic variables.

## **Chapter 4**

### **Results**

The results section is organized according to dependent measures at each time point (baseline, posttest (accounting for baseline), and change between posttest and baseline). First, participant characteristics are reported in relation to BMI Groupings. Next, baseline performance is reviewed: task performance measures of mean reaction time and response accuracy; P3 amplitude and latency; and academic achievement are presented. Then, correlational and regression analyses between body composition variables and task performance variables are explored. Finally, using the above mentioned variables, the effects of the physical activity intervention as well as changes between pretest and posttest are examined. Findings directly relevant to the central aims of the dissertation are included.

#### **Baseline**

Participant demographics are presented in Table 4.1. Healthy weight and obese children were matched for key demographic variables and did not differ in age, IQ, SES, or Fat Free VO<sub>2</sub>, confirming efficacy of the participant matching procedure. As expected, obese and healthy weight children did differ in the body composition variables of VAT, SAT, and TAT.



Table 4.1. Participant Demographics.

	Matched Healthy	Obese	Entire Sample
	Weight		
n	77 (49 females)	77 (49 females)	154 (94 females)
Age (years)	8.88 ± 0.08	8.81 ± 0.06	8.84 ± 0.05
IQ	105.81 ± 1.51	108.14 ± 1.38	106.97 ± 1.03
SES	1.68 ± 0.08	1.73 ± 0.09	1.70 ± 0.061
VO <sub>2</sub> FF (ml/ kg lean/ min)	56.63 ± 0.81	54.35 ± 0.86	55.49 ± 0.59
VAT* (g)	119.40 ± 5.22	320.67 ± 13.45	220.04 ± 10.86
SAT* (g)	536.65 ± 30.62	1509.29 ± 57.19	1022.97 ± 50.90
TAT* (g)	656.04 ± 30.66	1829.96 ± 66.95	1243.00 ± 59.99

Note: IQ = intelligent quotient; SES = socioeconomic status; VO<sub>2</sub> FF = maximal oxygen volume; VAT = visceral adipose tissue; SAT = subcutaneous adipose tissue; TAT = total abdominal adipose tissue; \* $p \leq 0.05$

### Repeated Measures

Repeated measures analyses employed a BMI Group (2: Healthy Weight, Obese) x Time (2: pre, post) x Compatibility (2: compatible, incompatible) x Congruency (congruent, incongruent) ANOVA.

Mean Reaction Time: The ANOVA revealed a main effect of Compatibility,  $F(1, 152) = 65.78, p < 0.001, \eta^2 = 0.30$ , with the compatible condition ( $552.89 \pm 9.39$  ms) having shorter reaction times than the incompatible condition ( $609.17 \pm 9.49$  ms), and Congruency,  $F(1, 152) =$

116.25,  $p < 0.001$ ,  $\eta^2 = 0.43$ , with congruent trials ( $566.52 \pm 8.66$  ms) having shorter reaction times than incongruent trials ( $595.54 \pm 9.11$  ms) (see Figure 4.1). No main effects or interactions involving BMI Group were observed for mean reaction time,  $F$ 's (1,152)  $\leq 2.0$ ,  $p_s \geq 0.09$ ,  $\eta_p^2 \leq 0.02$  (see Figure 4.2).

Figure 4.1. Baseline mean reaction time ( $\pm$  SE) for each trial type collapsed across BMI Group.

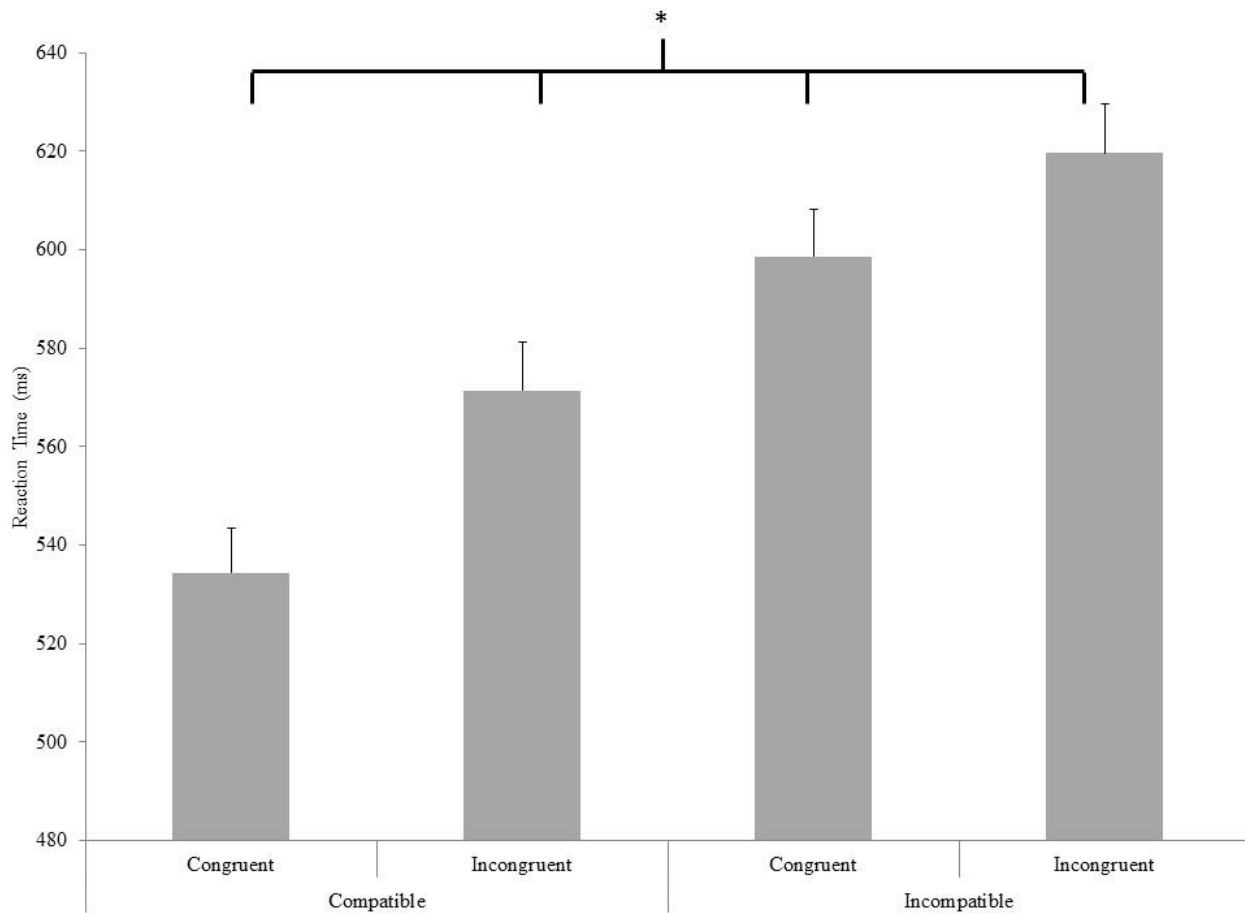
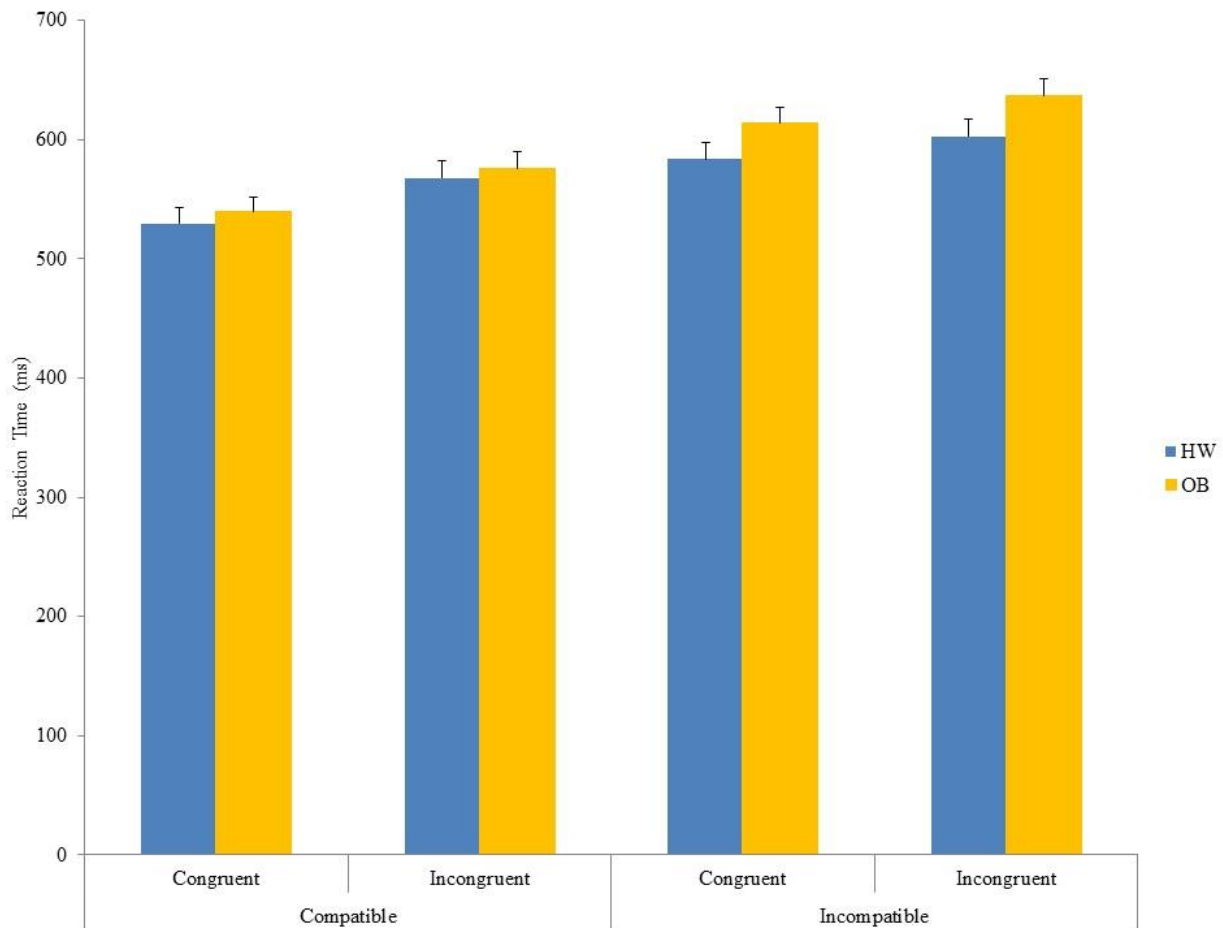


Figure 4.2. Baseline mean reaction time ( $\pm$  SE) for each trial type by BMI Group.



Response Accuracy: The ANOVA revealed a main effect of Compatibility,  $F(1, 152) = 13.77, p \leq 0.001, \eta^2 = 0.08$ , with increased response accuracy in the compatible condition ( $76.65 \pm 0.88\%$ ) relative to the incompatible condition ( $73.13 \pm 1.21\%$ ), and Congruency,  $F(1, 152) = 104.82, p \leq 0.001, \eta^2 = 0.41$ , with increased accuracy in congruent trials ( $77.10 \pm 0.96\%$ ) relative to incongruent trials ( $72.68 \pm 0.68\%$ ) (see Figure 4.3). No main effects or interactions involving BMI Group were observed for response accuracy,  $F's(1, 152) \leq 1.10, p_s \geq 0.30, \eta_p^2 \leq 0.01$  (see Figure 4.4).

Figure 4.3. Baseline response accuracy ( $\pm$  SE) for each trial type collapsed across BMI Group.

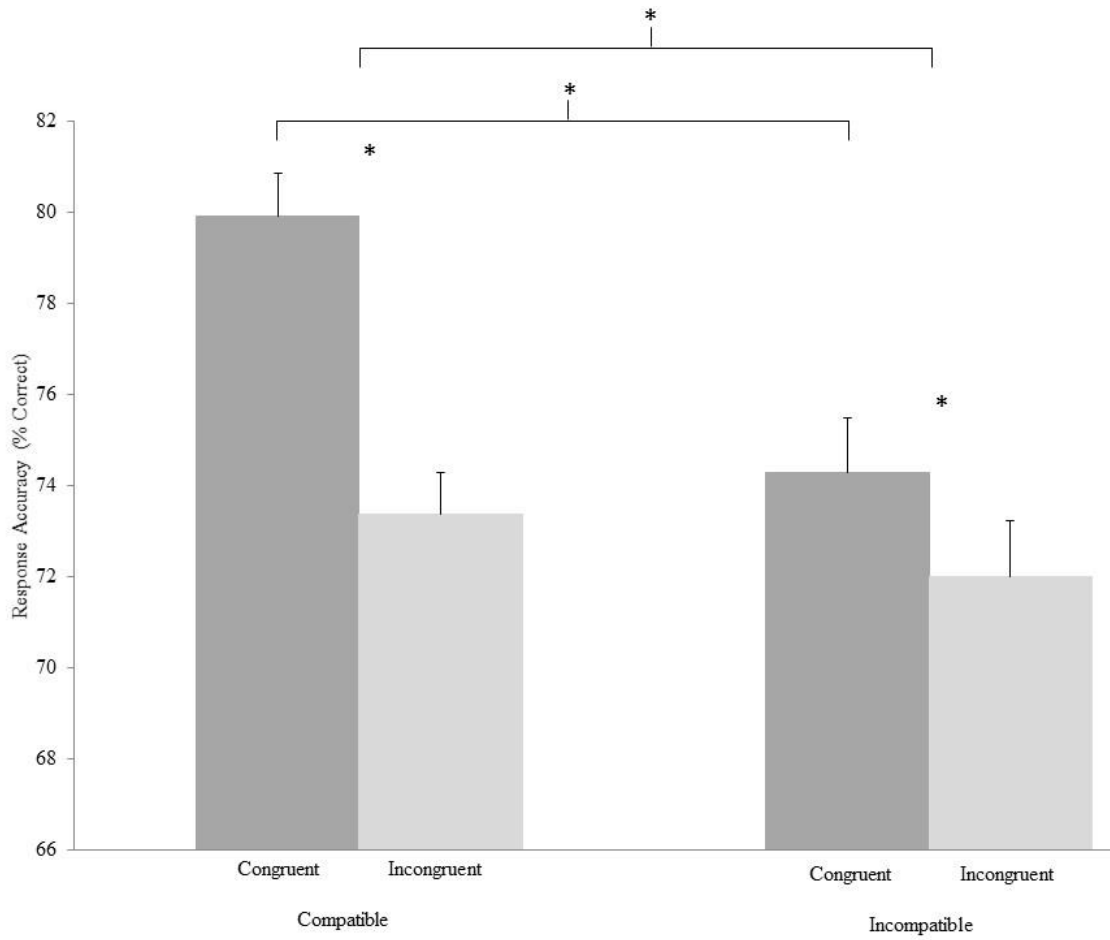
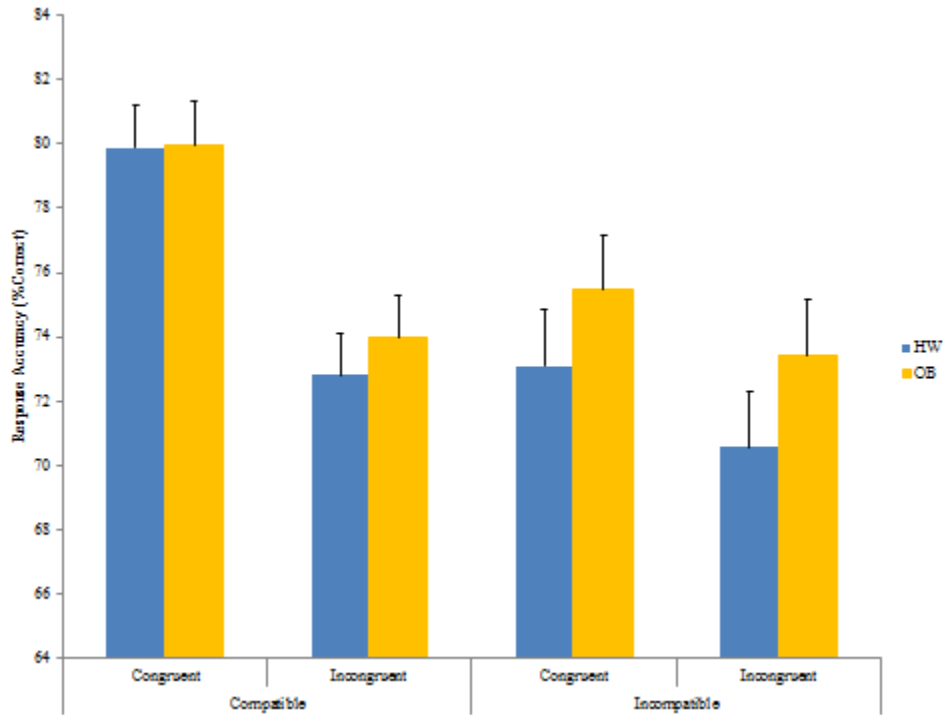


Figure 4.4. Baseline response accuracy ( $\pm$  SE) for each trial type by BMI Group.

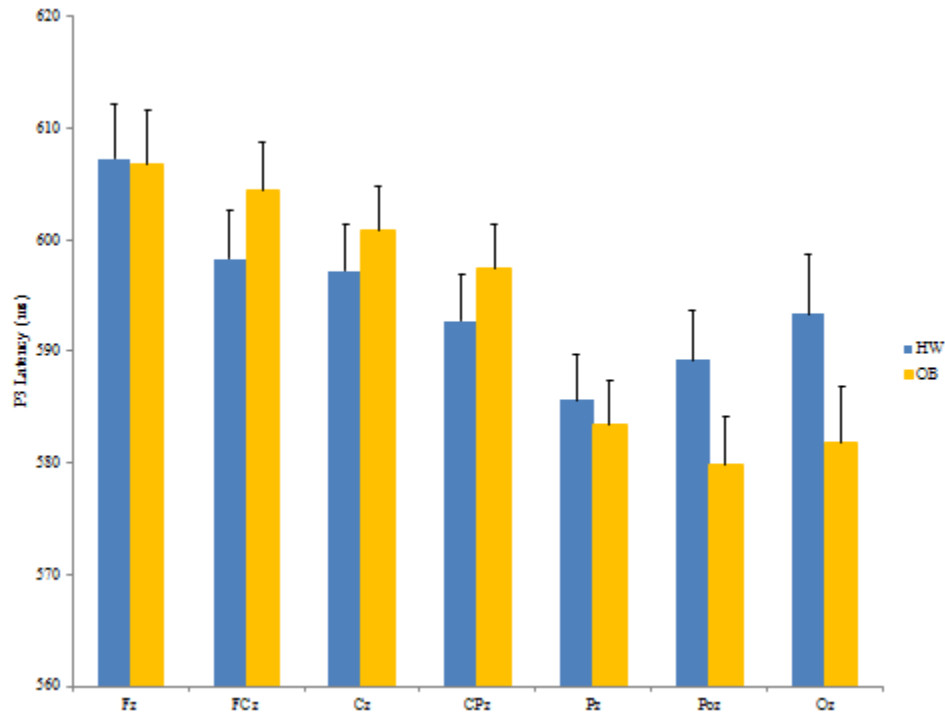


P3 Amplitude: The ANOVA revealed a main effect of Congruency,  $F(1, 151) = 28.81$ ,  $p \leq 0.001$ ,  $\eta^2 = 0.16$ , with increased amplitude for the incongruent trials ( $8.71 \pm 0.43 \mu V$ ) compared to congruent trials ( $7.39 \pm 0.41 \mu V$ ), Site,  $F(6, 151) = 71.39$ ,  $p \leq 0.001$ ,  $\eta^2 = 0.32$ , with the midline revealing a topographic maximum at CPz with smaller amplitudes observed moving towards the anterior and occipital scalp regions. No main effects or interactions involving BMI Group were observed for P3 amplitude,  $F$ 's (6,906)  $\leq 1.77$ ,  $p \geq 0.19$ ,  $\eta_p^2 \leq 0.01$ .

P3 Latency: The ANOVA revealed a main effect of Compatibility,  $F(1, 146) = 19.20$ ,  $p \leq 0.001$ ,  $\eta^2 = 0.12$ , with the compatible condition ( $588.95 \pm 2.77$  ms) having shorter latency than the incompatible condition ( $599.35 \pm 2.69$  ms), and Congruency,  $F(1, 146) = 10.70$ ,  $p = 0.001$ ,  $\eta^2 = 0.07$ , with congruent trials ( $591.34 \pm 2.63$  ms) having a shorter latency than incongruent trials ( $596.93 \pm 2.57$  ms). These effects were superseded by a BMI Group x Site interaction,  $F(6,$

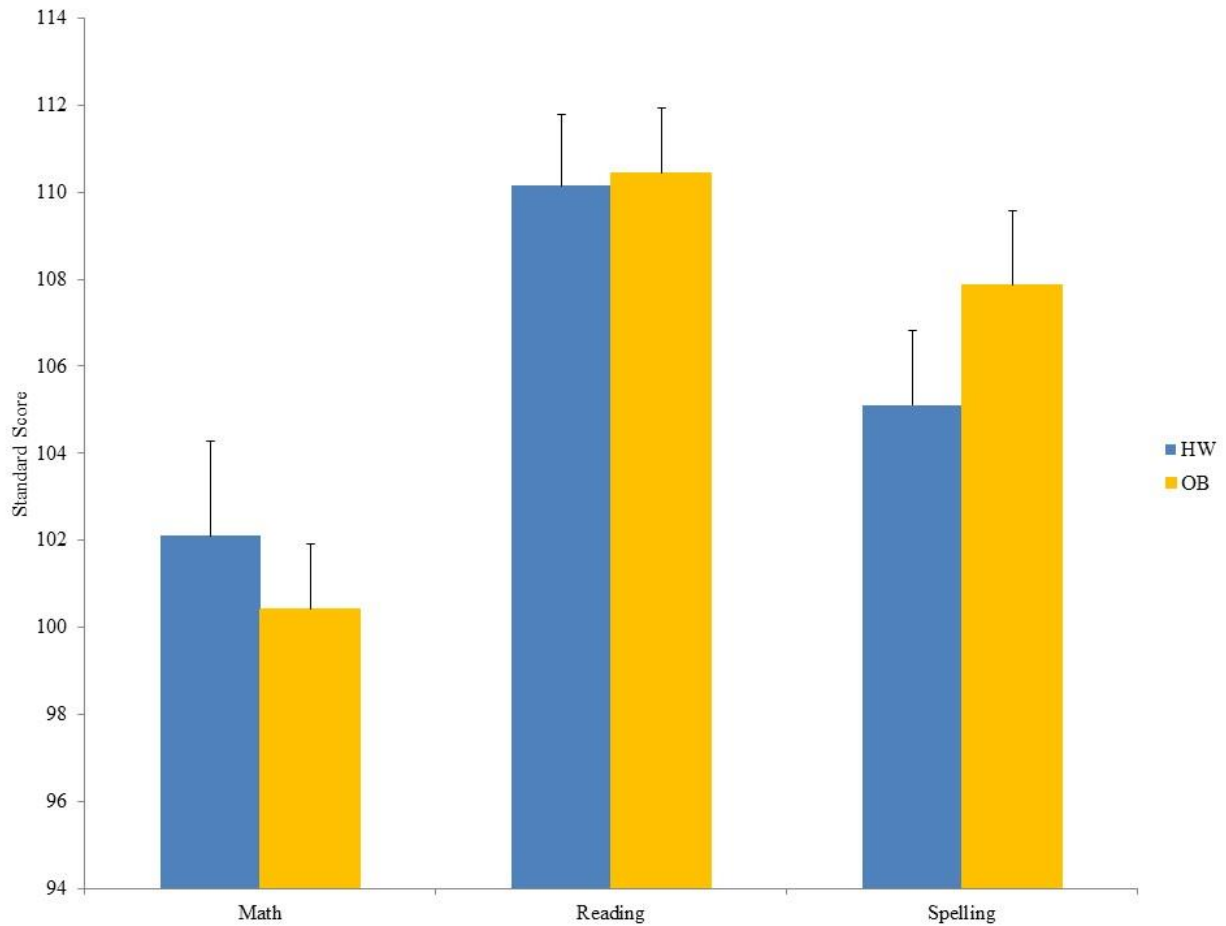
876) = 2.72,  $p = 0.041$ ,  $\eta^2 = 0.02$ . Decomposition of this interaction revealed no significant differences in P3 latency between BMI Groups at each site (see Figure 4.5).

Figure 4.5. P3 latency ( $\pm$  SE) collapsed across trial types by site for each BMI Group.



Academic Achievement: No significant differences were found between healthy weight and obese groups at baseline for the academic variables of math [ $t(152)=0.64$ ,  $p = 0.53$ ], reading [ $t(152)=0.13$ ,  $p = 0.90$ ], and spelling [ $t(152)=1.13$ ,  $p = 0.26$ ] (see Figure 4.6).

Figure 4.6. Baseline academic achievement ( $\pm$  SE) for each BMI Group.



## Correlations

Correlations were conducted across the entire sample. Based on correlations between demographic and body composition variables, age, sex, and IQ were most consistently correlated, and along with *a priori* expectations, were included in Step 1 of all regressions (see Table 4.2).

Table 4.2. Correlations between demographic and body composition variables.

	VAT	SAT	TAT
Age	0.29	0.28	0.29
Sex	0.12	-.28**	-.36**
IQ	0.04	0.08	0.08
SES	0.10	0.08	0.08
VO <sub>2</sub> FF	-0.10	-0.13	-0.14

Note: IQ = intelligent quotient; SES = socioeconomic status; VO<sub>2</sub> FF= maximal oxygen volume; \* $p \leq 0.05$ ; \*\* $p \leq 0.01$



Table 4.3. Correlations between demographics, body composition and flanker behavior.

	Compatible Congruent Accuracy	Compatible Incongruent Accuracy	Incompatible Congruent Accuracy	Incompatible Incongruent Accuracy	Compatible Congruent Reaction Time	Compatible Incongruent Reaction Time	Incompatible Congruent Reaction Time	Incompatible Incongruent Reaction Time
Sex	-.04	-.14	.02	-.007	-.14	-.15	-.19*	-.20*
Age	.29**	.29**	.33**	.35**	-.23**	-.21**	-.20*	-.18*
IQ	.11	.15	.15	.24**	-.16*	-.16	-.30**	-.23**
SES	.01	.04	.10	.07	-.04	-.03	-.13	-.13
VO <sub>2</sub> FF	.21**	.14	.17*	.19*	-.04	-.04	-.17*	-.18*
VAT	.03	.05	.09	.11	-.04	-.09	.04	.07
SAT	.05	.10	.08	.10	.002	-.04	.14	.15
TAT	.05	.09	.08	.11	-.01	-.05	.12	.14

Note: IQ = intelligent quotient; SES = socioeconomic status; VO<sub>2</sub> = maximal oxygen volume; VAT = visceral adipose tissue; SAT =

subcutaneous adipose tissue; TAT = total abdominal adipose tissue; \* $p \leq 0.05$ ; \*\* $p \leq 0.01$

Table 4.4. Correlations between demographics, body composition and flanker ERP variables.

a. Amplitude

	<b>FCz</b>				<b>Cz</b>				<b>CPz</b>			
	Compatible Congruent	Compatible Incongruent	Incompatible Congruent	Incompatible Incongruent	Compatible Congruent	Compatible Incongruent	Incompatible Congruent	Incompatible Incongruent	Compatible Congruent	Compatible Incongruent	Incompatible Congruent	Incompatible Incongruent
Sex	-0.14	-0.09	-0.14	-0.08	-0.15	-0.09	-0.10	-0.09	-0.12	-0.05	-0.06	-0.03
Age	-.17*	-0.06	-0.04	-0.08	-.18*	-0.07	-0.07	-0.08	-.18*	-0.11	-0.11	-0.11
IQ	-0.11	-0.03	-0.02	-0.08	-0.04	0.08	0.03	-0.04	-0.01	0.08	0.02	-0.04
SES	-.19*	-0.09	-0.14	-.19*	-.22**	-0.07	-0.13	-.18*	-.19*	-0.06	-0.15	-.20*
VO2 FF	-.18*	-0.15	-.24**	-.19*	-0.08	-0.06	-0.14	-0.11	-0.05	-0.04	-0.09	-0.08
VAT	-0.11	-0.09	-0.08	0.00	-0.13	-0.13	-0.07	-0.05	-0.07	-0.09	-0.05	0.00
SAT	0.03	0.02	0.04	0.08	0.01	-0.03	0.01	0.02	0.06	-0.01	0.02	0.04
TAT	0.01	0.00	0.02	0.07	-0.02	-0.05	-0.01	0.01	0.04	-0.02	0.01	0.03

Note: IQ = intelligent quotient; SES = socioeconomic status; VO<sub>2</sub> FF= maximal oxygen volume; VAT = visceral adipose tissue; SAT = subcutaneous adipose tissue; TAT = total abdominal adipose tissue; \* $p \leq 0.05$ ; \*\* $p \leq 0.01$

Table 4.4. (Cont.)

b. Latency

	<b>FCz</b>				<b>Cz</b>				<b>CPz</b>			
	Compatible Congruent	Compatible Incongruent	Incompatible Congruent	Incompatible Incongruent	Compatible Congruent	Compatible Incongruent	Incompatible Congruent	Incompatible Incongruent	Compatible Congruent	Compatible Incongruent	Incompatible Congruent	Incompatible Incongruent
Sex	0.10	0.03	-0.02	-0.01	0.09	0.05	0.03	-0.01	0.01	-0.03	0.01	0.02
Age	-0.14	-0.09	0.03	-0.09	-.18*	-.20*	-0.05	-0.14	-.18*	-.20*	-0.01	-.178*
IQ	0.00	0.00	-0.14	-0.07	0.13	0.12	-0.05	0.06	0.09	0.12	-0.01	0.06
SES	0.08	0.01	-0.04	0.01	0.06	0.06	-0.04	0.07	0.04	0.06	-0.04	0.03
VO <sub>2</sub> FF	-0.10	-0.11	-0.05	-0.05	-0.13	-0.14	-0.05	-0.12	-0.11	-0.10	-0.02	-0.11
VAT	-0.03	0.06	0.05	-0.02	0.05	-0.05	0.08	0.04	0.07	-0.04	0.05	0.06
SAT	-0.09	0.04	0.05	-0.04	-0.06	-0.09	0.04	0.02	-0.02	-0.06	-0.01	0.01
TAT	-0.08	0.05	0.05	-0.04	-0.04	-0.09	0.05	0.03	0.00	-0.06	0.01	0.02

Note: IQ = intelligent quotient; SES = socioeconomic status; VO<sub>2</sub> FF= maximal oxygen volume; VAT = visceral adipose tissue; SAT =

subcutaneous adipose tissue; TAT = total abdominal adipose tissue; \* $p \leq 0.05$ ; \*\* $p \leq 0.01$

## **Regressions**

There were no significant correlations between body composition variables (VAT, SAT, TAT) on cognitive outcomes at baseline. Thus, no further regression analyses were conducted at baseline.

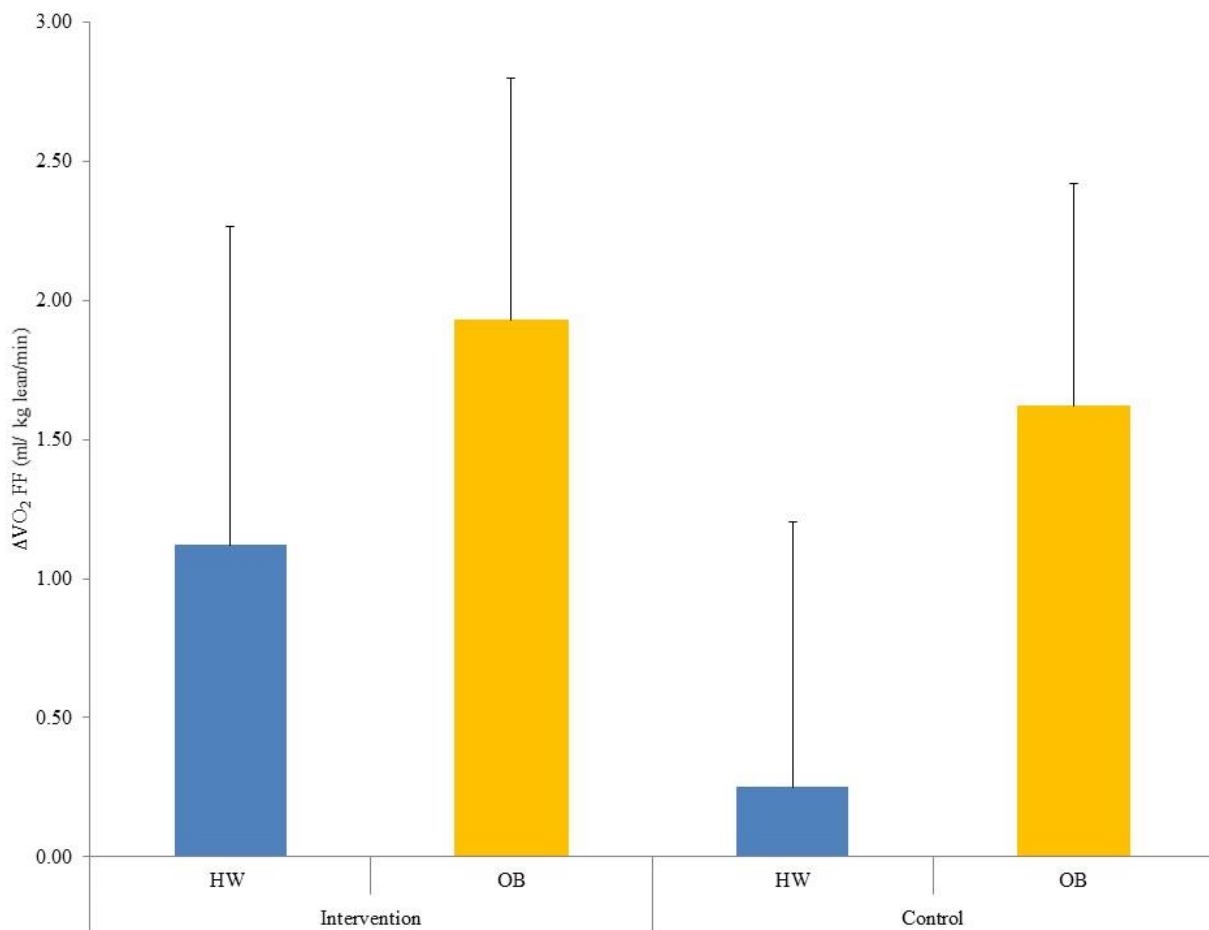
## Pre-Post<sup>1</sup>

### Change

#### Body Composition:

$\Delta\text{VO}_2$  FF: There were no significant differences in  $\Delta\text{VO}_2$  FF between intervention ( $1.52 \pm 0.72$  ml/ kg lean/ min) and control ( $0.94 \pm 0.62$  ml/ kg lean/ min) groups,  $t(151) = 0.60$ ,  $p = 0.055$ ; or between obese ( $1.79 \pm 0.59$  kg/m<sup>2</sup>) and healthy weight ( $0.74 \pm 0.76$  kg/m<sup>2</sup>),  $t(151) = 1.09$ ,  $p = 0.28$  (see Figure 4.7).

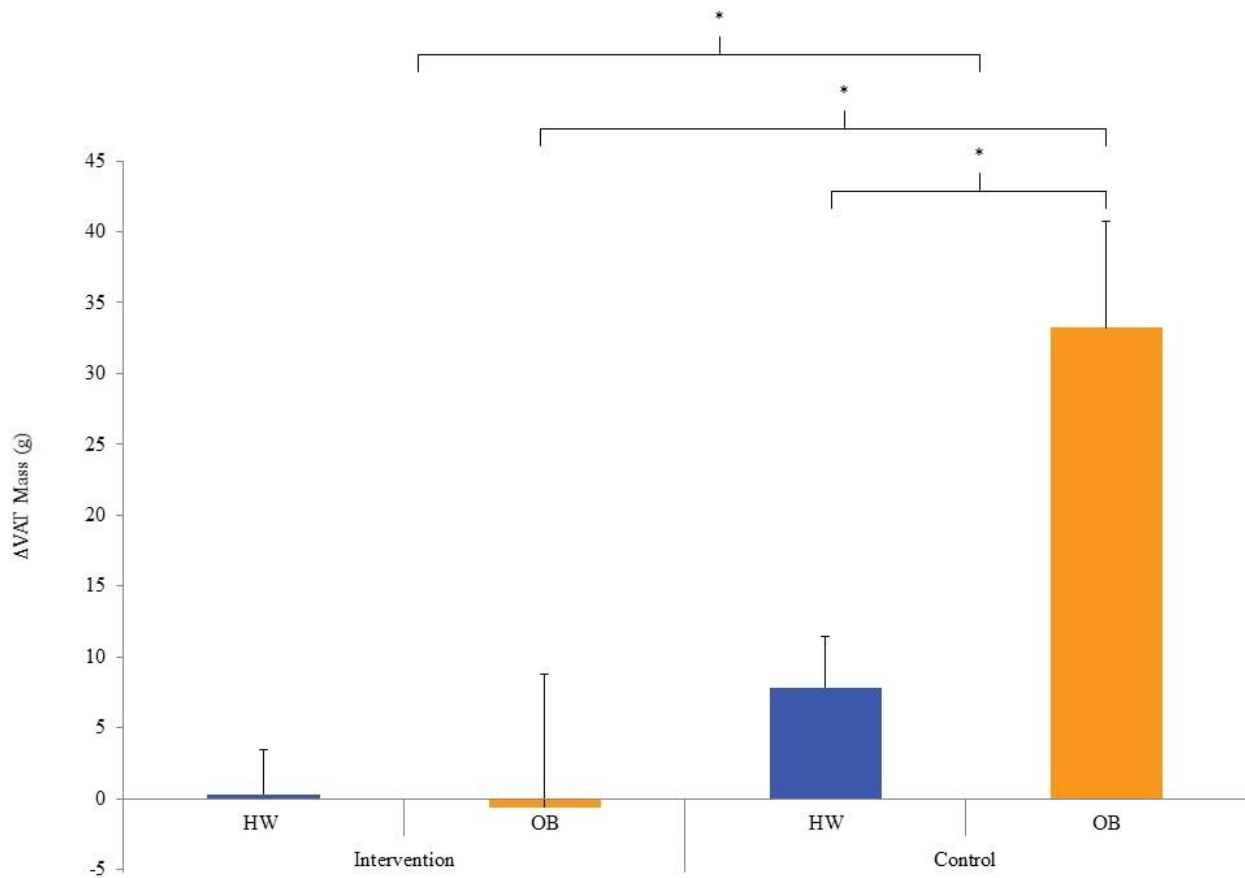
Figure 4.7.  $\Delta\text{VO}_2$  FF ( $\pm$  SE) by treatment and BMI Group.



<sup>1</sup> See Appendix for pre-post breakdown.

$\Delta$ VAT: The intervention group ( $-0.14 \pm 4.86$  g) had a smaller  $\Delta$ VAT than the control group ( $20.54 \pm 4.41$  g),  $t(151) = 3.08$ ,  $p = 0.002$ . Furthermore, the obese intervention group had smaller  $\Delta$ VAT ( $-0.62 \pm 9.36$  g) compared to the obese control group ( $33.24 \pm 7.49$  g),  $t(74) = 2.73$ ,  $p = 0.008$ . Additionally, healthy weight control ( $7.85 \pm 3.60$  g) had smaller  $\Delta$ VAT than the obese control ( $33.23 \pm 7.49$  g),  $t(66) = 3.05$ ,  $p = 0.004$ . There were no significant differences in  $\Delta$ VAT between healthy weight ( $3.63 \pm 2.38$  g) and obese ( $14.52 \pm 6.43$  g),  $t(151) = 1.60$ ,  $p = 0.12$  (see Figure 4.8).

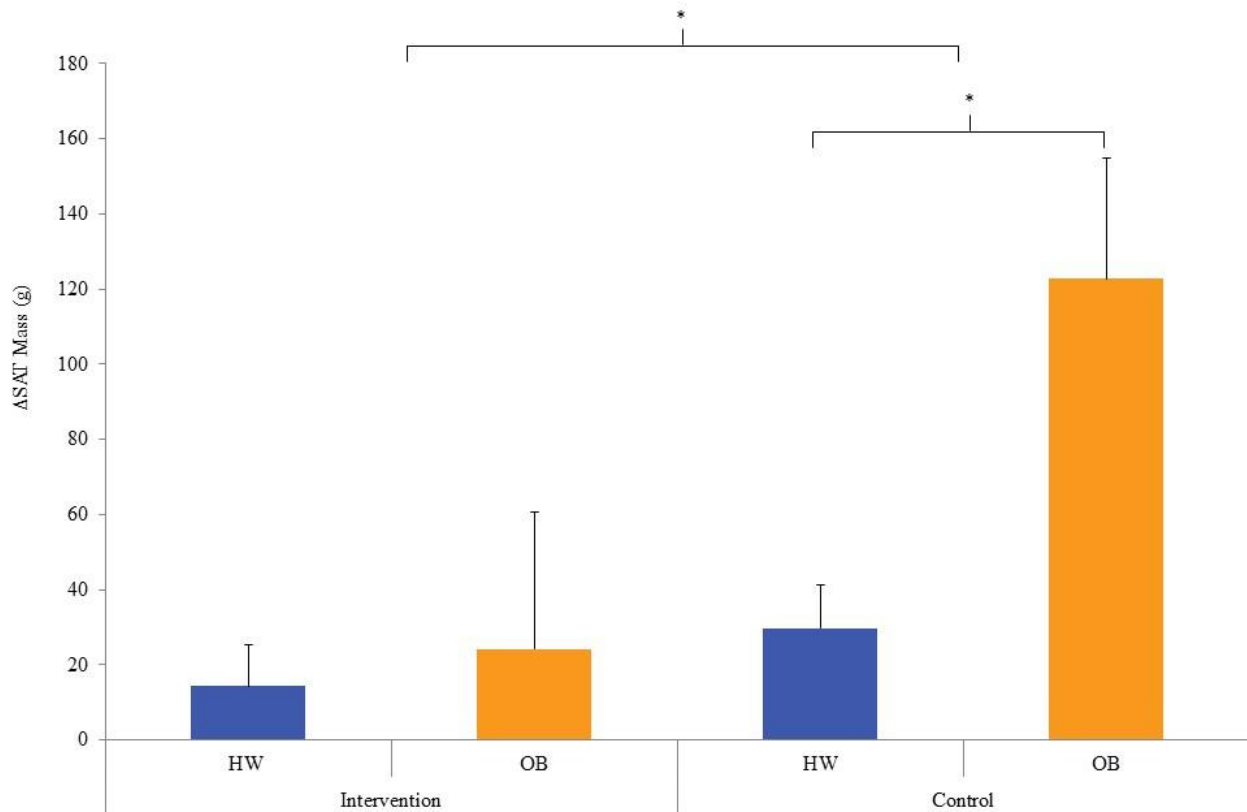
Figure 4.8.  $\Delta$ VAT ( $\pm$  SE) by treatment and BMI Group.



$\Delta$ SAT:  $\Delta$ SAT in the intervention ( $19.22 \pm 18.74$  g) was less than  $\Delta$ SAT in the control ( $76.19 \pm 17.88$  g),  $t(151) = 2.16$ ,  $p = 0.03$ . Additionally, healthy weight control ( $24.25 \pm 36.48$

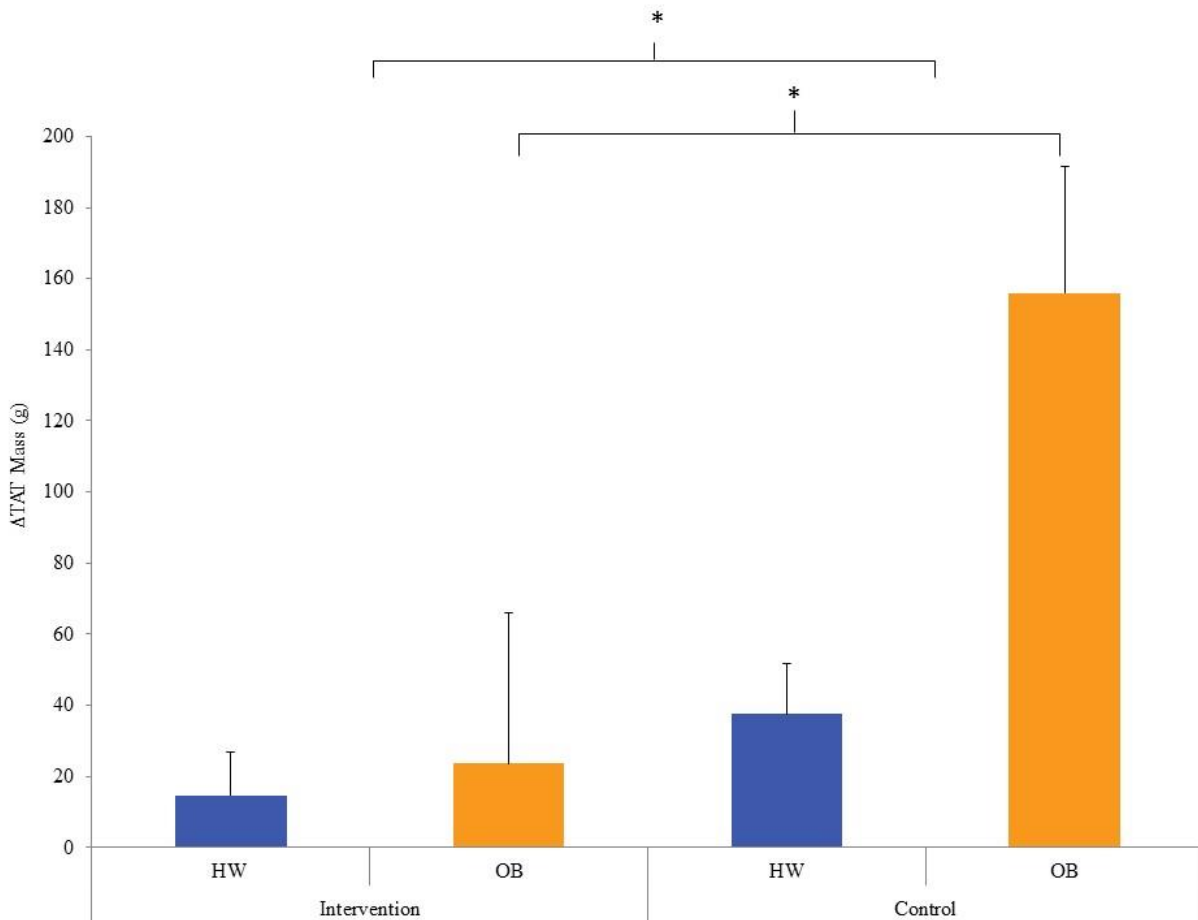
g) had smaller  $\Delta$ SAT than the obese control ( $122.61 \pm 32.24$  g),  $t(74) = 2.32$ ,  $p = 0.05$ . There was not a significant difference between  $\Delta$ SAT in healthy weight ( $21.13 \pm 7.86$  g) and obese ( $68.25 \pm 25.27$  g),  $t(151) = 1.79$ ,  $p = 0.08$  (see Figure 4.9).

Figure 4.9.  $\Delta$ SAT ( $\pm$  SE) by treatment and BMI Group.



$\Delta$ TAT: The intervention group ( $19.07 \pm 21.74$  g) had less  $\Delta$ TAT than the control group ( $96.74 \pm 20.39$  g),  $t(151) = 2.56$ ,  $p = 0.01$ . Furthermore, obese children in the intervention ( $23.63 \pm 42.4$  g) had smaller  $\Delta$ TAT than obese control children ( $155.85 \pm 42.41$  g),  $t(74)=2.32$ ,  $p = 0.02$ . There were no significant differences in  $\Delta$ TAT between healthy weight ( $24.77 \pm 9.28$  g) and obese ( $82.78 \pm 29.22$  g) children,  $t(151) = 1.89$ ,  $p = 0.06$  (see Figure 4.10).

Figure 4.10. TAT ( $\pm$  SE) by treatment and BMI Group.



**Repeated Measures:** Repeated measures analyses employed a 2 (Treatment: Intervention, Control) x 2 (BMI Group: Healthy Weight, Obese) x 2 (Compatibility: compatible, incompatible) x 2 (Congruency: congruent, incongruent) ANOVA.

Mean Reaction Time: The ANOVA revealed no significant main effects or interactions.

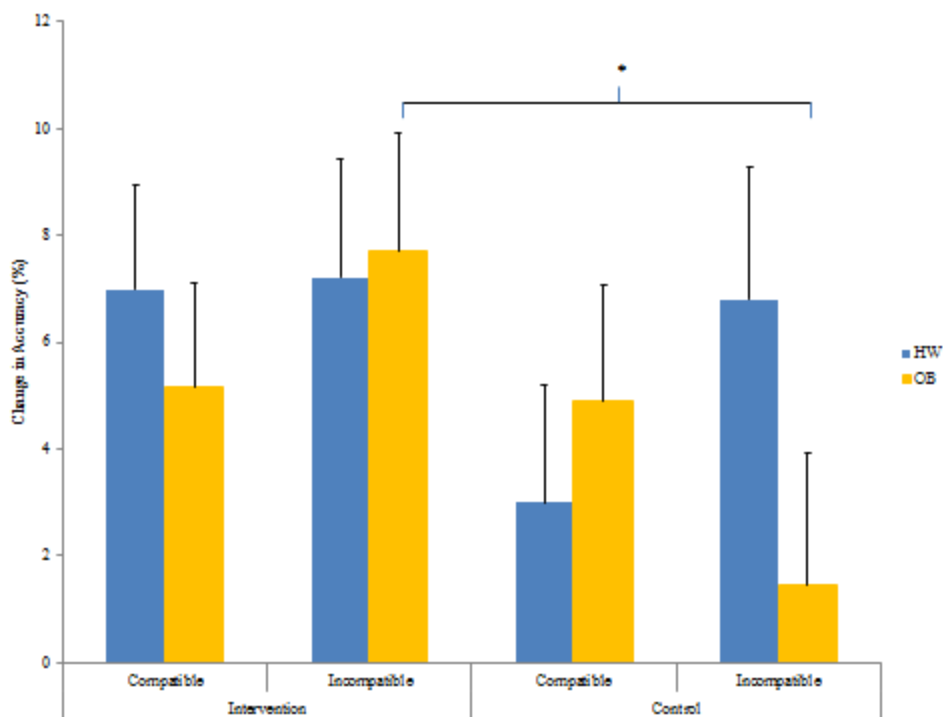
Response Accuracy: The ANOVA revealed an interaction of Treatment x Compatibility x Congruency,  $F(1, 150) = 4.30, p = 0.040, \eta^2 = 0.03$ . This interaction was decomposed by examining Treatment x Congruency within each compatibility. Within the compatible condition, there was a significant interaction of Congruency x Treatment,  $F(1, 152) = 5.37, p = 0.02, \eta^2 =$



0.03, such that the control group, change in congruent trials ( $2.92 + 1.44\%$ ) was less than change incongruent trials ( $4.97 \pm 1.46\%$ ),  $t(67) = 2.03$ ,  $p = 0.05$ .

The ANOVA also revealed an interaction of Treatment x BMI Group x Compatibility,  $F(1, 150) = 3.96$ ,  $p = 0.05$ ,  $\eta^2 = 0.03$ . Decomposition of the interaction assessing Treatment x BMI Group within each compatibility condition revealed no significant differences within the compatible condition,  $t_s(68) \leq 1.14$ ,  $p \geq 0.26$ . However, within the incompatible condition, the obese intervention group ( $7.69 \pm 2.25\%$ ) had greater changes than the obese control group ( $1.44 \pm 1.79\%$ ),  $t(75) = 2.09$ ,  $p = 0.04$  (see Figure 4.11).

Figure 4.11. Change in flanker accuracy ( $\pm$  SE) by treatment and BMI Group for compatible and incompatible conditions.



P3 Amplitude:

The ANOVA revealed an interaction of Treatment x BMI Group x Site,  $F(6, 894) = 3.03$ ,  $p = 0.03$ ,  $\eta^2 = 0.02$ . This interaction was decomposed by evaluating Treatment x

Congruency x Site within each BMI Group, and revealed no significant interactions,  $F$ 's (6, 444)  $\leq 2.37$ ,  $p_s \geq 0.06$ ,  $\eta_p^2 \leq 0.03$ .

P3 Latency: The ANOVA revealed a main effect of site,  $F(6, 858) = 5.13$ ,  $p = 0.001$ ,  $\eta^2 = 0.04$ , with the midline revealing a topographic maximum for change in P3 latency at Pz and smaller changes in latency observed moving towards the anterior and occipital scalp regions. There was an interaction of Treatment x BMI Group x Congruency x Site,  $F(6, 858) = 2.62$ ,  $p = 0.04$ ,  $\eta^2 = 0.02$ . This interaction was decomposed to assess Treatment x BMI Group x Congruency at each site. At Fz, there was a significant interaction of Treatment x BMI Group x Congruency,  $F(1, 143) = 4.72$ ,  $p = 0.03$ ,  $\eta^2 = 0.02$ . Breaking this interaction down to assess Treatment x Congruency within each BMI Group revealed no significant interactions,  $F$ 's (1, 69)  $\leq 2.22$ ,  $p_s \geq 0.14$ ,  $\eta_p^2 \leq 0.03$ . At FCz there was a significant interaction of Treatment x BMI Group x Congruency,  $F(1, 143) = 7.65$ ,  $p = 0.006$ ,  $\eta^2 = 0.05$ , however, breakdown of this interaction revealed no significant interactions,  $F$ 's (1, 143)  $\leq 2.04$ ,  $p_s \geq 0.16$ ,  $\eta_p^2 \leq 0.01$ .

### **Correlations**

Correlations were conducted across the entire sample. Based on baseline correlations between demographic and body composition variables, age, sex, and IQ were most consistently correlated and thus included in Step 1 of all regressions (see Table 4.2 above). Then, correlations were conducted to assess the relationship between changes in body composition as well as changes in task performance and ERPs.

Table 4.5. Correlations between Changes in Body Composition and Changes in Flanker Task Performance

a. Accuracy

	$\Delta$ Compatible Congruent	$\Delta$ Compatible Incongruent	$\Delta$ Compatible All	$\Delta$ Incompatible Congruent	$\Delta$ Incompatible Incongruent	$\Delta$ Incompatible All
$\Delta$ VO <sub>2</sub> FF	0.10	0.14	0.13	0.07	0.04	0.06
$\Delta$ VAT	-.198*	-0.10	-0.16	-.238**	-.198*	-.227**
$\Delta$ SAT	-.185*	-0.11	-0.16	-0.12	-0.07	-0.10
$\Delta$ TAT	-.204*	-0.12	-.170*	-.160*	-0.11	-0.14

b. Reaction Time

	$\Delta$ Compatible Congruent	$\Delta$ Compatible Incongruent	$\Delta$ Compatible All	$\Delta$ Incompatible Congruent	$\Delta$ Incompatible Incongruent	$\Delta$ Incompatible All
$\Delta$ VO <sub>2</sub> FF	.104	.077	.095	.094	.053	.075
$\Delta$ VAT	.058	.091	.077	.086	.123	.108
$\Delta$ SAT	-.015	-.012	-.013	.008	.039	.025
$\Delta$ TAT	.000	.010	.006	.026	.061	.046

Note VO<sub>2</sub> FF = maximal oxygen volume; VAT = visceral adipose tissue; SAT = subcutaneous adipose tissue; TAT = total abdominal adipose tissue; \* $p \leq 0.05$ ; \*\* $p \leq 0.01$

Table 4.6. Correlations between Changes in Body Composition and Changes in Flanker Task ERPs

a. P3 Amplitude

	FCz				Cz				CPz				Pz			
	$\Delta$ Compatible Congruent	$\Delta$ Compatible InCongruent	$\Delta$ Incompatible Congruent	$\Delta$ Incompatible Incongruent	$\Delta$ Compatible Congruent	$\Delta$ Compatible InCongruent	$\Delta$ Incompatible Congruent	$\Delta$ Incompatible Incongruent	$\Delta$ Compatible Congruent	$\Delta$ Compatible InCongruent	$\Delta$ Incompatible Congruent	$\Delta$ Incompatible Incongruent	$\Delta$ Compatible Congruent	$\Delta$ Compatible InCongruent	$\Delta$ Incompatible Congruent	$\Delta$ Incompatible Incongruent
$\Delta$ VO <sub>2</sub> FF	-0.03	-0.11	-0.04	-0.03	-0.06	-0.08	-0.07	-0.02	-0.07	-0.10	-0.07	-0.02	-0.01	-0.12	-0.12	-0.11
$\Delta$ VAT	-0.06	-0.09	-0.13	-0.04	-0.09	-0.12	-.18*	-0.07	-0.11	-0.13	-.21*	-0.10	-0.11	-0.15	-.24*	-0.14
$\Delta$ SAT	-0.11	-0.11	-0.16	-0.08	-0.06	-0.08	-0.14	-0.06	-0.07	-0.07	-.16*	-0.07	-0.08	-0.10	-.18*	-0.09
$\Delta$ TAT	-0.11	-0.12	-.16*	-0.08	-0.08	-0.09	-.16*	-0.07	-0.08	-0.09	-.18*	-0.08	-0.09	-0.12	-.20*	-0.11

Note: VO<sub>2</sub> FF= maximal oxygen volume; VAT = visceral adipose tissue; SAT = subcutaneous adipose tissue; TAT = total abdominal adipose tissue; \* $p \leq 0.05$ .

Table 4.6 (Cont.)

b. P3 Latency

	FCz				Cz				CPz				Pz			
	ΔCompatible Congruent	ΔCompatible InCongruent	ΔIncompatible Congruent	ΔIncompatible Incongruent	ΔCompatible Congruent	ΔCompatible InCongruent	ΔIncompatible Congruent	ΔIncompatible Incongruent	ΔCompatible Congruent	ΔCompatible InCongruent	ΔIncompatible Congruent	ΔIncompatible Incongruent	ΔCompatible Congruent	ΔCompatible InCongruent	ΔIncompatible Congruent	ΔIncompatible Incongruent
ΔVO <sub>2</sub> FF	0.05	0.05	0.05	0.08	-0.01	-0.05	0.06	-0.01	0.05	-0.03	0.12	-0.01	-0.03	-0.13	.20*	0.07
ΔVAT	0.01	-0.10	0.04	-0.01	0.04	0.00	0.11	0.07	0.11	0.06	.16*	0.14	.169*	.17*	.22**	0.12
ΔSAT	0.04	0.04	0.04	-0.07	-0.01	0.07	0.09	0.03	0.02	0.09	0.09	0.08	.17*	.18*	0.15	0.06
ΔTAT	0.04	0.01	0.04	-0.06	0.00	0.06	0.10	0.04	0.04	0.09	0.12	0.10	.18*	.19*	.18*	0.08

Note: VO<sub>2</sub> FF = maximal oxygen volume; VAT = visceral adipose tissue; SAT = subcutaneous adipose tissue; TAT = total abdominal adipose tissue; \* $p \leq 0.05$ ; \*\* $p \leq 0.01$

## Regressions

The above correlations were further examined using regression analysis to determine the unique impact of changes in body composition on cognitive outcomes. The dependent variables of interest were determined based on significant correlations, and included:  $\Delta$ compatible congruent accuracy,  $\Delta$ incompatible congruent accuracy,  $\Delta$ incompatible incongruent accuracy,  $\Delta$ incompatible accuracy,  $\Delta$ incompatible congruent Cz amplitude,  $\Delta$ incompatible congruent CPz amplitude,  $\Delta$ compatible incongruent Pz latency,  $\Delta$ incompatible congruent Pz latency,  $\Delta$ incompatible Pz amplitude,  $\Delta$ incompatible congruent CPz amplitude,  $\Delta$ incompatible congruent Pz amplitude, and  $\Delta$  incompatible congruent amplitude at FCz, Cz, and Pz. Based on previous correlations, age, sex, IQ, and  $\text{VO}_2$  FF correlated with both body composition and cognitive variables, thus they were entered into Step 1 of the regressions (prior research has also related these factors to measures of cognitive control; Kamijo et al., 2012; Pontifex et al., 2011, 2014). Furthermore, to account for baseline body composition and cognition, the baseline values of each of these measures (VAT, SAT, or TAT; task performance) were entered into Step 1. In addition, treatment group (intervention or control) as well as BMI Group (healthy weight or obese) were entered into Step 1. Changes in body composition variables ( $\Delta$ VAT,  $\Delta$ SAT, or  $\Delta$ TAT) were entered into Step 2 of the regressions. Each regression was first run using all children, and subsequent regressions were conducted within each treatment and BMI Group. The dependent variables that were significantly related to changes in body composition are presented below.

*$\Delta$ Compatible congruent accuracy:* The Step 1 regression analysis for  $\Delta$ compatible congruent accuracy was significant for all participants, adjusted  $R^2 = 0.40$ ,  $F(8, 144) = 13.71$ ,  $p \leq 0.001$ . Step 2 was also significant, adjusted  $R^2 = 0.42$ ,  $F(1, 143) = 13.14$ ,  $p \leq 0.001$ , such that

greater  $\Delta$ VAT was associated with smaller  $\Delta$ compatible congruent accuracy,  $\beta = -0.15$ ,  $t(143) = -2.30$ ,  $p = 0.02$ ,  $pr = -0.19$  (see Table 4.7).

Next, this regression was run separately for each treatment and BMI Group. All 4 groups demonstrated a significant Step 1 effect, adjusted  $R^2 \geq 0.23$ ,  $F(6, 27) \geq 2.65$ ,  $p \leq 0.04$ . For Step 2, only the obese intervention group showed a significant relationship, adjusted  $R^2 = 0.49$ ,  $F(1, 34) = 6.59$ ,  $p \leq 0.001$ , such that greater  $\Delta$ VAT was associated with smaller  $\Delta$ compatible congruent accuracy, with  $\Delta$ VAT accounting for an incremental amount of variance in  $\Delta$ compatible congruent accuracy beyond associated descriptive variables,  $\beta = -0.27$ ,  $t(35) = -2.26$ ,  $p = 0.03$ ,  $pr = -0.36$  (see Table 4.7).

Table 4.7. Regression Analyses for  $\Delta$ VAT predicting  $\Delta$ Compatible Congruent Accuracy

Measure:	<i>B</i>	<i>SE B</i>	$\beta$	<i>t</i>	<i>B</i>	<i>SE B</i>	$\beta$	<i>t</i>
	<i>All</i>				<i>Obese Intervention</i>			
Step 1								
Treatment	-1.64	1.73	-0.06	-0.95				
BMI Group	0.55	1.31	0.04	0.42				
Age	3.56	1.5	0.16	2.38*	5.03	3.71	0.17	1.36
Sex	0.7	1.8	0.03	0.39	-4.74	3.66	-0.16	-1.3
IQ	0.08	0.07	0.07	1.1	-0.11	0.15	-0.08	-0.7
VO <sub>2</sub> FF	-0.05	0.12	-0.3	-0.38	0.12	0.26	0.06	0.46
Pre-Test Behavior	-0.77	0.08	-0.67	-9.95*	-0.77	0.14	-0.66	-5.47**
Pre-Test VAT	-0.002	0.01	-0.3	-0.25	-0.02	0.02	-0.16	-1.28
Step 2								
$\Delta$ VAT	-0.05	0.02	-0.15	-2.30*	-0.07	0.03	-0.27	-2.26*

*$\Delta$ Incompatible accuracy:* The Step 1 regression analysis for  $\Delta$ incompatible accuracy was significant for the entire group, adjusted  $R^2 = 0.37$ ,  $F(8, 144) = 12.94$ ,  $p \leq 0.001$ . Step 2 was also

significant, adjusted  $R^2 = 0.41$ ,  $F(1, 143) = 12.70$ ,  $p = 0.01$ , such that greater  $\Delta$ VAT was associated with smaller  $\Delta$ incompatible accuracy,  $\beta = -0.17$ ,  $t(143) = -2.59$ ,  $p = 0.01$ ,  $pr = -0.21$  (see Table 4.8).

Next, this regression was run separately for each treatment and BMI Group. Three groups (all but obese controls) demonstrated a significant Step 1 effect, adjusted  $R^2$ 's  $\geq 0.45$ ,  $F$ 's (6, 35)  $\geq 6.63$ ,  $ps \leq 0.001$ . For Step 2, only the obese intervention group showed a significant relationship, adjusted  $R^2 = 0.66$ ,  $F(1, 34) = 12.11$ ,  $p \leq 0.001$ , such that greater  $\Delta$ VAT was associated with smaller  $\Delta$ incompatible accuracy, with  $\Delta$ VAT accounting for an incremental amount of variance in  $\Delta$ compatible accuracy beyond associated descriptive variables,  $\beta = -0.23$ ,  $t(34) = -2.36$ ,  $p = 0.02$ ,  $pr = -0.44$  (see Table 4.8).<sup>2</sup>

Table 4.8. Regression Analyses for  $\Delta$ VAT predicting  $\Delta$ Incompatible Accuracy

Measure:	<i>B</i>	<i>SE B</i>	$\beta$	<i>t</i>	<i>B</i>	<i>SE B</i>	$\beta$	<i>t</i>
	<i>All</i>				<i>Obese Intervention</i>			
Step 1								
Treatment	-3.24	1.88	-0.11	-1.72				
BMI Group	0.65	1.44	0.05	0.46				
Age	1.91	1.68	0.08	1.14	2.24	2.81	0.08	0.8
Sex	1.31	1.97	0.04	0.67	1.25	2.75	0.04	0.45
IQ	0.12	0.07	0.1	1.51	-0.19	0.12	-0.16	-1.57
VO <sub>2</sub> FF	0.14	0.13	0.07	1.05	0.21	0.19	0.11	1.12
Pre-Test Behavior	0.65	0.07	-0.68	-9.57*	-0.64	0.1	-0.69	-6.69*
Pre-Test VAT	-0.006	0.011	-0.05	-0.53	-0.04	0.01	-0.3	-2.93*
Step 2								
$\Delta$ VAT	-0.06	0.02	-0.17	-2.59	-0.05	0.02	-0.23	-2.36

<sup>2</sup> Similar findings were seen  $\Delta$ Incompatible Congruent Accuracy and  $\Delta$ Incompatible Incongruent Accuracy, see appendix for results.



*ΔIncompatible congruent CPz amplitude:* The Step 1 regression analysis for ΔIncompatible congruent amplitude at CPz was significant for the entire group, adjusted  $R^2 = 0.45$ ,  $F(8, 144) = 16.75$ ,  $p \leq 0.001$ . The Step 2 regression was also significant, adjusted  $R^2 = 0.47$ ,  $F(1, 143) = 15.82$ ,  $p \leq 0.001$ , such that greater ΔVAT was associated with smaller ΔIncompatible congruent amplitude at CPz,  $\beta = -0.14$ ,  $t(143) = -2.19$ ,  $p = 0.03$ ,  $pr = -0.18$  (see Table 4.9).

Next, this regression was run separately for each treatment and BMI Group. All 4 groups demonstrated a significant Step 1 effect, adjusted  $R^2$ 's  $\geq 0.26$ ,  $F$ 's  $(6, 36) \geq 3.46$ ,  $ps \leq 0.01$ . For Step 2, only the obese intervention group showed a significant relationship, adjusted  $R^2 = 0.41$ ,  $F(1, 34) = 4.98$ ,  $p = 0.001$ , such that greater ΔVAT was associated with smaller ΔIncompatible congruent amplitude at CPz, with ΔVAT accounting for an incremental amount of variance in ΔIncompatible congruent amplitude beyond associated descriptive variables,  $\beta = -0.30$ ,  $t(36) = -2.29$ ,  $p = 0.03$ ,  $pr = -0.36$  (see Table 4.9).<sup>3</sup>

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<sup>3</sup> Similar findings were seen in ΔCz Amplitude, see appendix for results.

Table 4.9. Regression Analyses for  $\Delta$ VAT predicting  $\Delta$ Incompatible Congruent CPz Amplitude

Measure:	<i>B</i>	<i>SE B</i>	$\beta$	<i>t</i>	<i>B</i>	<i>SE B</i>	$\beta$	<i>t</i>
	<i>All</i>				<i>Obese Intervention</i>			
Step 1								
Treatment	-0.84	0.98	-0.05	-0.85				
BMI Group	0.003	0.74	0	0.004				
Age	-1.22	0.82	-0.09	-1.5	0.36	2.1	0.02	0.17
Sex	-1.64	1.02	-0.1	-1.61	-2.69	2.11	-0.17	-1.27
IQ	-0.06	0.04	-0.1	-1.66	-0.11	0.09	-0.16	-1.22
VO <sub>2</sub> FF	-0.03	0.07	-0.03	-0.45	-0.03	0.14	-0.03	-0.21
Pre-Test ERP	-0.74	0.07	-0.7	-11.34	-0.82	0.18	-0.59	-4.58*
Pre-Test VAT	-0.002	0.07	-0.03	-0.34*	-0.001	0.01	-0.02	-0.12
Step 2								
$\Delta$ VAT	-0.03	0.01	-0.14	-2.19*	-0.04	0.02	-0.3	-2.29*

*$\Delta$ Compatible incongruent Pz latency:* The Step 1 regression analysis for  $\Delta$ compatible incongruent latency at Pz was significant for the entire group, adjusted  $R^2 \geq 0.22$ ,  $F(8, 141) = 6.26$ ,  $p \leq 0.001$ . The Step 2 was also significant, adjusted  $R^2 = 0.22$ ,  $F(1, 140) = 5.79$ ,  $p \leq 0.001$ , however  $\Delta$ SAT did not account for an incremental amount of variance in  $\Delta$ compatible incongruent Pz latency beyond associated descriptive variables,  $\beta = -0.10$ ,  $t(140) = 1.32$ ,  $p = 0.19$ ,  $pr = 0.11$ .

Next, this regression was run separately for each treatment and BMI Group. Three of the groups (not obese control) demonstrated a significant Step 1 effect, adjusted  $R^2$ 's  $\geq 0.34$ ,  $F$ 's (6, 24)  $\geq 3.58$ ,  $ps \leq 0.01$ . For Step 2, healthy weight control group showed a significant relationship, adjusted  $R^2 = 0.47$ ,  $F(1, 23) = 4.84$ ,  $p = 0.02$ , such that greater  $\Delta$ SAT was associated with smaller  $\Delta$ compatible incongruent latency, with  $\Delta$ SAT accounting for an incremental amount of

variance in  $\Delta$ compatible incongruent latency beyond associated descriptive variables,  $\beta = -0.38$   $t(23) = -2.65$ ,  $p = 0.01$ ,  $pr = -0.48$  (see Table 4.10).

The Step 2 regression was also significant for the obese intervention group, adjusted  $R^2 = 0.41$ ,  $F(1, 34) = 5.11$ ,  $p \leq 0.001$ , such that greater  $\Delta$ SAT was associated with greater  $\Delta$ compatible incongruent latency, with  $\Delta$ SAT accounting for an incremental amount of variance in  $\Delta$ compatible incongruent latency beyond associated descriptive variables,  $\beta = 0.27$ ,  $t(34) = 2.16$ ,  $p = 0.04$ ,  $pr = -0.35$  (see Table 4.10).<sup>4</sup>

Table 4.10. Regression Analyses for  $\Delta$ SAT predicting  $\Delta$ Incompatible Congruent Pz Latency

Measure:	<i>B</i>	<i>SE B</i>	$\beta$	<i>t</i>	<i>B</i>	<i>SE B</i>	$\beta$	<i>t</i>
	<i>Healthy Weight Control</i>				<i>Obese Intervention</i>			
Step 1								
Age	-1.63	14.57	-0.02	0.11	-16.72	14.86	-0.15	-1.12
Sex	28.19	35.62	0.22	0.79	-7.67	17.57	-0.07	-0.44
IQ	-0.78	0.87	-0.15	-0.9	0.66	0.61	0.14	1.08
VO <sub>2</sub> FF	0.93	1.53	0.1	0.61	-2.32	1.00	-0.29	-2.32*
Pre-Test ERP	-0.83	0.21	-0.64	-3.98*	-0.89	0.22	-0.57	-4.08*
Pre-Test SAT	0.06	0.06	0.29	0.97	0.01	0.02	0.14	0.93*
Step 2								
$\Delta$ SAT	-0.34	0.13	-0.38	-2.65 *	.06	.03	.27	2.16*

*$\Delta$ Compatible incongruent Pz latency:* The Step 1 regression analysis for  $\Delta$ compatible incongruent Pz latency was significant for the entire group, adjusted  $R^2 = 0.22$ ,  $F(8, 144) = 6.29$ ,  $p \leq 0.001$ . Step 2 was also significant, adjusted  $R^2 = 0.23$ ,  $F(1, 140) = 5.85$ ,  $p \leq 0.001$ , however

<sup>4</sup> Similar findings were seen  $\Delta$ TAT for the healthy weight control group, see appendix for results.

$\Delta$ TAT did not account for an incremental amount of variance in  $\Delta$ compatible incongruent Pz latency beyond associated descriptive variables,  $\beta = -0.11$ ,  $t(144) = 1.42$ ,  $p = 0.16$ ,  $pr = -0.12$ .

Next, this regression was run separately for each treatment and BMI Group. Three of the groups (not obese control) demonstrated a significant Step 1 effect, adjusted  $R^2$ 's  $\geq 0.19$ ,  $F$ 's (6, 36)  $\geq 2.68$ ,  $ps \leq 0.03$ . For Step 2, the healthy weight control group showed a significant relationship, adjusted  $R^2 = 0.47$ ,  $F(1, 23) = 4.77$ ,  $p = 0.002$ , such that greater  $\Delta$ TAT was associated with smaller  $\Delta$ compatible incongruent latency, with  $\Delta$ TAT accounting for an incremental amount of variance in  $\Delta$ compatible incongruent latency beyond associated descriptive variables,  $\beta = -0.36$ ,  $t(23) = -2.55$ ,  $p = 0.02$ ,  $pr = -0.21$  (see Table 4.11).

Additionally, the obese intervention group show a significant relationship, adjusted  $R^2 = 0.42$ ,  $F(1, 34) = 4.67$ ,  $p \leq 0.001$ , such that such that greater  $\Delta$ TAT was associated with greater  $\Delta$ compatible incongruent latency, with  $\Delta$ VAT accounting for an incremental amount of variance in  $\Delta$ compatible incongruent latency beyond associated descriptive variables,  $\beta = 0.28$ ,  $t(34) = 2.26$ ,  $p = 0.03$ ,  $pr = -0.36$  (see Table 4.11).

Table 4.11. Regression Analyses for  $\Delta$ TAT predicting  $\Delta$ Compatible Incongruent Pz Latency

Measure:	<i>B</i>	<i>SE B</i>	$\beta$	<i>t</i>	<i>B</i>	<i>SE B</i>	$\beta$	<i>t</i>
	<i>Healthy Weight Control</i>				<i>Obese Intervention</i>			
Step 1								
Age	-2.49	14.63	-0.03	-0.17	-16.46	14.86	-0.15	-1.11
Sex	22.09	28.91	0.17	0.76	-9.54	16.82	-0.08	-0.57
IQ	-0.84	0.87	-0.16	-0.96	0.65	0.61	0.14	1.01
VO <sub>2</sub> FF	0.96	1.52	0.11	0.63	-2.34	1	-0.3	-2.33*
Pre-Test ERP	-0.83	0.21	-0.63	-3.96*	-0.89	0.22	-0.57	-4.10*
Pre-Test TAT	0.06	0.05	0.26	1.06	0.11	0.01	0.13	0.89
Step 2								
$\Delta$ TAT	-0.26	0.1	-0.36	-2.55*	0.06	0.03	0.28	2.26*

## **Chapter 5**

### **Discussion**

In this investigation, behavioral and neuroelectric differences between healthy weight and obese children during performance of an inhibitory control task was assessed. Novel to this investigation is the focus on body composition and fat distribution rather than use of BMI as a surrogate measure. Although BMI has a dominant role in obesity research, it neglects the important influence of body composition as well as fat deposition, thus this study was designed to delve deeper into this issue by examining the influence of different types of tissues on brain and cognition. As such, this is the first study to date to examine associations between measures of body composition (VAT, SAT, TAT) and cognitive control, specifically neuroelectric measures.

Furthermore, this study examined the extent to which a 9-month physical activity intervention might be effective in improving behavioral and neuroelectric indices in obese children. The influence of changes in body composition after a 9-month physical activity intervention on changes in cognition was also assessed. Contrary to the initial hypotheses, there were no differences between healthy weight and obese children on the flanker task at baseline. Specifically, obese and healthy weight children exhibited similar response accuracy and reaction times during the modified flanker task. Neuroelectric findings revealed no differences in P3 amplitude or latency between obese and healthy weight children at baseline. Furthermore, there were no significant relationships between body composition and cognition.

The FITKids intervention is a 9-month program designed to provide children with the 60 minutes of recommended moderate to vigorous physical activity per day. This 9-month physical activity intervention prevented excess, unfavorable changes in body composition, particularly

central adiposity, in healthy weight and obese children. Obese intervention children gained less VAT than obese children assigned to the wait-list control condition. Of public health concern, obese children in the control group gained more central adiposity, in terms of VAT, SAT, and TAT, over just 9 months, than their healthy weight control counterparts. In addition, the 9-month physical activity intervention significantly improved behavioral indices of executive control. Importantly, these effects were selective to aspects of cognition that required extensive amounts of inhibition, particularly in obese children. Further, these benefits appear related to changes in VAT, a particularly metabolically dangerous fat type; with smaller changes in VAT being associated with larger changes in neural indices of attention (i.e., P3 amplitude).

### ***Baseline Differences***

As expected, obese children had greater amounts of VAT, SAT, and TAT compared to their healthy weight counterparts. These findings are potentially dangerous as different fat compartments carry different health risks. SAT is the fat present directly underneath skin; it is a physical buffer for the body as well as where excess energy in the form of triglycerides is stored (Freedland, 2004). When the storage capacity of SAT is exceeded, or the body is not able to make more fat cells, fat begins to accumulate in other locations such as the viscera. VAT is fat that is stored within the abdominal cavity, around vital organs including the liver, pancreas, and intestines; and increased VAT is related to a high risk of metabolic disease.

Previous studies have shown a maladaptive relationship between obesity and aspects of cognitive health in children, such that increased obesity is generally associated with decreased cognitive health, and these results range from brain structure to behavior (N. A. Khan, Raine, Donovan, & Hillman, 2014). Obesity in children is associated with impairments in scholastic performance as well as cognitive processes involving inhibition, working memory, cognitive

flexibility, attention, and memory (Castelli et al., 2007; Kamijo et al., 2014; Kamijo, Khan, et al., 2012; Li et al., 2008; E. Smith et al., 2011). Specifically, childhood obesity is related to longer reaction times on the most difficult condition of flanker tasks, decreased P3 amplitude (reflecting decreased attentional resource allocation) during an oddball task (Kamijo, Pontifex, et al., 2012; Tascilar et al., 2011), and less efficient neuroelectric patterns associated with response inhibition and conflict monitoring (Kamijo et al., 2014; Kamijo, Pontifex et al., 2012).

However, contrary to the *a priori* hypotheses, in the present study, obese and healthy weight children performed equally well on a task of inhibitory control in terms of accuracy, reaction time, P3 amplitude, and P3 latency. The flanker task has only been used in one other study assessing differences between healthy weight and obese individuals, with obese children having longer reaction times relative to their healthy weight peers (Kamijo, Pontifex et al., 2012). The contradictory findings may be due in part to different analytic approaches utilized in each study, and that the children in the present study were also more fit ( $55.49 \pm 7.3$  ml/ kg lean/min) than the children in the study by Kamijo et al. ( $50.2 \pm 6.5$  ml/kg lean/min). This latter finding may have diminished group difference given that fitness has a robust and consistent relationship with the outcomes assessed in this study. There were also no differences in academic performance at baseline between healthy weight and obese children. Our null findings do not stand alone, as other studies have also failed to find an association between weight status and markers of cognition including cognitive control, verbal memory, and attention (Gunstad et al., 2008). Others have also not found an association between obesity and academic test performance (LeBlanc et al., 2014).

There are a number of potential reasons for these discrepancies. The majority of studies that have observed differences between obese and healthy weight children have utilized a Go-



NoGo task (Kamijo et al., 2014; Tascilar et al., 2011). Although both flanker and Go-NoGo tasks require inhibitory control, they are distinct tasks that tap different aspects of inhibition, and may require different levels of control. Furthermore, few studies have controlled for many critical variables as well as the current investigation did. Many of the previous findings may be inflated as they did not ensure that healthy weight and obese children were matched on important demographic variables, such as IQ, SES, and aerobic fitness (Reyes et al., 2015; Schwartz et al., 2013; Tascilar et al., 2011), which also have unique relationships with cognitive function. Thus, the addition of these control variables is an improvement from many of the past studies, adding to the understanding of the relationship between obesity and cognition during childhood. Thus, contrary to previous work suggesting a negative relationship between obesity and cognition, the present study found no differences between closely matched obese and healthy weight children on an inhibitory control task and tests of academic achievement. Therefore, effects of the intervention are not due to baseline differences between obese and healthy weight children, and thus do not reflect ‘catch up’ changes or regression toward the mean.

### ***Intervention Effects***

Although the intervention did not reveal significant changes in measures of aerobic fat free fitness, the FITKids trial has previously been shown to impact both relative and percent aerobic fitness (Hillman et al., 2014; Kamijo et al., 2011). However, the present intervention had a beneficial impact on body composition for all children, and especially for obese children. This speaks to the efficacy of the FITKids physical activity intervention, as very few interventions have been able to show improvements in body composition (Kamath et al., 2008; Metcalf, Henley, & Wilkin, 2012; Summerbell, Waters, Edmunds, Kelly, & Brown, 2005). Not only did healthy weight and obese children benefit equally from the physical activity intervention in terms

of body composition, but obese children in the control group gained nearly four times the amount of abdominal fat over 9 months compared to their healthy weight control peers, suggesting that the intervention is effective in preventing unhealthy weight gain, particularly in obese children. This is concerning because these differences in fat gained over 9 months between healthy weight and obese children suggest that obese children are already on an unhealthy trajectory; with excess central adiposity linked to a substantially higher risk of insulin resistance and metabolic syndrome (Després, 2006; Després et al., 2008), and VAT implicated in insulin resistance and cardiovascular disease (Eisenmann et al., 2005).

Although the physical activity intervention did not impact academic achievement, obese children failed to show improvements in spelling over 9 months. This is again concerning as it suggests that obese children may already be showing delays in development, and do not follow the typical developmental patterns as their healthy weight peers. These findings are in concert with a large-scale, long-term finding that children who became obese between kindergarten and third grade had reductions in test scores compared to those who remained healthy weight (Datar & Sturm, 2006). Together, these findings, along with the baseline findings, suggest that the timing and duration of being obese may be an important factor to consider.

Furthermore, obese children in the intervention also showed greater improvements in the incompatible flanker task (the task condition requiring an upregulation of control) compared to obese children in the control group, and smaller gains in VAT were related to larger improvements in incompatible flanker task performance. This is in concert with previous findings that have shown physical activity to exhibit a greater influence on cognitively demanding tasks with larger inhibitory control requirements (Colcombe et al., 2006; Colcombe & Kramer, 2003; Hillman et al., 2006, 2008; Lichtman & Poser, 1983; Sibley & Etnier, 2003).

This further suggests that changes in VAT may influence complex cognitive functions, implying that physical activity intervention may be particularly beneficial to obese children.

The use of event related potentials (ERPs) in this investigation allowed for a greater understanding of the relationship between physical activity, obesity, and cognition in terms of the specific component processes underlying goal directed behavior, specifically the P3 potential. That is, smaller gains in VAT were related to greater increases in P3 amplitude and this was particularly true for obese children in the intervention. Such findings suggest that with decreases in VAT, obese intervention children exhibited the largest benefit from physical activity involvement, with an increased capacity to allocate attentional resources. Furthermore, decreases in SAT and TAT were related to faster P3 latencies in obese intervention children, whereas increases in SAT and TAT were related to slower P3 latency in the healthy weight control group. Such findings suggest that with increases in SAT and TAT, healthy weight control children had delayed stimulus classification and processing speed. This differential relationship between healthy weight control and obese intervention children is not surprising as nearly 80% of body fat is stored as SAT (Berthomieu & Menasche, 1983; Wajchenberg, 2000). It is important to highlight that these changes in body composition, even when controlling for the non-significant changes in fitness, led to changes in brain health and cognition, suggesting an independent effect of body composition. Thus, different types of abdominal adipose tissue may differentially affect brain function.

These results extend previous findings demonstrating that chronic physical activity is associated with structural changes within the brain. Specifically, increased tissue volume in the prefrontal and temporal cortices (Colcombe et al., 2004, 2006) as well as the basal ganglia and hippocampus (Chaddock, Erickson, Prakash, Kim et al., 2010; Chaddock, Erickson, Prakash,

VanPatter et al., 2010). Further, physical activity is associated with functional enhancements in neural processes related to the allocation of attentional resources (Hillman, Buck, Themanson, Pontifex, & Castelli, 2009; Pontifex, Hillman, & Polich, 2009; Pontifex et al., 2011) and increased brain activation in neural networks involved in executive control (Chaddock-Heyman et al., 2013). Relative to physical activity interventions, the present results extend previous findings demonstrating a beneficial effect for neuroimaging and behavioral indices of flanker performance following intervention (Chaddock-Heyman et al., 2013; Hillman et al., 2014) such that children enrolled in a physical activity intervention exhibit decreased fMRI activation and improved performance during the incongruent flanker condition compared to control children, which is indicative of a more ‘adult like’ pattern of brain function (Chaddock-Heyman et al., 2013). Among sedentary, obese children, previous research suggests a beneficial effect of physical activity on executive function and math achievement (Davis et al., 2007, 2011) as well as white matter integrity (Krafft, Schaeffer, et al., 2014; Krafft, Schwarz, et al., 2014). Therefore, the present study, along with others, highlights the importance of physical activity interventions for optimizing brain health.

### ***Potential Mechanisms***

Although the exact mechanisms linking physical activity intervention to changes in body composition and changes in cognition are unknown at this time, particularly in obese children, several potential mechanisms have been proposed in the literature.

One potential mechanism is inflammation, such that with increased systemic inflammation, there is a decrease in brain volume (Jefferson et al., 2007), memory function (Marsland et al., 2006), and cognitive processes involving speed and executive function (Trollor et al., 2012). Decreases in brain volume are further related to decreases in cognitive and memory

function. That is, increased inflammation is linked to decreased hippocampal grey matter, which in turn has been related to decreased performance on tasks of memory and attention (Marsland, Gianaros, Abramowitch, Manuck, & Hariri, 2008). Furthermore, increased central inflammation is related to a disruption in neural circuits, specifically decreased neuronal proliferation and differentiation, which are also critical for cognition and memory (A. A. Miller & Spencer, 2014). Thus, low grade inflammation associated with obesity may be related to cognitive decline.

Another mechanism linking obesity and cognition may be through brain structure itself, such that increased BMI is associated with overall lower brain volume (Brooks et al., 2013; Enzinger et al., 2005; Fotuhi, Do, & Jack, 2012; Liang et al., 2014; Raji et al., 2010), lower gray matter density (Horstmann et al., 2011; Jagust, Harvey, Mungas, & Haan, 2005; Maayan et al., 2011; Pannacciulli et al., 2006; Raji et al., 2010; Taki et al., 2008), and increased rates of hippocampal brain atrophy (Debette et al., 2011). Obesity in adolescence is further related to reduced hippocampal volumes and compromised white matter microstructural integrity (Yau, Castro, Tagani, Tsui, & Convit, 2012).

Although the exact mechanisms linking physical activity interventions to changes in body composition and changes in cognition are unknown, particularly in obese children, there are a few potential mechanisms. Evidence suggests that brain derived neurotrophic factor (BDNF), insulin like growth factor (IGF1), and vascular endothelial growth factor (VEGF) are implicated in physical activity induced increases in angiogenesis, neurogenesis, cellular proliferation, and neural plasticity (Brezun & Daszuta, 2000; Russo-Neustadt, Ha, Ramirez, & Kesslak, 2001; van Praag, Kempermann, & Gage, 1999; Vaynman & Gomez-Pinilla, 2005), and these factors may enable the observed physical activity induced changes in cognition (Cotman, Berchtold, & Christie, 2007; Gomez-Pinilla & Hillman, 2013). In contrast, obesity impairs the production of

new neurons and cell survival in the brain (Nguyen, Killcross, & Jenkins, 2014). BDNF is also lower in obese individuals (Rios et al., 2007). However, plasma BDNF increases in obese children who lose weight and participate in physical activity (Corripio et al., 2012). Given the vast array of potential mechanisms, future research should include metabolic and inflammatory markers, as well as additional measures of brain structure to better understand the mechanisms linking physical activity, obesity, and brain health.

### ***Limitations***

Although obese children in the FITKids intervention exhibited greater improvements in executive control relative to their obese control counterparts, this study is not without limitations. Despite the control group serving as a comparison of “typical”/un-intervened children, the activities and lifestyles of these children over 9 months is unknown. Thus, it is difficult to attribute the observed group differences entirely to physical activity participation. As previously indicated, the mechanisms linking physical activity intervention in obese children to improved cognitive outcomes is not well understood. The present study does not provide metabolic markers of health for either obese or healthy weight children, thus despite our best efforts to match groups on critical demographic characteristics, they may have differed in certain unassessed metabolic measures (i.e., glucose, insulin, etc). Additionally, an understanding of the causal direction of the association between adiposity and cognition remains unknown.

### ***Conclusions***

For the first time in history, today’s children are expected to live less healthy and shorter lives their parents (Fontaine et al., 2003; Layden et al., 2005). Although the exact reasons for this trend remains an open question, physical inactivity and obesity have been implicated. Around the world, children have become increasingly unfit and inactive. Worldwide, there are an estimated 1

billion overweight and 300 million obese individuals (James, Leach, Kalamara, & Shayeghi, 2001), with 32% of today's youth being overweight and 17% being obese. These rates of obesity in children are triple to that of recent history, with the greatest increases in the highest BMI percentiles (Ogden, Carroll, Curtin, Lamb, & Flegal, 2013). In the United States, over 50% of 6-11 year olds do not meet the recommended 60 minutes/day of moderate to vigorous physical activity (Troiano et al., 2008). This is concerning because childhood is a period of significant neural and cognitive development (Casey, 2005; Caviness, Kennedy, Richelme, & Rademacher, 1996). Furthermore, obesity in childhood predicts future poor health outcomes, including risk for mortality (Must, Jacques, Dallal, Bajema, & Dietz, 1992). Thus, it is not surprising that the rising rates of obesity in childhood are expected to cause a significant decrease in life expectancy (Layden et al., 2005). Complicating the situation, obese children engage in less moderate to vigorous physical activity than their healthy weight peers (Andersen et al., 1998; Trost et al., 2001). Clearly, obesity is a major public health concern that has myriad of health consequences (de Onis, Blössner, & Borghi, 2010; Ogden et al., 2012). However, physical activity interventions can positively impact both body composition and brain health in obese children.

The results from this study suggest a beneficial effect of the FITKids program, particularly in obese children, both in terms of improving body composition as well as improving cognition, especially demanding cognitive tasks. The current findings suggest that the FITKids intervention is an effective method for preventing excess weight gain in children and contributes to a greater understanding of the relationship between physical activity interventions and neurocognitive function. Thus, these findings add to a growing body of research indicating the beneficial impact of physical activity on selective aspects of cognitive control requiring extensive amounts of inhibition.

Accordingly, these findings indicate that physical activity interventions may serve to prevent excess central fat gain as well as a means to improve cognitive health of obese children in particular. As there is a rapid decline of physical activity opportunities at schools, these findings have broad relevance for public health and the educational environment, and the dissemination of these findings is critically important for schools. The results provide causal evidence for the beneficial effects of physical activity on body composition as well as cognitive health in obese children.



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## Appendix

### Additional Results

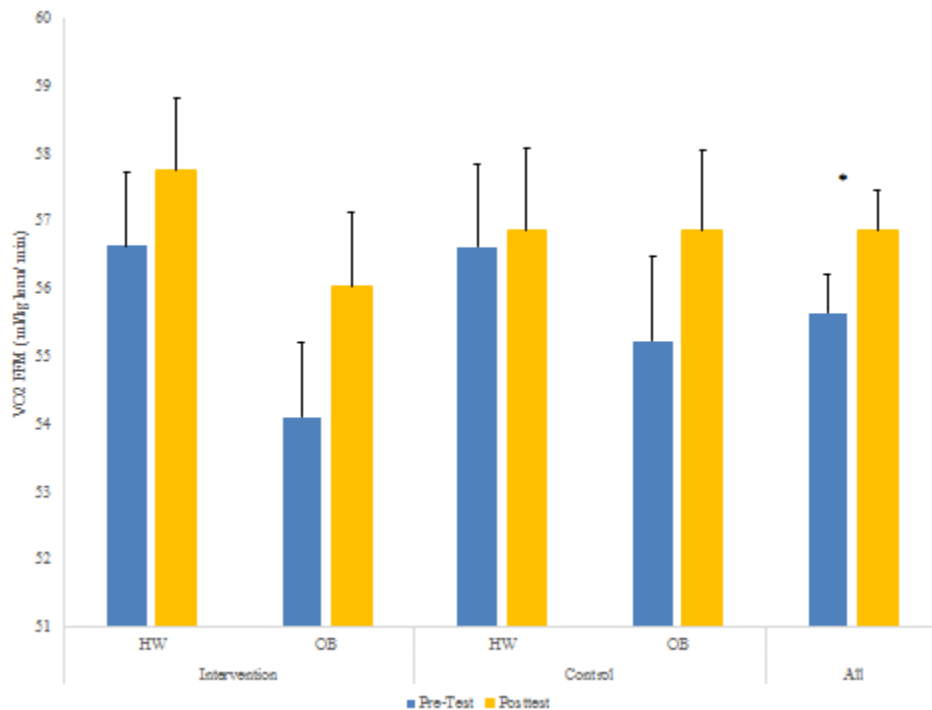
#### <sup>1</sup>Pre-Post

##### Repeated Measures

Body Composition: For body composition, repeated measures analyses employed a 2 (Treatment: Intervention, Control) x 2 (BMI Group: Healthy Weight, Obese) x 2 (Time: pre, post) repeated measures ANOVA.

VO<sub>2</sub> FF: The ANOVA revealed a main effect of Time,  $F(1, 149) = 6.30, p = 0.01, \eta^2 = 0.04$ , with a significant increase from pre-test ( $55.65 \pm 0.58$  ml/kg lean/min) to posttest ( $56.88 \pm 0.57$  ml/kg lean/min). There were no effects of Treatment group or BMI group (see Figure A.1).

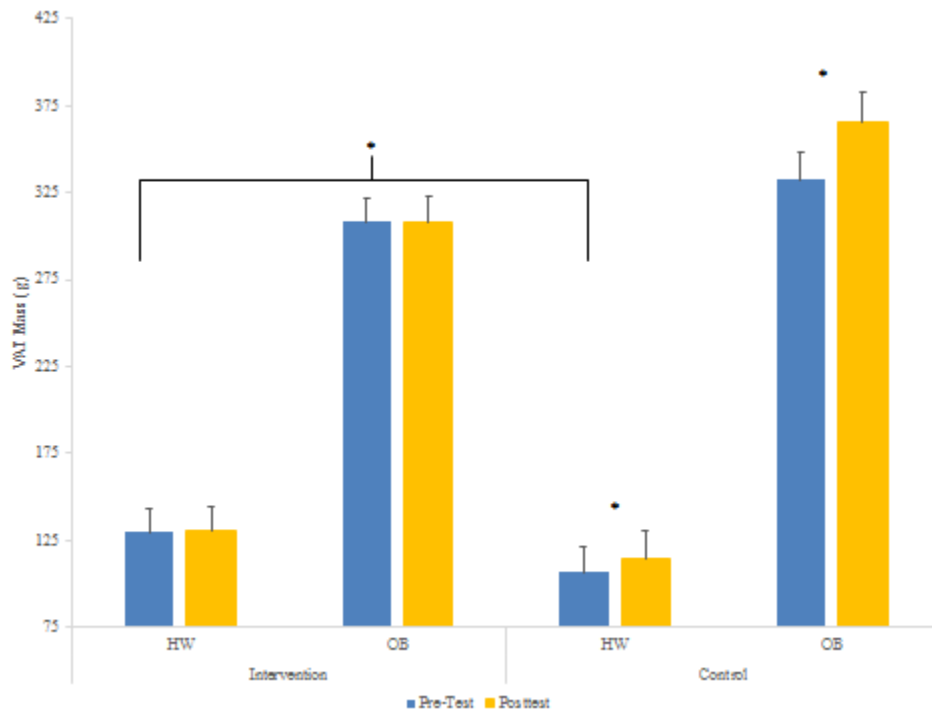
Figure A.1. VO<sub>2</sub> FF ( $\pm$  SE) at pre-test and posttest for BMI and treatment groups.



VAT: The ANOVA revealed a main effect of Time,  $F(1, 149) = 9.51, p = 0.002, \eta^2 = 0.06$ , with VAT being lower at pre-test ( $219.16 \pm 7.24$  g) compared to posttest ( $229.36 \pm 7.90$  g);

and BMI group,  $F(1, 149) = 198.60, p = 0.001, \eta^2 = 0.57$ , with healthy weight children ( $120.08 \pm 10.43$  g) having lower VAT compared to obese children ( $328.44 \pm 10.48$  g). These effects were superseded by interactions of Treatment x Time,  $F(1, 149) = 9.80, p = 0.002, \eta^2 = 0.06$  and an interaction of Treatment x BMI group,  $F(1, 149) = 4.27, p = 0.04, \eta^2 = 0.03$ , which were again superseded by a 3-way interaction of Treatment x BMI group x Time,  $F(1, 149) = 3.96, p = 0.05, \eta^2 = 0.03$ . Decomposition of the 3-way interaction assessed Time x Treatment within each BMI group, and revealed a significant interaction within the obese group,  $F(1, 74) = 7.45, p = 0.008, \eta^2 = 0.09$ , such that a significant increase was only observed in the obese control group, from pre-test ( $332.59 \pm 120.25$  g) to posttest ( $365.83 \pm 112.06$  g),  $t(33) = 4.44, p \leq 0.001$ . No such effect was found for the other three groups (see Figure A.2).

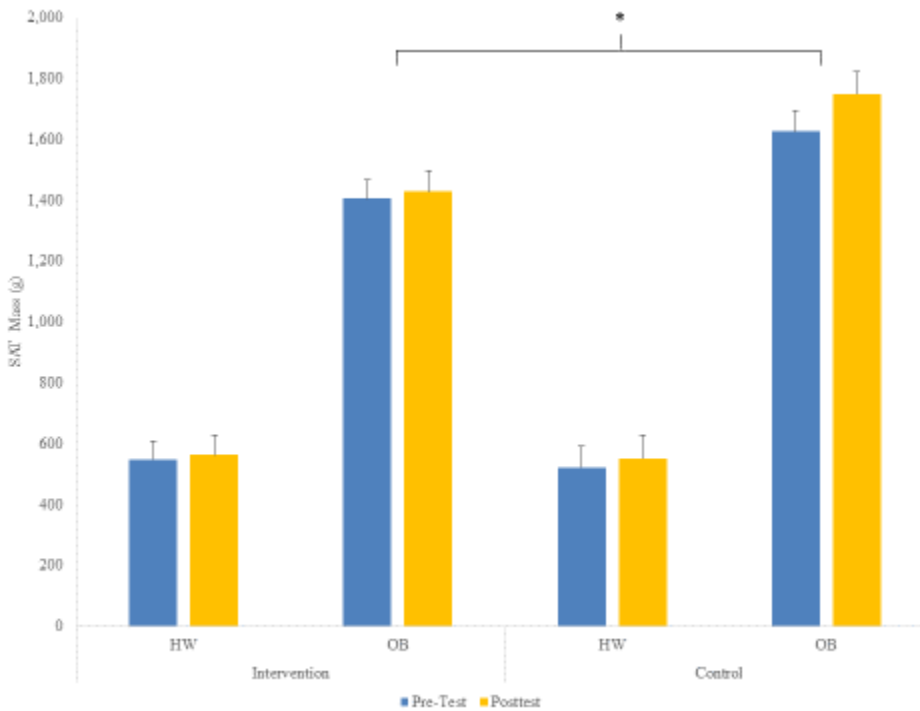
Figure A.2. VAT ( $\pm$  SE) at pre-test and posttest for BMI and treatment groups.



SAT: The ANOVA revealed a main effect of Time,  $F(1, 149) = 13.44, p < 0.001, \eta^2 = 0.08$ , with increases from pre-test ( $1025.24 \pm 32.32$  g) to posttest ( $1072.97 \pm 35.68$  g); and a

main effect of BMI group,  $F(1, 149) = 226.60, p \leq 0.001$ , with the healthy weight group having less SAT ( $546.15 \pm 47.13$  g) than the obese group ( $1552.06 \pm 47.38$  g). These main effects were superseded by interactions of Treatment x BMI group,  $F(1, 149) = 4.67, p = 0.03, \eta^2 = 0.03$ , with obese intervention children having significantly less SAT ( $1416.69 \pm 87.36$  g) than obese control children ( $1687.42 \pm 73.68$  g),  $t(74) = 2.3, p = 0.02$ ; an interaction of Treatment x Time,  $F(1, 149) = 4.78, p = 0.03, \eta^2 = 0.03$ , with significant increases in SAT from pre-test ( $1074.16 \pm 78.11$  g) to posttest ( $1150.36 \pm 87.82$  g) only in the control group,  $t(67) = 4.26, p \leq 0.001$ ; and an interaction of BMI group x Time,  $F(1, 149) = 3.90, p = 0.05$ . Decomposition of this interaction revealed that at pre-test, obese children had significantly greater SAT ( $1509.29 \pm 57.19$  g) than healthy weight children ( $536.64 \pm 30.62$  g),  $t(152) = 14.99, p = 0.001$ , and at posttest, this pattern remained for obese ( $1571.93 \pm 65.00$  g) and healthy weight ( $557.78 \pm 33.34$  g) children,  $t(151) = 14.67, p = 0.001$ , there were significant increases in SAT in the healthy weight group from pre-test ( $536.64 \pm 30.62$  g) to posttest ( $557.79 \pm 33.34$  g),  $t(76) = 2.69, p = 0.01$ ; and significant increases in the obese group from pre-test ( $1503.68 \pm 57.67$  g) to posttest ( $1571.93 \pm 65.00$ ),  $t(75) = 2.70, p = 0.01$  (see Figure A.3).

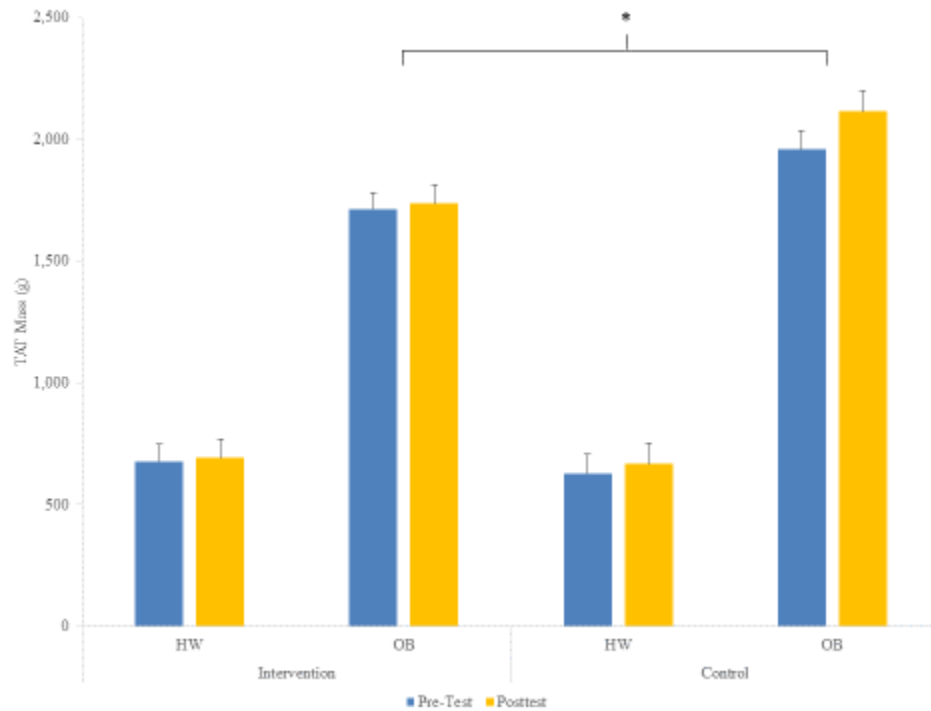
Figure A.3. SAT ( $\pm$  SE) at pre-test and posttest for BMI and treatment groups.



TAT: The ANOVA revealed a main effect of Time,  $F(1, 149) = 15.02, p = 0.001, \eta^2 = 0.09$ , with TAT increasing from pre-test ( $1244.40 \pm 36.65$  g) to posttest ( $1302.02 \pm 40.85$  g); and BMI group  $F(1, 149) = 254.23, p \leq 0.001$ , with the obese group having greater TAT ( $1880.50 \pm 53.991$  g) than the healthy weight group ( $666.23 \pm 53.71$  g). These main effects were superseded by interactions of Treatment x Time,  $F(1, 149) = 6.74, p = 0.01, \eta^2 = 0.04$ , with only the control group exhibiting increases in TAT from pre-test ( $1293.64 \pm 92.90$  g) to posttest ( $1390.37 \pm 103.75$  g),  $t(67) = 4.74, p \leq 0.001$ ; BMI group x Time,  $F(1, 149) = 4.53, p = 0.03, \eta^2 = 0.03$ , with the obese group having greater TAT at pre-test ( $1829.96 \pm 66.95$  g) and posttest ( $1905.45 \pm 77.03$  g) than the healthy weight group (pretest:  $656.04 \pm 30.66$  g, posttest:  $680.82 \pm 33.20$  g),  $t$ 's(151)  $> 14.6, p$ s = 0.001; and an interaction of Treatment x BMI group,  $F(1, 149) = 5.28, p = 0.02, \eta^2 = 0.03$ , with obese intervention children ( $1724.37 \pm 103.75$  g) having lower TAT than obese control children ( $2036.63 \pm 85.93$  g),  $t(74) = 2.25, p = 0.03$  (see Figure A.4).



Figure A.4. TAT ( $\pm$  SE) at pre-test and posttest for BMI and treatment groups.



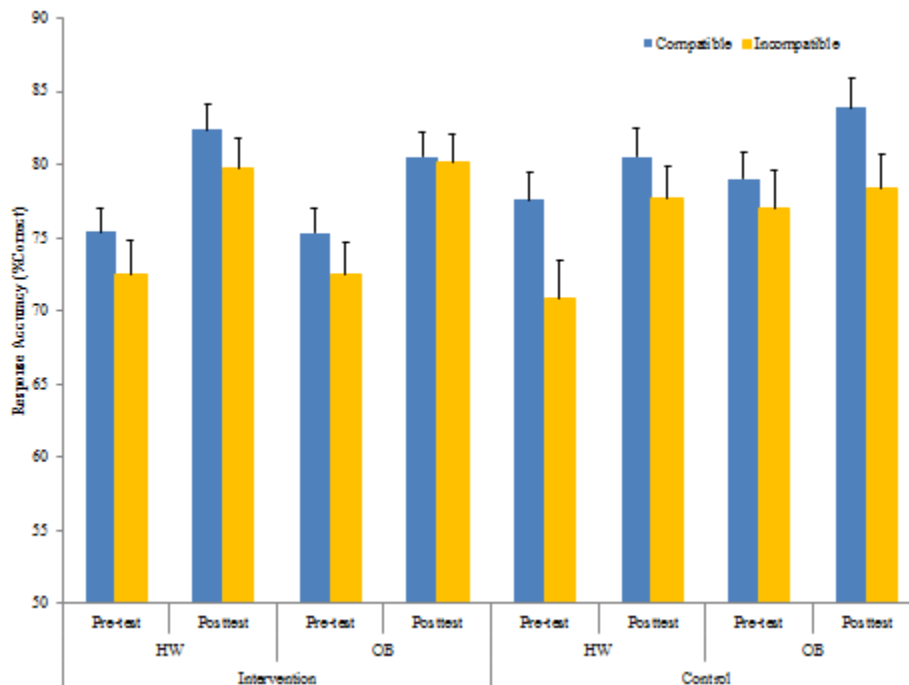
For behavioral analyses, repeated measures analyses employed a 2 (Treatment: Intervention, Control) x 2 (BMI Group: Healthy Weight, Obese) x 2 (Time: pre, post) x 2 (Compatibility: compatible, incompatible) x 2 (Congruency: congruent, incongruent) ANOVA.

Mean Reaction Time: The ANOVA revealed a main effect of Time,  $F(1, 150) = 35.74, p \leq 0.001, \eta^2 = 0.19$ , with shorter reaction times at posttest ( $535.97 \pm 8.61$  ms) relative to pretest ( $580.88 \pm 8.76$  ms); Compatibility,  $F(1, 150) = 102.71, p \leq 0.001, \eta^2 = 0.41$ , with shorter reaction times in the compatible condition ( $531.79 \pm 8.00$  ms) compared to the incompatible condition ( $585.06 \pm 8.52$  ms); and Congruency,  $F(1, 150) = 245.18, p \leq 0.001, \eta^2 = 0.62$ , with congruent trials ( $544.09 \pm 7.72$  ms) having shorter reaction times than incongruent trials ( $572.76 \pm 8.05$  ms). There was also a significant interaction of Treatment x BMI group,  $F(1, 150) = 5.07, p = 0.03, \eta^2 = 0.03$ ; however, decomposition of this interaction revealed no significant effects between BMI groups.

Response Accuracy: The ANOVA revealed main effects of Time,  $F(1, 150) = 33.35, p \leq 0.001, \eta^2 = 0.18$ , with greater accuracy at posttest ( $80.42 \pm 0.89\%$ ) relative to pre-test ( $75.02 \pm 0.95\%$ ), Compatibility,  $F(1, 150) = 20.96, p \leq 0.001, \eta^2 = 0.12$ , with increased accuracy in the compatible condition ( $79.33 \pm 0.74\%$ ) relative to the incompatible condition ( $76.11 \pm 0.74\%$ ), and Congruency,  $F(1, 150) = 185.51, p \leq 0.001, \eta^2 = 0.55$ , with higher accuracy for congruent ( $79.98 \pm 0.79\%$ ) relative to incongruent ( $75.45 \pm 0.83\%$ ) trials.

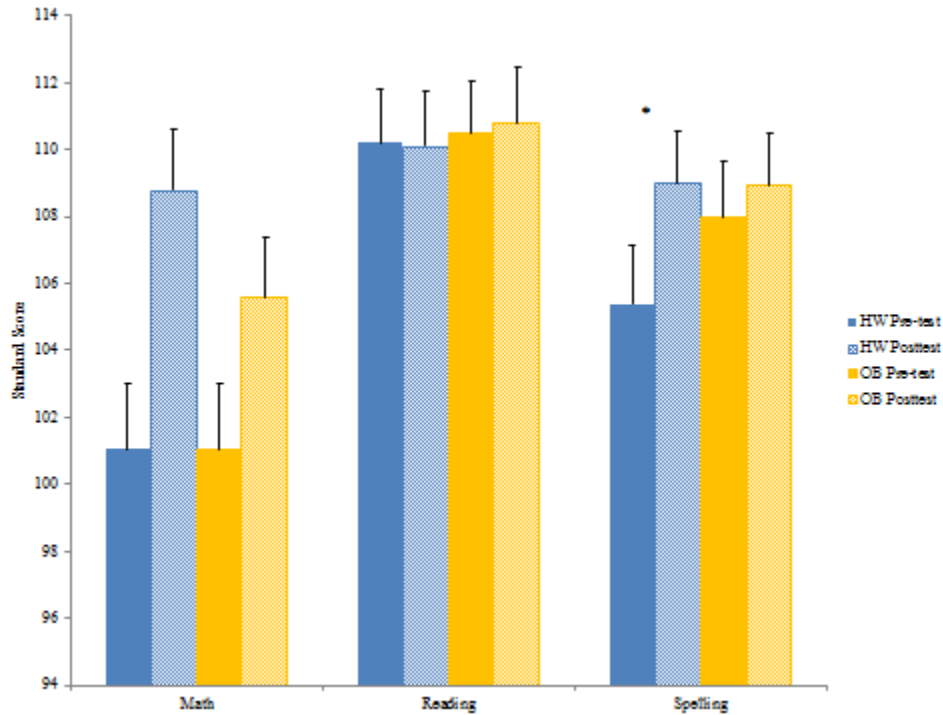
In addition, a 4-way interaction of Treatment x BMI group x Time x Compatibility was observed,  $F(1, 150) = 3.96, p = 0.048, \eta^2 = 0.026$ . The interaction was decomposed by assessing BMI group x Compatibility within each treatment and revealed no significant interactions [ $F$ 's ( $1, 84) \leq 0.32, p_s \geq 0.57, \eta_p^2 \leq 0.004$ ] (see Figure A.5). Additional attempts to deconstruct this 4-way interaction in a meaningful manner did not yield significant findings.

Figure A.5. Response accuracy ( $\pm$  SE) at pre-test and posttest for compatible and incompatible conditions by treatment and BMI group.



Academic Achievement: The ANOVA for Math revealed a main effect of Time  $F(1, 135) = 34.45, p \leq 0.001, \eta^2 = 0.20$  with performance improving from pre-test ( $101.05 \pm 1.38$ ) to posttest ( $107.20 \pm 1.28$ ). The ANOVA for Reading revealed no significant effects,  $F(1, 149) \leq 0.82, p \geq 0.37, \eta_p^2 \leq 0.01$ . The ANOVA for Spelling revealed a main effect of Time,  $F(1, 149) = 13.25, p \leq 0.001, \eta^2 = 0.08$ , with performance improving from pre-test ( $106.67 \pm 1.22$ ) to posttest ( $108.95 \pm 1.13$ ); and Treatment,  $F(1, 149) = 4.42, p = 0.04, \eta^2 = 0.03$ , with the control group ( $110.19 \pm 1.69$ ) performing better than the intervention group ( $105.43 \pm 1.51$ ). In addition, an interaction of BMI group x Time was observed,  $F(1, 149) = 4.37, p = 0.04, \eta^2 = 0.03$ . Decomposition of this interaction revealed significant differences only in the healthy weight group between pre-test ( $105.00 \pm 1.75$ ) and posttest ( $108.58 \pm 1.63$ ), [ $t(75) = 4.00, p \leq 0.001$ ], indicating that obese children, regardless of group assignment did not improve in their Spelling achievement from pretest to posttest (see Figure A.6).

Figure A.6. Pre-test and posttest academic achievement by BMI group.

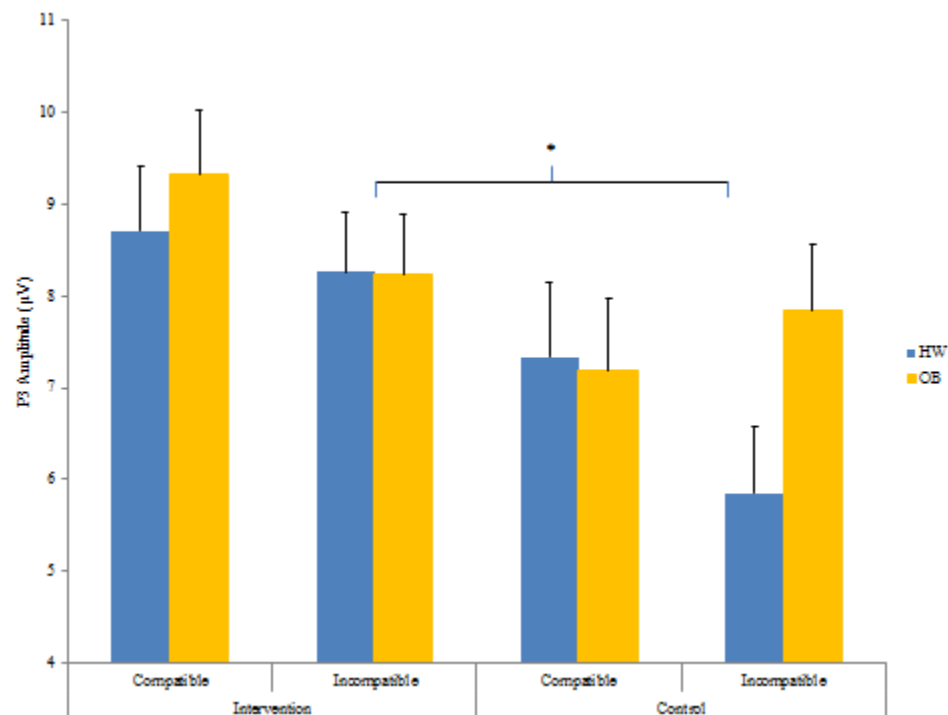


P3 Amplitude: The ANOVA revealed a main effect of Congruency,  $F(1, 149) = 52.84, p \leq 0.001, \eta^2 = 0.26$ , with incongruent trials ( $8.49 \pm 0.33 \mu\text{V}$ ) having increased amplitude than congruent trials ( $7.20 \pm 0.35 \mu\text{V}$ ). There was a main effect of Treatment,  $F(1, 149) = 5.80, p = 0.02, \eta^2 = 0.04$ , with the intervention group having increased P3 amplitude ( $8.63 \pm 0.43 \mu\text{V}$ ) compared to the control group ( $7.06 \pm 0.49 \mu\text{V}$ ). There was also a main effect of Site  $F(6, 894) = 91.25, p \leq 0.001, \eta^2 = 0.38$ , with the midline indicating a topographic maximum at CPz with smaller amplitudes observed moving towards the anterior and occipital scalp regions.

Further, the ANOVA revealed an interaction of Treatment x BMI group x Compatibility,  $F(1, 149) = 5.54, p = 0.020, \eta^2 = 0.04$ . This interaction was decomposed to assess BMI group x Treatment within each compatibility. Results revealed that in the compatible condition, the intervention group ( $9.01 \pm 0.47 \mu\text{V}$ ) had a significantly larger amplitude than the control group ( $7.26 \pm 0.60 \mu\text{V}$ ),  $t(151) = 2.35, p = 0.02$ . In the incompatible condition, the intervention group

( $8.24 \pm 0.43 \mu\text{V}$ ) had a significantly larger amplitude than the control group ( $6.86 \pm 0.55 \mu\text{V}$ ),  $t(151) = 2.00, p = 0.05$ . Furthermore, within the healthy weight group, the intervention had significantly larger ( $8.24 \pm 0.64 \mu\text{V}$ ) amplitudes than the control ( $5.86 \pm 0.53 \mu\text{V}$ ),  $t(74) = 2.73, p = 0.006$  (see Figure A.7).

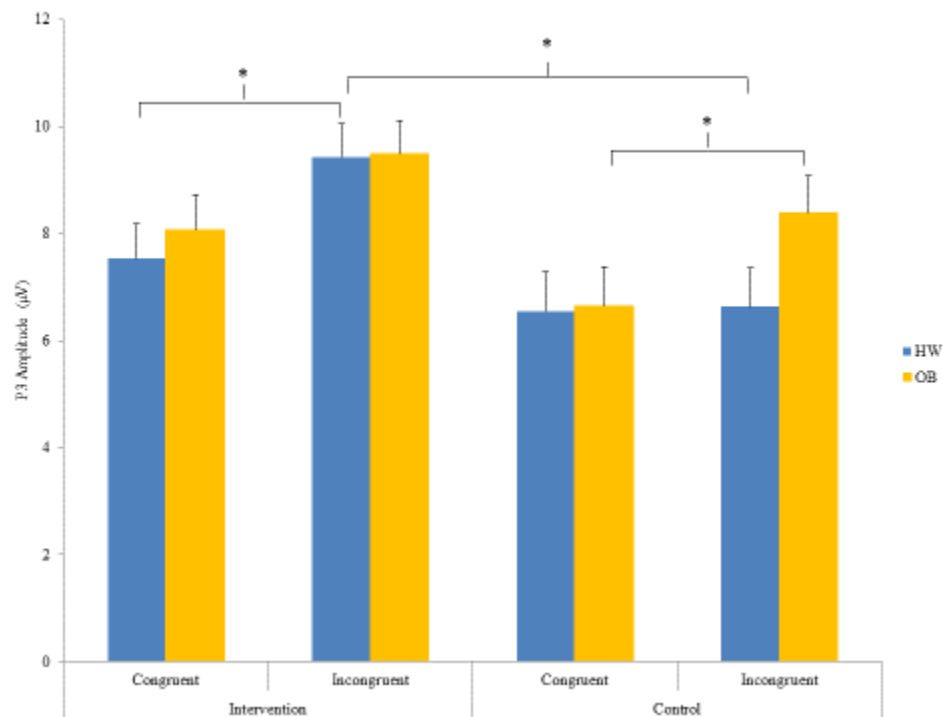
Figure A.7. Mean ( $\pm$  SE) P3 amplitude by treatment and BMI group for compatible and incompatible conditions.



The ANOVA also revealed an interaction of Treatment x Congruency,  $F(1, 149) = 4.40, p = 0.04, \eta^2 = 0.03$ , which was superseded by an interaction of Treatment x BMI group x Congruency,  $F(1, 149) = 9.23, p = 0.003, \eta^2 = 0.06$ . This interaction was decomposed by examining BMI group x Congruency within each treatment. For the control group, there was a significant interaction of BMI group x Congruency  $F(1, 65) = 8.08, p = 0.006, \eta^2 = 0.11$ , which further revealed that in the obese control group, congruent amplitude ( $6.64 \pm 0.94 \mu\text{V}$ ) was

significantly smaller than incongruent amplitude ( $8.38 \pm 0.83 \mu\text{V}$ ),  $t(33)=4.05$ ,  $p \leq 0.001$ . No such effect was found for the healthy weight group (see Figure A.8).

Figure A.8. Mean ( $\pm$  SE) P3 amplitude by treatment and BMI group for congruent and incongruent conditions.



The ANOVA further revealed interactions of Treatment x Time x Congruency x Site,  $F(6, 894) = 3.49$ ,  $p = 0.023$ ,  $\eta^2 = 0.023$ . This interaction was decomposed by assessing Treatment x Time x Congruency at each site. At Fz and FCz, there was significant 3-way interaction,  $F's(1, 151) = 5.41$ ,  $p = 0.02$ ,  $\eta^2 = 0.04$ . This interaction was further broken down by examining Treatment x Time within each congruency, however no significant interactions were revealed,  $F's(1, 151) \leq 2.22$ ,  $ps \geq 0.14$ ,  $\eta_p^2 \leq 0.01$ . At Pz, there was an interaction of Treatment x Congruency,  $F(1, 151) = 6.54$ ,  $p = 0.01$ ,  $\eta^2 = 0.04$ , revealing that in both the intervention and control groups, congruent amplitude was smaller than incongruent amplitude,  $ts(85) > 2.03$ ,  $ps <$

0.05; and incongruent amplitude for the intervention group ( $11.17 \pm 0.52 \mu\text{V}$ ) was larger than incongruent amplitude for the control group ( $8.68 \pm 0.65 \mu\text{V}$ ),  $t(151)=3.05$ ,  $p = 0.003$ .

The ANOVA also revealed an interaction of Treatment x BMI group x Time x Site,  $F(6, 894) = 3.02$ ,  $p = 0.029$ ,  $\eta^2 = 0.02$ . This interaction was decomposed by assessing the interaction of Treatment x Time x Site for each BMI group, which revealed that only the healthy weight group exhibited a significant interaction of Treatment x Time x Site [ $F$ 's (1, 444) = 3.76,  $p = 0.008$ ,  $\eta^2=0.05$ ]. This interaction was further broken down to examine the interaction of Time x Site for each treatment, indicating a significant interaction only in the intervention group,  $F(2, 252) = 5.88$ ,  $p \leq 0.002$ ,  $\eta^2 = 0.12$ , such that at Oz, pre-test amplitude ( $4.60 \pm 0.96 \mu\text{V}$ ) was smaller than posttest amplitude ( $6.52 \pm 0.96 \mu\text{V}$ ),  $t(42) = 2.22$ ,  $p \leq 0.03$ .

P3Latency: The ANOVA revealed a main effect of Time,  $F(1, 43) = 21.13$ ,  $p \leq 0.001$ ,  $\eta^2 = 0.13$ , with latency during posttest being shorter ( $584.12 \pm 2.39$  ms) than latency during pre-test ( $593.83 \pm 2.50$  ms); Compatibility,  $F(1, 143) = 25.40$ ,  $p \leq 0.001$ ,  $\eta^2 = 0.15$ , with the compatible condition ( $584.22 \pm 2.40$  ms) having shorter latency than the incompatible condition ( $593.73 \pm 2.39$ ms); Congruency,  $F(1, 143) = 20.74$ ,  $p \leq 0.001$ ,  $\eta^2 = 0.13$ , with congruent trials ( $586.23 \pm 2.30$  ms) having a shorter latency than incongruent trials ( $591.71 \pm 2.27$ ms); Site,  $F(6, 858) = 40.50$ ,  $p \leq 0.001$ ,  $\eta^2= 0.22$ , with latency at each site being significantly different besides Pz, POz, and Oz.

These main effects were superseded by an interaction of Treatment x Compatibility x Site,  $F(6, 858) = 3.17$ ,  $p = 0.02$ ,  $\eta^2 = 0.02$ . This interaction was decomposed by examining the interaction of Compatibility x Site within each Treatment group. In both the intervention and control groups, there was a significant interaction of Compatibility x Site,  $F$ 's (6, 492) > 15.66,  $ps < 0.001$ ,  $\eta_p^2 > 0.20$ . In the intervention group, compatible latency was shorter than

incompatible latency at Fz, FCz, Cz, and CPz,  $t(82) \geq 2.04$ ,  $p < 0.04$ ; and in the control group, compatible latency was shorter than incompatible latency at Cz, CPz, Pz, and POz,  $t(63) > 3.48$ ,  $p < 0.001$ .

The ANOVA also revealed interactions of Treatment x Congruency x Site,  $F(6, 858) = 3.62$ ,  $p = 0.007$ ,  $\eta^2 = 0.03$ ; and Treatment x BMI group x Congruency,  $F(1, 143) = 9.34$ ,  $p = 0.003$ ,  $\eta^2 = 0.06$ ; which were superseded by an interaction of Treatment x BMI group x Congruency x Site,  $F(6, 858) = 2.59$ ,  $p = 0.04$ ,  $\eta^2 = 0.02$ . This interaction was decomposed by assessing Treatment x BMI group x Congruency within each site. Results revealed that at Fz, there was a significant interaction of Treatment x BMI group x Congruency,  $F(1, 143) = 18.37$ ,  $p \leq 0.001$ ,  $\eta^2 = 0.11$ . Further breakdown of this interaction of Treatment x Congruency within each BMI indicated that only in the healthy weight group was there a significant interaction of Treatment x Congruency,  $F(1, 69) = 19.02$ ,  $p < 0.001$ ,  $\eta^2 = 0.22$ , which indicated that in the intervention group, congruent latency ( $605.35 \pm 6.28$  ms) was shorter than incongruent latency ( $613.62 \pm 5.41$  ms),  $t(40) = 2.09$ ,  $p = 0.04$ . In the control group, congruent latency ( $610.93 \pm 5.49$  ms) was significantly longer than incongruent latency ( $593.18 \pm 6.09$  ms),  $t(29) = 4.04$ ,  $p \leq 0.001$ ; and the intervention incongruent latency ( $612.86 \pm 5.20$  ms) was longer than the control incongruent latency ( $593.87 \pm 5.93$  ms),  $t(72) = 2.40$ ,  $p = 0.02$ .

At Pz there was a significant interaction of Treatment x Congruency,  $F(1, 143) = 4.71$ ,  $p = 0.03$ ,  $\eta^2 = 0.03$ , revealing that in the intervention group, congruent latency ( $575.81 \pm 3.43$  ms) was shorter than incongruent latency ( $579.88 \pm 3.34$  ms),  $t(82) = 2.06$ ,  $p = 0.04$ ; and in the control group, congruent latency ( $568.09 \pm 4.21$  ms) was faster than incongruent latency ( $580.79 \pm 4.32$  ms),  $t(63) = 3.58$ ,  $p = 0.001$ .



At POz, there was a significant interaction of Treatment x Congruency,  $F(1, 143)=8.57$ ,  $p<0.004$ ,  $\eta^2 = 0.06$ , revealing that in the control group, congruent latency ( $568.46 \pm 4.56$  ms) was significantly shorter than incongruent latency ( $581.71 \pm 4.85$  ms),  $t(63) = 4.24$ ,  $p \leq 0.001$ .

At Oz, there was a significant interaction of Treatment x BMI group x congruency,  $F(1, 413) = 4.30$ ,  $p = 0.04$ ,  $\eta^2 = 0.03$ , which was further broken down by examining Treatment x Congruency within each BMI group. Findings revealed that in the obese group, there was a significant interaction of Treatment x Congruency  $F(1, 74)=6.60$ ,  $p = 0.01$ ,  $\eta^2 = 0.08$ , indicating that in the obese control group, congruent latency ( $574.20 \pm 8.23$  ms) was significantly shorter than incongruent latency ( $586.32 \pm 8.18$  ms),  $t(33) = 2.98$ ,  $p = 0.005$ . Decomposing this interaction by examining BMI group x Congruency within each treatment revealed that in the control group, there was a significant interaction of BMI group x Congruency,  $F(1, 62) = 4.62$ ,  $p = 0.031$ ,  $\eta^2 = 0.07$ . Similar to the results above, in the obese control group, congruent latency ( $574.25 \pm 8.23$  ms) was shorter than incongruent latency ( $586.32 \pm 8.18$  ms),  $t(33)=2.98$ ,  $p = 0.005$ .

## Regressions

<sup>2</sup> $\Delta$ Incompatible congruent accuracy: The Step 1 regression analysis for  $\Delta$ incompatible congruent accuracy was significant for the entire group, adjusted  $R^2 = 0.39$ ,  $F(8, 144) = 13.31$ ,  $p \leq 0.001$ . Step 2 was also significant, adjusted  $R^2 = 0.42$ ,  $F(1, 143) = 13.37$ ,  $p \leq 0.001$ , such that greater  $\Delta$ VAT was associated with smaller  $\Delta$ compatible congruent accuracy,  $\beta = -0.19$ ,  $t(143) = -2.89$ ,  $p = 0.004$ ,  $pr = -0.24$  (see Table A.1). Next, this regression was run separately for each treatment and BMI group. All 4 groups demonstrated a significant Step 1 effect, adjusted  $R^2$ 's  $\geq 0.24$ ,  $F$ 's (6, 27)  $\geq 2.73$ ,  $ps \leq 0.03$ . For Step 2, only the obese intervention group showed a significant relationship, adjusted  $R^2 = 0.58$ ,  $F(1, 34) = 9.07$ ,  $p \leq 0.001$ , such that greater  $\Delta$ VAT

was associated with smaller  $\Delta$ incompatible congruent accuracy, with  $\Delta$ VAT accounting for an incremental amount of variance in  $\Delta$ incompatible congruent accuracy beyond associated descriptive variables,  $\beta = -0.23$ ,  $t(41) = -2.11$ ,  $p = 0.04$ ,  $pr = -0.34$  (see Table A.1).

Table A.1. Regression Analyses for  $\Delta$ VAT predicting  $\Delta$ Incompatible Congruent Accuracy

Measure:	<i>B</i>	<i>SE B</i>	$\beta$	<i>t</i>	<i>B</i>	<i>SE B</i>	$\beta$	<i>t</i>
	<i>All</i>				<i>Obese Intervention</i>			
Step 1								
Treatment	-3.51	1.88	-0.12	-1.87				
BMI Group	0.97	1.44	0.07	0.67				
Age	1.9	1.67	0.08	1.14	3.53	3.08	0.13	1.15
Sex	1.9	1.97	0.02	0.26	1.34	3.03	0.05	0.44
IQ	0.5	0.08	0.13	1.98*	-0.22	0.13	-0.189	-1.68
VO2 FF	0.15	0.13	0.07	1.02	0.26	0.21	0.13	1.22
Pre-Test Behavior	0.13	0.07	-0.68	-9.85**	-0.61	0.11	-0.64	-5.71*
Pre-Test VAT	-0.65	0.01	-0.05	-0.48	-0.04	0.01	-0.3	-2.67*
Step 2								
$\Delta$ VAT	-0.01	0.02	-0.19	-2.89*	-0.05	0.03	-0.23	-2.11*

*$\Delta$ Incompatible incongruent accuracy*: The Step 1 regression analysis for  $\Delta$ incompatible incongruent accuracy was significant for the entire group, adjusted  $R^2 = 0.38$ ,  $F(8, 144) = 12.77$ ,  $p \leq 0.001$ . Step 2 was also significant, adjusted  $R^2 = 0.40$ ,  $F(1, 143) = 12.11$ ,  $p \leq 0.001$ , such that greater  $\Delta$ VAT was associated with smaller  $\Delta$ incompatible incongruent accuracy,  $\beta = -0.14$ ,  $t(143) = -2.09$ ,  $p = 0.03$ ,  $pr = -0.17$  (see Table A.2).

Next, this regression was run separately for each treatment and BMI group. Three of the groups (all but obese control) demonstrated a significant Step 1 effect, adjusted  $R^2$ 's  $\geq 0.45$ ,  $F$ 's  $(6, 27) \geq 5.44$ ,  $ps \leq 0.001$ . For Step 2, only the obese intervention group showed a significant

relationship, adjusted  $R^2 = 0.68$ ,  $F(1, 34) = 13.54$ ,  $p \leq 0.001$ , such that greater  $\Delta$ VAT was associated with smaller  $\Delta$ incompatible incongruent accuracy, with  $\Delta$ VAT accounting for an incremental amount of variance in  $\Delta$ incompatible incongruent accuracy beyond associated descriptive variables,  $\beta = -0.21$ ,  $t(34) = -2.20$ ,  $p = 0.04$ ,  $pr = -0.36$  (see Table A.2).

Table A.2. Regression Analyses for  $\Delta$ VAT predicting  $\Delta$ Incompatible Incongruent Accuracy

Measure:	<i>B</i>	<i>SE B</i>	$\beta$	<i>t</i>	<i>B</i>	<i>SE B</i>	$\beta$	<i>t</i>
	<i>All</i>				<i>Obese Intervention</i>			
Step 1								
Treatment	-2.94	2.03	-0.09	-1.45				
BMI Group	0.38	1.55	0.03	0.25				
Age	2.12	1.82	0.08	1.17	1.28	2.95	0.04	0.44
Sex	2.15	2.12	0.07	1.01	1.26	2.88	0.04	0.44
IQ	0.09	0.08	0.07	1.05	-0.14	0.12	-0.11	-1.1
VO <sub>2</sub> FF	0.15	0.14	0.07	1.05	-0.18	0.2	0.09	0.91
Pre-Test Behavior	-0.68	0.07	-0.67	-9.35*	-0.73	0.1	-0.74	-7.56*
Pre-Test VAT	-0.01	0.01	-0.05	-0.54	-0.04	0.01	-0.27	-2.77*
Step 2								
$\Delta$ VAT	-0.05	0.02	-0.14	-2.09	-0.05	0.02	-0.21	-2.19

<sup>3</sup> $\Delta$ Incompatible congruent Cz amplitude: The Step 1 regression analysis for  $\Delta$ incompatible congruent amplitude at Cz was significant for the entire group, adjusted  $R^2 = 0.42$ ,  $F(8, 144) = 14.68$ ,  $p \leq 0.001$ . Step 2 was also significant, adjusted  $R^2 = 0.43$ ,  $F(1, 143) = 13.57$ ,  $p \leq 0.001$ , however  $\Delta$ VAT did not account for an incremental amount of variance in  $\Delta$ incompatible congruent amplitude beyond associated descriptive variables,  $\beta = -0.11$ ,  $t(143) = -0.3$ ,  $p = 0.08$ ,  $pr = -0.14$ .

Next, this regression was run separately for each treatment and BMI group. All 4 groups demonstrated a significant Step 1 effect, adjusted  $R^2$ 's  $\geq 0.24$ ,  $F$ 's (6, 36)  $\geq 3.15$ ,  $p$ 's  $\leq 0.01$ . For Step 2, only the healthy weight control group showed a significant relationship, adjusted  $R^2 = 0.65$ ,  $F(1, 26) = 9.91$ ,  $p \leq 0.001$ , such that greater  $\Delta$ VAT was associated with smaller  $\Delta$ incompatible congruent amplitude, with  $\Delta$ VAT accounting for an incremental amount of variance in  $\Delta$ incompatible congruent amplitude beyond associated descriptive variables,  $\beta = -0.25$ ,  $t(36) = -2.29$ ,  $p = 0.03$ ,  $pr = -0.41$  (suggesting that health weight children in the control group increase in VAT, P3 amplitude decreases) (see Table A.3).

Table A.3. Regression Analyses for  $\Delta$ VAT predicting  $\Delta$ Incompatible Congruent Cz Amplitude in the Healthy Weight Control Group

Measure:	<i>B</i>	<i>SE B</i>	$\beta$	<i>t</i>
Step 1				
Age	-0.28	1.82	-0.02	-0.15
Sex	2.93	2.84	0.14	1.03
IQ	0.04	0.12	0.05	0.352
VO <sub>2</sub> FF	0.12	0.19	0.08	0.67
Pre-Test ERP	-1.11	0.17	-0.79	-6.63*
Pre-Test VAT	-0.06	0.03	-0.27	-1.73
Step 2				
$\Delta$ VAT	-0.11	0.05	-0.25	-2.29*

<sup>4</sup> *$\Delta$ Incompatible congruent Pz latency*: The Step 1 regression analysis for change in incompatible congruent Pz latency was significant for the entire group, adjusted  $R^2 = 0.44$ ,  $F(8,$

142) = 15.50,  $p \leq 0.001$ . Step 2 was also significant, adjusted  $R^2 = 0.43$ ,  $F(1, 141) = 13.76$ ,  $p \leq 0.001$ , however  $\Delta TAT$  did not account for an incremental amount of variance in  $\Delta$ incompatible congruent Pz latency beyond associated descriptive variables,  $\beta = -0.04$ ,  $t(142) = 0.63$ ,  $p = 0.53$ ,  $pr = 0.05$  (see Table A.4).

Next, this regression was run separately for each treatment and BMI group. Three of the groups (not obese control) demonstrated a significant Step 1 effect, adjusted  $R^2 \geq 0.49$ ,  $F's(6, 35) \geq 7.65$ ,  $ps \leq 0.001$ . For Step 2, only the healthy weight control group showed a significant relationship, adjusted  $R^2 = 0.62$ ,  $F(1, 24) = 4.77$ ,  $p \leq 0.001$ , such that greater  $\Delta TAT$  was associated with smaller  $\Delta$ incompatible congruent Pz latency, with  $\Delta TAT$  accounting for an incremental amount of variance in  $\Delta$ incompatible congruent Pz latency beyond associated descriptive variables,  $\beta = 0.29$ ,  $t(35) = 2.48$ ,  $p = 0.02$ ,  $pr = 0.45$  (see Table A.4).

Table A.4. Regression Analyses for  $\Delta TAT$  predicting Incompatible Congruent Pz Latency

<b>Measure:</b>	<b><i>B</i></b>	<b><i>SE B</i></b>	<b><math>\beta</math></b>	<b><i>t</i></b>
Step 1				
Age	-4.14	11.80	0.05	-0.35
Sex	15.78	23.99	0.12	0.66
IQ	-1.89	0.72	-0.35	-2.62*
VO <sub>2</sub> FF	-0.94	1.24	-0.10	-0.76
Pre-Test ERP	-0.85	0.14	-0.76	-5.92*
Pre-Test TAT	0.04	0.04	0.20	1.00
Step 2				
$\Delta TAT$	0.22	0.09	0.30	2.48*