PHYSICAL ACTIVITY FOR THE BRAIN, BUT FOR WHOM? AN INDIVIDUAL DIFFERENCE INVESTIGATION OF THE FITKIDS CLINICAL TRIAL ON COGNITIVE CONTROL AND ERPS IN CHILDREN

BY

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DISSertation

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ABSTRACT

The present dissertation examined the interaction of cardiorespiratory fitness, socioeconomic status (SES), and sex to cognitive control outcomes associated with a 9-month physical activity intervention (FITKids clinical trial) in preadolescent children. This was accomplished by randomizing three hundred eighty-four children into an afterschool physical activity intervention or a wait-list control group. All participants at pre- and post-test completed a cardiorespiratory fitness assessment as well as a modified flanker task while event-related potentials (ERP) were collected. Pre-test cardiorespiratory fitness results revealed insufficient sample size for higher-fit children. Thus, fitness was utilized as a matching variable with one hundred seventy-two participants (n = 86 treatment; n = 86 wait-list) successfully matched across treatment, SES, and sex. Results demonstrated that a 9-month physical activity intervention significantly improved flanker accuracy and post-error accuracy for all children in the intervention compared to the wait-list group, regardless of SES or sex. Additionally, ERP findings revealed sexual dimorphic facilitation in error processing networks and conflict adaptation such that only females in the treatment group demonstrated decreased N2 amplitude while only females in the wait-list group demonstrated increase ERN amplitude from pre- to post-test. Together, these results have considerable implications for promoting organized physical activity interventions for improving cognitive health, regardless of SES or sex, with further implications for sexual selective benefits to performance monitoring brain patterns in preadolescent females.
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A major threat to global public health is the pandemic of physical inactivity (Beaglehole, Bonita, Horton, Adams, Alleyne et al., 2011; Hallal, Andersen, Bull, Guthold, Haskell et al., 2012; Kohl, Craig, Lambert, Inove, Alkandari et al., 2012; World Health Organization [WHO], 2009) with recent reports revealing that physical inactivity is responsible for an estimated three-million preventable premature deaths worldwide (WHO, 2009) making inactivity the fourth leading risk factor for non-communicable diseases (Lee, Shiroma, Lobelo, Puska, Blair et al., 2012). Arguably, the most devastating health consequence of current trends will be on younger generations as they are predicted to be less healthy and have shorter life expectancies compared to previous generations (Olshansky, Passaro, Hershov, Layden, Carnes et al., 2005). Such maladaptive trends in youth are unmistakable today with increasing rates of school age children diagnosed with type-II diabetes, obesity, and other metabolic disorders (Centers for Disease Control and Prevention, 2012; Eisenmann, 2003).

Surprisingly, given that such health consequences are at the forefront of concern for our youth (Institute of Medicine of the National Academies [IOM], 2013), schools continue to decrease time spent in physical activity during school hours in order to facilitate core academic learning (e.g., more than 44% of school districts in the US have reported reductions; Andersen, Crespo, Bartlett, Cheskin, & Pratt, 1998; Centers for Education Policy, 2007; Sisson, Church, Martin, Tudor-Locke, Smith et al., 2009). Such trends represent a maladaptive adjustment in school curriculum (Sallis, 2010) given recent evidence suggesting a positive relation with physical activity to better brain health, cognition, and scholastic achievement (Hillman, Erickson, & Kramer, 2008; Hillman, Kamijo, & Scudder, 2011; Sibley & Etnier, 2003; Tomporowski, McCullick, Pendleton, & Pesce, 2015). However, few investigations evaluate this
relationship while simultaneously considering various individual differences in demographic and cognitive identity. Therefore, there remains a necessity to delve deeper and understand the degree to which individual differences interact with physical activity to benefit brain and cognitive health. Such investigations have considerable implications for the academic environments and may further provide school administrators and teachers critical information for tailoring physical activity interventions to afford the best opportunity for benefits to all children.

More recently, a steady increase in the number of randomized controlled physical activity trials (RCT) assessing cognition and academic achievement in school age children has occurred (Adsiz, Dorak, Ozsaker, & Vurgun, 2012; Ardoy, Fernandez-Rodriguez, Jimenez-Ravon, Castillo, Ruiz et al., 2014; Castelli, Hillman, Hirsch, Hirsch, & Drollette, 2011; Chaddock-Heyman, Erickson, Voss, Knecht, Pontifex et al., 2013; Crova, Struzzolino, Marchetti, Masi, Vannozzi et al., 2013; Davis, Tomporowski, McDowell, Austin, Miller et al., 2011; Fisher, Boyle, Paton, Tomporowski, Watson et al., 2011; Hill, Williams, Aucott, Milne, Thomson et al., 2010; Hillman, Pontifex, Castelli, Khan, Raine et al., 2014; Kamijo, Pontifex, O’Leary, Scudder, Wu et al., 2011; Krafft, Pierce, Schwarz, Chi, Weinberger et al., 2014; Monti, Hillman, & Cohen, 2012; Reed, Einstein, Hahn, Hooker, Gross et al., 2010; Reed, Maslow, Long, & Hughey, 2013). Results are consonant in demonstrating cognitive benefits with selective improvements observed for aspects of cognitive control (i.e., top-down coordination of willed action) including inhibitory control, working memory, and cognitive flexibility (Chaddock-Heyman et al., 2013; Davis et al., 2011; Hillman et al., 2014; Kamijo et al., 2011; Krafft et al., 2014). However, a limitation of these and other investigations is that results are typically generalized across the sample population such that various individual difference factors are not systematically tested to determine whether such factors benefit differentially from the
intervention. Specifically, separate avenues of research have demonstrated the significance of multiple individual difference factors on mediating changes in the developing brain, both structurally and functionally, with further implications related to differences in cognitive control performance. Such factors include cardiorespiratory fitness (Chaddock, Erickson, Prakash, Voss, VanPatter et al., 2012; Pontifex, Raine, Johnson, Chaddock, Voss et al., 2011; Pontifex, Scudder, Drollette, & Hillman, 2012; Scudder, Federmeier, Raine, Direito, Boyd et al., 2014; Voss, Chaddock, Kim, VanPatter, Pontifex et al., 2011), socioeconomic status (SES; Hackman & Farah, 2008; Hackman, Farah, & Meaney, 2010), and sex (Cahill, 2006). These specific factors are important given that participation in active behaviors may have selective benefits to cognitive control for individuals who differ in demographic identity (Drollette, Scudder, Raine, Moore, Saliba et al., 2014; Drollette, Scudder, Raine, Moore, Pontifex et al., 2016; Kwak, Kremers, Bergman, Ruiz, Rizzo et al., 2009; Reed et al., 2013; Tine & Butler, 2012). Thus, the present dissertation seeks to explore the relation and interaction of cardiorespiratory fitness, SES, and sex to cognitive control outcomes associated with a 9-month physical activity intervention.

Investigations of fitness effects on cognition in children are consonant in demonstrating a relation of increased cardiorespiratory fitness to greater performance on cognitive control tasks (Hillman, Castelli, & Buck, 2005; Hillman, Buck, Themanson, Pontifex, & Castelli, 2009; Pontifex et al., 2011). Furthermore, event-related potentials (ERPs; a neuroimaging technique that provides high temporal resolution of cognitive operations occurring between stimulus engagement and response execution) reveal increased P3 amplitude (greater allocation of attentional resources) and shorter P3 latency (faster stimulus classification and mental processing speed) for higher-fit children compared to their lower-fit peers (Pontifex et al., 2011). Interestingly, such behavior and neuroelectric modulation is similar to previous RCT
investigations (see Hillman et al., 2014). Therefore, based on such evidence it is apparent that accounting for fitness is critical when determining the effects of a physical activity intervention on cognitive and neural processes.

Similar to fitness, socioeconomic status (SES) is an indicator of cognitive control differences across the lifespan (Hackman et al., 2008; Lipina, Martelli, Vuelta, & Colombo, 2005; Lupien, King, Meaney, & McEwen, 2001; Mezzacappa, 2004; Noble, Norman, & Farah, 2005; Noble, McCandliss, & Farah, 2007; Noble, Houston, Kan, & Sowell, 2012). Children from lower-SES backgrounds demonstrate poorer task performance and attenuated processes of neural development compared to higher-SES peers (Kishiyama, Boyce, Jimenez, Perry, & Knight, 2009; Stevens, Lauinger, & Neville, 2009). Interestingly, such deficits have also been observed across various neuroimaging techniques suggesting that environmental factors have the potential to disrupt typical neural development of young children (Kishiyama et al., 2009; Lawson, Duda, Avants, Wu, & Farah, 2013). However, increasing opportunities for stimulating environments has been shown to mediate the deleterious effects of SES on brain and cognitive development. That is, by simulating an enriched environment in mice (i.e., improving SES), researchers observe an up-regulation of cellular processes including brain-derived neurotrophic factors (BDNF) associated with healthy neural functioning (van Praag, Kempermann, & Gage, 2000; Kempermann, Kuhn, & Gage, 1997). Interesting, such up-regulation is also observed following several days of voluntary wheel running in mice (Neeper, 1995; van Praag, Christie, Sejnowski, & Gage, 1999; van Praag, Shubert, Zhao, & Gage, 2005) suggesting that physical activity interventions and enriched environments share a similar underlying neural mechanism. Therefore, based on such evidence it is apparent that SES is critical when assessing physical activity effects on cognitive control and functional neural processes.
Finally, accumulating evidence demonstrates unique sexual dimorphic differences in cognition. However, unlike demographic factors discussed previously, sex differences in cognition are not specific to a particular sex and are selective depending on cognitive demands. That is, females typically outperform males on tasks involving verbal memory, verbal fluency, and word recognition tasks (Guillem & Mograss, 2005; Hill, Grut, Wahlin, Herlitz, Winblad et al., 1995; Hyde & Linn, 1988; Kramer, Delis, & Daniel, 1988; Kramer, Delis, Kaplan, O’Donnell, & Prifitera, 1997; Larabee & Crook, 1993; Lowe, Mayfield, & Reynolds, 2003; McGlone, 1980; Temple & Cornish, 1993; Voyer, Postma, Brake, & Imperato-McGinley, 2007); while males outperform females on spatial rotation and working memory related tasks (Astur, Tropp, Sava, Constable, & Markus, 2004; Geiger & Litwiller, 2005; Kaufman, 2007; Levine, Huttenlocher, Taylor, & Langrock, 1999; Linn & Petersen, 1985; Masters & Sanders, 1993; Moore & Johnson, 2008; Parsons, Larson, Kratz, Thiebaux, Bluestein et al., 2004; Peters, Laeng, Latham, Jackson, Zaïyoua et al., 1995; Postma, Jager, Kessels, Koppeschaar, & Van Honk, 2004; Quinn & Liben, 2008; Shepard & Metzler, 1971; Vandenberg & Kuse, 1978; Vecchi & Girelli, 1998). However, researchers suggest that the superior performance typically observed between males and females might be the product of sexual dimorphic strategies used to suppress interference (MacLeod, 1991; Mekarski, Cutmore, & Suboski, 1996). For example, female children demonstrate greater prefrontal cortex (PFC) activation during motor inhibitory and switch tasks compared to males (Christakou, Halari, Smith, Ifkovits, Brammer, & Rubia, 2009; Garavan, Hester, Murphy, Fassbender, & Kelly, 2006) with select investigations demonstrating superior performance for females compared to males (Lahat, Lamm, Chronis-Tuscano, Pine, Henderson et al., 2014; Uebel, Albrecht, Asherson, Borger, Butler et al., 2010). Given the PFC is considered a key neuroanatomical mediator of cognitive control, including inhibitory control
(Peterson, Kane, Alexander, Lacadie, Skudlarski et al., 2002), these findings suggest that females demonstrate a more mature and specialized activation pattern in cortical regions associated with cognitive control compared to male counterparts (Christakou et al., 2009; Giedd, Blumenthal, Jeffries, Castellanos, Liu et al., 1999; Giedd, Clasen, Lenroot, Greenstein, Wallace et al., 2006). Brumback and colleagues (2012) provide further support by demonstrating sexual dimorphic ERP patterns such that shorter P3 latency and smaller P3 amplitude were observed for female compared to male children. Based on these results, the authors suggest that females are quicker and more efficient at categorizing the stimuli presented during the task. Taken together, males appear more likely to experience greater cognitive control modulation patterns compared to females. Consonant with these findings, separate investigations demonstrate no sex differences for cognitive control among lower-SES and lower-fit children while middle-to-high SES and higher-fit children demonstrate superior performance for males compared to females on select cognitive control tasks (Drollette et al., 2016; Levine, Vasilyeva, Lourenco, Newcombe, & Huttenlocher, 2005). Thus, these investigations suggest that SES and fitness are not only mediating variables for typically observed sex differences in cognitive control, but also appear selective, thus further implying that male children of a particular age are more susceptible to environmental and demographic influences on typical neural and cognitive development compared to females of comparable age.

Accordingly, when considered together, these factors not only modulate cognitive control indices separately but also demonstrate unique interacting relations that are surprisingly not accounted for in previous RCT investigations in children. Thus, it is vital to understand the degree of influence each of the individual difference factors described previously contribute to the modulation of cognitive control, particularly when determining the outcome of a physical
activity intervention on cognition and brain health. *To that end, the present dissertation seeks to utilize behavioral and ERP techniques and further discriminate fitness, SES, and sex differences associated with cognitive control outcomes following a 9-month physical activity intervention.*

To date, no RCT investigation has explored the moderating interaction of multiple individual differences, thus the hypothesis regarding the expected outcome is based on the limited data demonstrating unique and selective interactive effects. Therefore, the purpose of the dissertation is to determine the degree to which individual differences moderate the expected cognitive control outcomes following a 9-month physical activity intervention. It was predicted that:

- Baseline measures will yield independent dimorphic relations of cognitive control performance separately for each of the factors such that greater performance will be observed for: 1) higher-fit compared to lower-fit children, 2) higher-SES compared to lower-SES children, and 3) females compared to males.

- Baseline measures will yield differences in ERP components separately for each factor, similar to prior research, reflecting greater deficits in neuroelectric indices of cognitive control for those who are lower-fit, lower-SES, and male.

- Participation in a physical activity intervention will yield greater performance and increase modulation of ERP indices of cognitive control with selectively greater benefits observed for males who are lower-fit and lower-SES, indicating that physical activity induced changes necessitates healthy neurocognitive benefits for all individuals with greater benefits expected for children who experience the greatest deficits in typically developing cognitive operations.

By evaluating multiple factors, the present dissertation may provide additional insight into the moderating interaction of individual differences on physical activity participation and
neuroelectric and cognitive outcomes with further implications for how physical activity may be implemented in a school setting. Such investigations are imperative given that schools are represented by diverse differences in children, and thus make it difficult for rigorously controlled investigations to generalize across all children. Furthermore, given the significance of aspects of cognitive control to the academic environment (Diamond, 2006; Diamond & Lee, 2011; Gathercole, Alloway, Kirkwood, Elliott, Holmes et al., 2008) the present investigation attempts to determine to whom will a physical activity intervention provide the necessary means to counter potentially distracting behaviors that are detrimental to the educational and social environment (DuPaul & Stoner, 2003; Nigg, 2006). Therefore, directly evaluating the interaction of such factors with a physical activity intervention is not only relevant to improving cognitive and brain health but also has implications for tailoring school interventions to optimize cognitive benefits for all children.
CHAPTER 2 – REVIEW OF THE LITERATURE

Given the breadth of available literature for each of the individual difference factors and their shared relation with physical activity participation associated with cognitive control modulation, it is necessary to review the literature-base to provide a foundation for the present dissertation. Specifically, this review will provide an overview of physical activity effects on brain structure and function. Next, the literature associated with each individual difference factor will be reviewed to elucidate the modulation of cognitive control separately for each of the different factors, demonstrating the potential benefit of an exercise intervention by highlighting shared underlying neural processes.

Physical Activity and the Brain

Physical Activity and Brain Structure

Early evidence of physical activity effects on brain growth and development stem from research utilizing animal models. Such investigations demonstrate exercise-induced up-regulation of angiogenesis (growth of new blood vessels; Black, Isaacs, Anderson, Alcantara, & Greenough, 1990; Creer, Romberg, Saksida, van Praag, & Bussey, 2010; Isaacs, Anderson, Alcantara, Black, & Greenough, 1992; Kleim, Cooper, & VandenBerg, 2002; Swain, Harris, Wiener, Dutka, Morris et al., 2003), neurogenesis (growth of new neurons; Aguiar, Speck, Prediger, Kapezinski, & Pinho, 2008; Neeper et al., 1995; van Praag et al., 1999), and synaptogenesis (formation of new synapses between neurons; Eadie, Redila, & Christie, 2005; Hu, Ying, Gomez-Pinilla, & Frautschy, 2009) in select cortical and subcortical regions of the brain including the cerebellum (Black et al., 1990; Isaacs et al., 1992), primary motor cortex (Kleim et al., 2002; Swain et al., 2003), hippocampus (Creer et al., 2010; van Praag et al., 2005), basal ganglia (Aguiar et al., 2008), and prefrontal cortex (Neeper et al., 1995). These exercise-
induced processes have been observed during development (Kim, Lee, Kim, Yoo, & Kim, 2007; Lou, Liu, Chang, & Chen, 2008) and are crucial for effective brain health and functioning by enhancing cell proliferation and providing neuroprotection for critical developing and aging brain regions. For example, voluntary wheel running in mice has been shown to up-regulate neurogenesis in the hippocampus by increasing the production of brain-derived neurotrophic factor (BDNF) and insulin-like growth factor (IGF-1; van Praag et al., 1999). These neurotrophic factors facilitate longevity of synaptic efficacy and neuronal connectivity (Altar & Distefano, 1998; Lu & Chow, 1999; McAllister, Katz, & Lo, 1999; Schinder & Poo, 2000). Additionally, these exercise-induced changes further undergo synaptogenesis such that new neurons are further integrated functionally into the neural network (Eadie et al., 2005; Hu et al, 2009; Lledo, Alonso, & Grubb, 2006), thus potentially facilitating healthy cognitive operations within these neural cortices.

Together, these exercise-induced processes that facilitate brain health and structural integrity in select cortical regions in animals have significant implications for human brain health. Furthermore, although such invasive observations are difficult in human participants, advances in neuroimaging techniques provide compelling evidence to further corroborate the results observed in animals. Specifically, in older adults (see Bherer, Erickson, & Liu-Ambrose, 2013 for review), investigations demonstrate less age-related brain tissue loss in cortical and subcortical areas of the brain including the frontal, parietal, and hippocampal regions for adults engaging in a physical activity intervention compared to healthy controls (Colcombe, Erickson, Scalf, Kim, Prakash, et al., 2006; Erickson, Voss, Prakash, Basak, Szabo et al., 2011; Floel, Ruscheweyh, Kruger, Willemer, Winter et al., 2010; Gordon, Rykhlevskaia, Brumback, Lee, Elavsky et al., 2008; Ruscheweyh, Willemer, Kruger, Duning, Warnecke et al., 2011; Voss,
Nagamatsu, Liu-Ambrose, & Kramer, 2011). For example, Colcombe and colleagues (2006) had healthy older adults participate in a 6-month aerobic exercise intervention or a stretching and toning control group. Results following the intervention demonstrated significant increases in grey and white matter volumes compared to the control group primarily in regions associated with top-down cognitive control operations including the prefrontal and temporal cortices. Furthermore, similar physical activity RCT interventions in children (Schaeffer, Krafft, Schwarz, Chi, Rodrigue et al., 2014) and older adults (Colcombe et al., 2006) demonstrate that physical activity participation has a positive effect on large-scale brain networks such that improvements in neural connectivity were observed in regions that support frontal cognitive control networks. Collectively, these findings provide evidence for the link of healthy brain infrastructure to physical activity participation with further implications for functional significance related to cognitive processes including cognitive control.

**Physical Activity and Brain Function**

**Cognitive Control**

Several empirical investigations, descriptive reviews, and meta-analyses in older adults and children demonstrate that physical activity participation effects on cognitive function are selectively greater for tasks involving cognitive control operations (Angevaren, Aufdemkampe, Verhaar, Aleman, & Vanhees, 2008; Colcombe & Kramer, 2003; Heyn, Abreu, & Ottenbacher, 2004; Hillman et al., 2011; Hillman et al., 2014; van Uffelen, Chinapaw, van Mechelen, & Hopman-Rock, 2008). Cognitive control is multidimensional and represents a collection of cognitive operations that are goal-directed and responsible for the selection, scheduling, and coordinating of willed action (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Meyer & Keiras, 1997; Norman & Shallice, 1986; Rogers & Monsell, 1995). The core cognitive processes
underlying cognitive control include a set of unified yet diverse processes including working memory, inhibitory control, and cognitive flexibility (Miyake & Friedman, 2012; Miyake, Friedman, Emerson, Witzki, & Howarter, 2000; Diamond, 2006).

The interaction of cognitive control processes are dependent on the development and coordinative actions occurring in cortical and subcortical brain structures including the prefrontal cortex (PFC) and the anterior cingulate cortex (ACC) (Dempster, 1992). For example, prior investigations demonstrate that patients with PFC lesions perform poorly on select cognitive control tasks compared to healthy controls (Stuss & Levine, 2002). Interestingly, healthy children demonstrate a similar pattern of performance (Bunge, Dudukovic, Thomason, Vaidya, & Gabrielli, 2002) suggesting that the PFC follows a protracted development reaching maturation late in adolescence and into adulthood (Diamond, 2002). Therefore, given the delicate and early stages of neural development occurring in regions associated with cognitive control, children represent a critical population for examining environmental interactions (i.e., physical activity) that potentially alter the developmental trajectory of cognitive control operations and associated brain processes.

Arguably, inhibitory control is a particularly important aspect of cognitive control operations especially in developing children (Barkley, 1997; Brocki & Brohlin, 2004; Korkman, Kemp, & Kirk, 2001; Raaijmakers, Smidts, Sergeant, Maassen, Posthumus et al., 2008). Inhibitory control is the ability to manage attention and adapt to a shifting environment by overriding prepotent responses to robust but irrelevant information in order to perform correct responses (Barkley, 1997; Bunge et al., 2002; Davidson, Amso, Anderson, & Diamond, 2006; Posner & DiGirolamo, 1998; Miller & Cohen, 2001). Analyses of the dimensionality of cognitive control demonstrates the emergence of inhibitory control prior to other processes.
(Barkley 1997; Brocki & Brohlin, 2004), whereas working memory and cognitive flexibility are not clearly detected until later in development (Korkman et al., 2001), suggesting that inhibitory control is a robust driving factor of other developing cognitive control operations (Raaijmakers et al., 2008). Furthermore, prior evidence demonstrates that inhibitory control precludes working memory processes by gating out irrelevant information in order to ‘clear the workspace’ thus fostering other cognitive operations to effectively manipulate and maintain existing information (Diamond, 2013; Hasher & Zacks 1988; Zacks & Hasher, 2006). Accordingly, age related improvements (i.e., development in children) and decrements (i.e., aging older adults) in working memory are likely the result of underlying impairments in the ability to inhibit interference (Diamond, 2013). That is, the ability to sustain attention and control one’s actions as a child is an important predictor of positive psychological, social, and healthy outcomes later in life. For example, adults with greater inhibitory capacity as children are more likely to stay in school, less likely to engage in risky behavior (i.e., smoking), less likely to be obese as an adult, and demonstrate greater overall life satisfaction compared to adults who demonstrated poor inhibitory control capacity during childhood (Moffitt, Arseneault, Belsky, Dickson, Hancox et al., 2011). Taken together, inhibitory control is a vital contributor not only for effective functioning of cognitive control operations in developing populations but also for healthy social and psychological outcomes in everyday life (Diamond, 2013).

The present dissertation manipulated inhibitory control through compatible- and incompatible-response conditions of a modified Eriksen flanker task (Eriksen & Eriksen, 1974; Friedman, Nessler, Cycowicz, & Horton, 2009; Mullane, Corkum, Klein, & McLaughlin, 2009). Specifically, the compatible condition requires participants to attend and respond quickly and accurately (typically a button press on a response pad) to the directionality of a central target
presented amidst an array of lateral flanking stimuli. Typical flanker tasks involve congruent arrays (e.g., <<<<< or >>>>) and incongruent arrays (e.g., <<<<, or >>>>) that are presented with equal probability. The incongruent arrays are unique in that they simultaneously elicit correct (central target arrow) and incorrect (flanking arrows) response feedback; thus, necessitating up-regulation of inhibitory control operations to override a prepotent response (Gratton, Coles, & Donchin, 1992; Spencer & Coles, 1999). Performance on incongruent trial types typically demonstrates longer reaction time (RT) and decrease accuracy compared to congruent trial types. This difference provides evidence for the validity of flanker tasks in that additional inhibitory control is necessitated for the incongruent trial types to filter the distracting information (Riderinkhof & van der Stelt, 2000). Similar to the compatible condition, the incompatible condition (Friedman et al., 2009; Riderinkhof & van der Molen, 1997) requires participants to respond in the opposite direction of the centrally presented target, thus reversing previously learned response mappings (e.g., left facing targets require a right hand response). Such manipulation of response mapping further necessitates a response override (Botvinick, Cohen, & Carter, 2004), not only for competing flanking stimuli but also for previous rule sets learned during the compatible condition.

**Event-Related Brain Potentials**

Further representation of cognitive control can be assessed utilizing a neuroimaging technique known as event related potentials (ERPs). ERPs are voltage fluctuations measured at the scalp (i.e., summation of postsynaptic potentials) that are time-locked to an event such as a stimulus in the environment or a response to that stimulus (Luck, 2005). These time-locked fluctuations are characterized by positive (P) and negative (N) components identified according to the relative time of occurrence (Hruby & Marsalek, 2003). Unlike overt behavior, ERPs
provide a continuous millisecond-by-millisecond measure of cognitive processing prior to and following an event (Luck, 2005), and thus provide high-temporal resolution of cognitive operations as they occur. Furthermore, ERPs are a valuable tool in furthering scientific progress by advancing the understanding of cognitive operations eliciting a neural response across various task conditions, uncovering and parsing known cognitive processes, and allowing for observation of neural processing when overt behavior is not viable or appropriate (Kappenman & Luck, 2012). As such, previous investigations have utilized the flanker task as a means to evaluate such processes and have suggested various ERP components as indices of cognitive control including conflict monitoring (ERN and Pe) (Falkenstein, Hohnsbein, Hoormann, & Blanke, 1991; Gehring, Coles, Meyer, & Donchin, 1990; Gehring, Goss, Coles, Meyer, & Donchin, 1993), conflict adaptation (N2) (Clayson & Larson, 2012), and attentional allocation (P3) (Polich, 2007).

**Error-Related Negativity (ERN).**

The ERN is a response-locked negative deflection occurring 50-150 ms on trials encompassing an error of commission. Larger amplitude is typically observed topographically over fronto-central recording sites following an error compared to correct response trials (Falkenstein et al., 1991; Falkenstein, Hoormann, Christ, & Hohnsbein, 2000; Gehring et al., 1990, 1993). The ERN neural generator has been localized to the dorsal portion of the anterior cingulate cortex (ACC) (Debener, Ullsperger, Siegel, Fiehler, von Cramon et al., 2005; Dehaene, Posner, & Tucker, 1994; Holroyd, Dien, & Coles, 1998), while the pathways between the PFC and ACC is also critical for ERN operations (Gehring & Knight, 2000; Ullsperger, Fischer, Nigbur, & Endrass, 2014). The production of the ERN represents the concurrent activation of multiple competing responses with increasing conflict signaling the need for increased control
(Falkenstein et al., 1991; Gehring et al., 1990). That is, the ERN represents a marker of failed performance necessitating up-regulation and implementation of cognitive control (Gehring, Liu, Orr, & Carp, 2012; Gehring & Knight, 2000). Thus, the size (i.e., magnitude) of the ERN represents changes in response strategy (Holroyd & Coles, 2002) and attentional focus (Botvinick et al., 2001), such that smaller ERN amplitude is interpreted as a reduction in conflict threshold for detection and error signaling between the PFC and ACC, thus, improving performance. Furthermore, the ERN is a highly robust component and demonstrates convergent validity such that the relation of ERN modulation to indices of cognitive control is similar regardless of the inhibitory task employed (Stoop, flanker, and go/nogo; Riesel, Weinberg, Endrass, Meyer, & Hajcak, 2013). Furthermore, previous research demonstrates a decrease in ERN amplitude for difficult tasks (Johannes, Wieringa, Nager, Muller-Vahl, Dengler et al., 2002) or for tasks where response mapping is indirect compared to direct (Hoffmann & Falkenstein, 2010). Thus, in regards to the present dissertation, it is expected that ERN amplitude would be attenuated for incompatible flanker performance compared to compatible given the reversal in response mapping, which elicits greater reliance upon cognitive control operations.

**N2.**

The N2 component is a negative deflection with a frontocentral scalp distribution that peaks around 250-350 ms following stimulus presentation (Folstein & Van Petten, 2008; Nieuwenhuis, Yeung, van den Wildenberg, & Ridderinkhof, 2003; Yeung, Botvinick, & Cohen, 2004; Yeung & Cohen, 2006) with localization studies postulating the ACC as the neural generator (Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004). Previous research suggests that modulation of N2 amplitude reflects conflict adaptation (Clayson & Larson, 2012). For example, prior research, utilizing the flanker task, demonstrates increased amplitude (more
negative) on high conflict trials (i.e., incongruent trials) compared to low conflict trials (i.e.,
neutral or congruent trials; Nieuwenhuis et al., 2003). Further evidence suggests that N2 reflects
processing of task-irrelevant information such that greater attention to task irrelevant information
(flanking stimuli) is related to greater N2 amplitude (Clayson & Larson, 2012; Danielmeier,
Wessel, Steinhauser, & Ullsperger, 2009). Furthermore, developmental research indicates a
decrease in amplitude and latency with age (Davis, Bruce, Snyder, & Nelson, 2003; Johnstone,
Pleffer, Barry, Clarke, & Smith, 2005).

**P3.**

The P3 component, also known as the P300 or P3b, is a positive deflection with a parietal
scalp distribution that peaks around 300 to 800 ms following stimulus presentation (Polich &
Kok, 1995). The P3 is classified as an endogenous component and reflects neural activity
associated with context updating or attentional resource allocation (Polich, 2007) and is thought
to reflect similar cognitive operations in children (Curry & Polich, 1992; Gill & Polich, 2002).
Specifically, amplitude is thought to reflect the neural resources allocated in order to effectively
suppress interfering neural processing, necessitated by distraction in the environment, in order to
facilitate the process of attention towards a goal (Polich, 2007). Furthermore, P3 latency
represents evaluation time necessary for stimulus detection and classification (Ilan & Polic
h, 1999); thus, shorter latencies are typically associated with improved cognitive performance
(Emmerson, Dustman, Shearer, & Turner, 1989; Polich & Martin, 1992). Finally, localization
research has suggested the neural circuitry pathways between the frontal and temporal-parietal
lobe junctions to be among the neural generators of the P3 component (Ebmeier, Steele,
MacKenzie, O’Carroll, Kydd et al., 1995; Kirino, Belger, Gore, Goldman-Rakic, & McCarthy,
2000; Soltani & Knight, 2000), with further evidence demonstrating a positive correlation between P3 amplitude and hippocampal size relative to temporal lobe size (Polich, 2004).

**Physical Activity, Cognitive Control, and Brain Function**

Only in the past decade has a steady increase in the number of physical activity investigations utilizing RCT to assess cognitive control in school age children occurred (Adsiz et al., 2012; Ardoy et al., 2014; Castelli et al., 2011; Chaddock-Heyman et al., 2013; Crova et al., 2013; Davis et al., 2011; Fisher et al., 2011; Hill et al., 2010; Hillman et al., 2014; Kamijo et al., 2011; Krafft et al., 2014; Monti et al., 2012; Reed et al., 2010; Reed et al., 2013; Schaeffer et al., 2014), with only a small subset of the investigations evaluating functional modulation of neural indices of cognitive control (Chaddock-Heyman et al., 2013; Davis et al., 2011; Hillman et al., 2014; Kamijo et al., 2011; Krafft et al., 2014). Specifically, ERP research with children demonstrates improved functional changes in brain with improved performance on cognitive control tasks (Hillman et al., 2014; Kamijo et al., 2011). For example, Hillman and colleagues (2014) had preadolescent children take part in a nine-month physical activity intervention program designed to improve fitness. Both the waitlist control and treatment groups were administered various cognitive control tasks, including a modified flanker task, while measuring ERPs at baseline and following the intervention. Results demonstrated greater accuracy for the treatment group specifically for trial types that necessitated greater cognitive control demand. In addition, ERP findings revealed greater increases for P3 amplitude and shorter latency for the treatment group suggesting early stimulus classification and increase in the allocation of attentional resources. Additional analyses revealed a unique dose-response relation for greater attendance rate and cognitive function. That is, greater attendance rate was associated with
increased in P3 amplitude, decreased P3 latency, and greater change in behavior performance on trials necessitating the greatest amount of cognitive control.

Additionally, separate investigations had children (who varied in weight status) perform various cognitive control tasks while brain activation (functional magnetic resonance imaging; fMRI) was monitored prior to and following a prolonged (8- to 9-month) physical activity intervention (Chaddock-Heyman et al., 2013; Krafft et al., 2014). Results subsequent to the intervention demonstrated decrease hemodynamic activation in the frontal cortex (Chaddock-Heyman et al., 2013) and decreased resting state synchrony (i.e., task-free resting state activation) associated with the default mode network (i.e., predisposition for goal directed cognitive operations; Krafft et al., 2014) selective for the intervention group compared to the wait-list control children. In addition, Chaddock-Heyman and colleagues (2013) demonstrated increase performance during the flanker task for trial types that necessitate greater cognitive control (i.e., incongruent). Taken together, these results suggest that participation in a physical activity intervention may facilitate early cortical development processing, similar to more mature brain operations revealed in young adults (Chaddock-Heyman et al., 2013), with further implications for improved cognitive control operations. Such investigations highlight the unique association of physical activity to cognitive control operations and associated neural cortices.

Together, these investigations are broadly consistent such that participation in a physical activity intervention enhances brain structure and function with associated improvements in task performance during conditions that require greater cognitive control demand. Additionally, such modulatory patterns are robust given that each investigation consists of a large spectrum of heterogeneous children across sexes with varied fitness differences and environmental backgrounds. As such, further insight may be gained by examining individual differences that
possibly facilitate or attenuate the effects of a physical activity intervention. Thus, it is necessary to review the available literature on individual differences that may contribute to the physical activity-cognition relationship.

**Individual Differences and the Brain**

**Cardiorespiratory Fitness**

Ongoing cross-sectional investigations consistently demonstrate a positive association of cardiorespiratory fitness to cognitive operations including cognitive control, memory, language, and arithmetic and learning operations in children (Berchicci, Pontifex, Drollette, Pesce, Hillman et al., 2015; Buck, Hillman, & Castelli, 2008; Chaddock et al., 2012; Chaddock, Erickson, Prakash, Kim, Voss et al., 2010; Chaddock, Erickson, Prakash, VanPatter, Voss et al., 2010; Chaddock, Hillman, Buck, & Cohen, 2011; Hillman et al., 2009; Moore, Drollette, Scudder, Bharij, & Hillman, 2014; Pontifex et al., 2011; Pontifex et al., 2012; Raine, Lee, Saliba, Chaddock-Heyman, Hillman, & Kramer, 2013; Scudder et al., 2014; Scudder, Lambourne, Drollette, Herrmann, Washburn et al., 2014; Voss et al., 2011; Wu, Pontifex, Raine, Chaddock, Voss et al., 2011; Wu & Hillman, 2013), with further evidence demonstrating enhanced brain operations (Berchicci, et al., 2015; Pontifex et al., 2011) and increased structural integrity in select developing cortical regions (Chaddock et al., 2010; Voss et al., 2011). Such observations are not limited to children as older adults demonstrate similar patterns such that higher levels of fitness are associated with greater cognitive control performance (Kramer, Colcombe, McAuley, Scalf, & Erickson, 2005; Kramer, Hahn, Cohen, Banich, McAuley et al., 1999), a reduced loss of grey and white matter in the prefrontal, frontal, and temporal regions (Colcombe et al., 2003), and enhanced error-monitoring processes (Colcombe, Kramer, Erickson, Scalf, McAuley et al., 2004; Themanson, Pontifex, & Hillman, 2008; Themanson & Hillman, 2006) compared to
lower-fit young and older adult peers. Thus, cardiorespiratory fitness represents a robust indicator of brain health and effective cognitive operations across the life span with further implications for shared underlying mechanisms associated with regular physical activity participation.

Specifically highlighting cognitive control investigations in children, of the various tasks implemented in prior research, the flanker task is the most utilized and demonstrates consistent findings across investigations such that better performance is observed for higher-fit children compared to lower-fit peers with selectively greater differences observed for trial types or conditions that necessitate greater cognitive control demand (Chaddock et al., 2010; Chaddock, et al., 2012; Pontifex et al., 2011; Scudder, et al., 2014; Voss et al., 2011). These differences are consonant across structural and functional investigations suggesting underlying neural processes that facilitate improved flanker performance. For example, brain structural investigations demonstrate unique fitness related differences in regions associated with cognitive control processing (see Chaddock et al., 2011 for review). Specifically, Chaddock and colleagues demonstrate greater volume in the basal ganglia, a subcortical structure implicated in cognitive control operations, for higher-fit children compared to lower-fit peers (Chaddock et al., 2010) with further positive associations observed for flanker performance. Additionally, Pontifex and colleagues (2011) incorporated compatible and incompatible conditions of the flanker task when evaluating individual differences in fitness. Results demonstrated that performance of the compatible compared to the incompatible condition was equivalent for higher-fit children while lower-fit children demonstrated decreased accuracy for incompatible compared to compatible trials. These results were further supported by associated ERP indices such that higher-fit children demonstrated increase P3 amplitude, shorter P3 latency, and decrease ERN amplitude
for the compatible condition with greater modulation of all such components across compatibility. Thus, given the unique modulatory patterns observed for behavior and ERP indices between fitness groups, the researchers suggest that higher-fit compared to lower-fit participants were better able to flexibly adjust inhibitory control processes to the new rule set necessitated by the incompatible condition of the flanker task.

Together, these results suggest that fitness level facilitates cortical development and cognitive processing in a similar manner as physical activity interventions given that such modulatory patterns are similar to previously discussed RCT investigations (see Hillman et al., 2014). Therefore, based on such evidence it is apparent that accounting for fitness is critical when determining the effects of a physical activity intervention on cognitive and neural processes. As such, it is likely that lower-fit children may be more prone to the facilitation effects of a physical activity intervention on typical cognitive and brain development processes.

**Sex**

Sexual dimorphic differences in cognitive ability have been widely researched (Halpern, 2012; Hedges & Nowell, 1995; Kimura & Hampson, 1994; Weiss, Siedentopf, Hofer, Deisenhammer, Hoptman et al., 2003). Such investigations highlight the selectivity of sex differences contingent on the type of task and cognitive demands. That is, females typically demonstrate superior performance compared to males on tasks involving verbal memory, verbal fluency, and word recognition tasks (Guillem & Mograss, 2005; Hill et al., 1995; Hyde & Linn, 1988; Kramer et al., 1997; Kramer, et al., 1988; Larrabee & Crook, 1993; Lowe, et al., 2003; McGlone, 1980; Temple & Cornish, 1993; Voyer et al., 2007); while males outperform females on spatial rotation and working memory related tasks (Astur et al., 2004; Geiger & Litwiller, 2005; Kaufman, 2007; Levine et al., 1999; Linn & Petersen, 1985; Masters & Sanders, 1993;
Moore & Johnson, 2008; Parsons et al., 2004; Peters et al., 1995; Postma et al., 2004; Quinn & Liben, 2008; Vecchi & Girelli, 1998; Shepard & Metzler, 1971; Vandenberg & Kuse, 1978).

These sex differences have been attributed to various dimorphic developmental trajectories of brain structure and function between male and female children such that by adulthood females demonstrate less total brain volume, greater cortical grey matter volume, and less white matter volume compared to males (Allen, Damasio, Grabowski, Bruss, & Zhang, 2003; Filipek, Richelme, Kennedy, & Caviness, 1994; Lemaitre, Crivello, Grassiot, Alperovitch, Tzourio et al., 2005; Nopoulos, Flaum, O’Leary, & Andreasen, 2000). Thus, the developmental period represents a critical time of continual neuronal changes with pronounced differences observed between males and females. For example, female children demonstrate earlier maturational peaks in cortical brain structures associated with fronto-striatal cognitive control networks compared to age matched males (Bramen, Hranilovich, Dahl, Forbes, Chen et al., 2011; Christakou et al., 2009; Giedd et al., 1999, 2006; Sowell, Peterson, Kan, Woods, Yoshii et al., 2007). Furthermore, researchers’ postulate that fluctuations in sex steroid hormones play a key role in such early development in brain networks (Neufang, Specht, Hausmann, Gunturkun, Herpertz-Dahlmann et al., 2009; Sisk & Zehr, 2005), with evidence for sex differences in cognitive control becoming more pronounced with the onset of puberty (Sisk & Zehr, 2005).

However, research demonstrates that when matching for pubertal timing in children, such structural differences remain (Bramen et al., 2011), suggesting that dimorphic neural developmental trajectories in males and females occur irrespective of early female pubertal development. Therefore, such differences in brain development may account in part for sex differences observed in brain function and cognitive differences.
Consonant with structural changes in cortical regions associated with cognitive control, functional research reveals similar findings. Specifically, recent neuroimaging evidence demonstrates sexual dimorphism in cognitive control networks such that females demonstrate greater PFC activation while males demonstrate greater parietal activation (Christakou et al., 2009; Steffensen, Ohran, Shipp, Hales, Stobbs et al., 2008), and select investigations demonstrate superior performance for females compared to males (Lahat et al., 2014; Uebel et al., 2010). Thus, such patterns observed in neural recruitment and behavior performance suggest an adult-like pattern of findings specific for developing females (Christakou et al., 2009; Garavan et al., 2006; Giedd et al., 1999, 2006). Furthermore, such differences lead some researchers to conclude that performance typically observed between males and females on spatial and verbal tasks might be the product of sexual dimorphic neural recruitment strategies used to suppress interference or inhibitory control (MacLeod, 1991; Mekarski et al., 1996). Brumback and colleagues (2012) provide further support for this hypothesis by investigating ERP sex differences in children at select stages across pubertal development. Overall, results demonstrate that while accounting for pubertal development, females demonstrate shorter P3 latencies and smaller P3 amplitude compared to males while performing a typical oddball task. Based on these results, the authors suggest that females are quicker and more efficient at categorizing the stimuli presented during the task. Interestingly, the results further demonstrate that when correlating age with P3 latency only males reveal a significant relation, in that older males exhibit shorter latencies indicative of developmental delays in such processes compared to females.

Together, such observations further corroborate the conclusion of efficient cognitive processing in young females compared to males (Raznahan, Lee, Stidd, Long, Greenstein et al.,
by demonstrating a more mature and specialized activation pattern associated with cognitive control indices compared to male counterparts, similar to previous findings (Giedd et al., 1999, 2006; Christakou et al., 2009). Therefore, male children of a particular age appear more susceptible to developmental modulation patterns effects on maturing neural and cognitive processes compared to female children. As discussed previously, participation in a physical activity intervention may facilitate early cortical developmental processing; therefore, it is likely that males may be more susceptible to the facilitation effects of a physical activity intervention on cortical development.

**SES**

Although controversies circumscribe the measurement of SES, the majority of research is consonant in suggesting that SES encompasses a collection of familial characteristics including household income, parental occupation, parental level of education, and provision of cognitively stimulating environments (Bradley & Corwyn 2002; Braveman, Cubbin, Egerter, Chideya, Marchi et al., 2005; Krieger, Williams, & Moss, 1997). Such factors have been shown to be strong predictors of overall health, psychological well-being, and emotional development across the lifespan (Adler & Rehkopf, 2008; Bradley & Corwyn, 2002; Brooks-Gunn & Duncan, 1997; Conger & Donnellan, 2007; Evans, 2004; McLoyd, 1998). Unfortunately, children from lower-SES backgrounds face not only economic barriers for success but also have the added disadvantage of greater likelihood of depression, anxiety, attentional disorders, with further evidence demonstrating deficits in cognitive control and associated neural processes (Hackman et al., 2010; Kishiyama et al., 2009; Lawson et al., 2013; Stevens et al., 2009). Given the detrimental effects of SES on typical mental development of young children, it is imperative to
understand the interaction of a physical activity intervention on cognitive and brain health outcomes.

Prior individual difference research demonstrates SES-related cognitive control differences with associated brain structural and functional modulation (Farah, Shera, Savage, Betancourt, Giannetta et al., 2006; Mezzacappa, 2004; Noble et al., 2005, 2007). Specifically, children from lower-SES backgrounds demonstrate reductions in prefrontal cortical thickness, attenuated cognitive control processes of neural development, and poorer task performance on measures of cognitive control compared to higher-SES peers (Stevens et al., 2009; Kishiyama et al., 2009; Mezzacappa, 2004; Lawson et al., 2013; Noble et al., 2012). These investigations suggest that environmental factors have the potential to disrupt typical neural development of young children in such a manner that negatively influences cognitive control performance (Stevens, et al., 2009; Kishiyama et al., 2009; Lawson et al., 2013). For example, Kishiyama and colleagues (2009) investigated the effects of SES on various cognitive and ERP measures in 7-12 year-old children. Behavior results were consistent with prior work in that poor performance was observed for low-SES compared to high-SES on multiple cognitive control tasks. In addition, ERP results revealed reduced amplitude for early attentional components of ERPs, similar to prior investigations (Stevens, et al., 2009). These findings are unique in that they demonstrate potential functional neural underpinnings representing aspects of cognitive control attenuated by environmental factors that shape the development of young children. Interestingly, others have found that such differences observed for ERP attentional differences were unrelated to stress, boredom, and other task-related perceived states (D’Angiulli, Lipina, & Olesinska, 2012), further ruling out potential confounds between SES groups and highlighting the significance of cognitive control differences observed in prior work.
Conversely, cognitively stimulating environments have been shown to mediate the deleterious effects of SES on neural development. Specifically, animal models demonstrate that enriched environments facilitate up-regulation in cellular processes associated with healthy neural functioning including IGF-1 and BDNF (Kempermann et al., 1997; Sale, Berardi, & Maffei, 2008; van Praag et al., 2000) with additional research demonstrating greater functional benefits for mice that were exposed to stressful life factors early in life (simulating low SES; Rampon, Tang, Goodhouse, Shimizu, Kyin et al., 2000; Sale et al., 2008). Of interest to the present dissertation, such up-regulation processes are also observed following several days of voluntary wheel running in mice (Neeper et al., 1995). Thus, given that physical activity interventions and enriched environments share a similar underlying neural mechanism, it is apparent that SES factors are crucial when assessing physical activity effects on brain health and functioning.

Purpose

The previously discussed literature has demonstrated several unique and selective neural substrates through which physical activity and individual differences may shape brain function and structure. Prior investigations further demonstrate unique interactions and mediating relations of individual difference variables on physical activity and brain health. When considered together, it is surprising that such factors are not accounted for in previous physical activity interventions with children. If the intended goal is to implement evidence-informed methods useful for schools and parents that will encourage all children to attain the minimum physical activity recommendations, it is vital to understand the degree of influence each of the individual difference factors may contribute to brain health and functioning, particularly when determining the outcome of a physical activity intervention. Accordingly, the present dissertation
seeks to utilize behavioral and ERP techniques to tease apart fitness, SES, and sex differences associated with cognitive control outcomes following a 9-month physical activity intervention.

**Hypotheses**

Given that no prior RCT investigation has explored the moderating interaction of multiple individual differences, our hypothesis regarding the expected outcome is based on limited data demonstrating unique and selective interactive effects. It was predicted that:

- Baseline measures will yield independent dimorphic relations of cognitive control performance separately for each of the factors such that greater performance will be observed for: 1) higher-fit compared to lower-fit children, 2) higher-SES compared to lower-SES children, and 3) females compared to males.

- Baseline measures will yield differences in ERP components separately for each factor, similar to prior research, reflecting greater deficits in neuroelectric indices of cognitive control for children who are lower-fit, lower-SES, and male.

- Participation in a physical activity intervention will yield greater performance and increase modulation of ERP indices of cognitive control with selectively greater benefits observed for males who are lower-fit, and lower-SES; indicating that physical activity induced changes necessitates healthy neurocognitive benefits for all individuals, with greater benefits expected for children who experience the largest deficits in typically developing cognitive operations.
Chapter 3 – METHODOLOGY

The present dissertation seeks to apply an underutilized methodological approach to the FITKids (Hillman et al., 2014; Khan, Raine, Drollette, Scudder, Pontifex et al., 2014) and FITKids2 clinical trials by directly evaluating interactions of individual differences associated with cognitive outcomes of a physical activity intervention. To date, 300+ children have been recruited from the East-Central Illinois area and undergone neuroelectric and behavioral assessment prior to and following the physical activity intervention or the wait-list control condition. Given the large sample size, these data will provide sufficient power to explore the interacting relations of multiple individual difference factors on cognition and neuroelectrical outcomes related to physical activity participation. Accordingly, the research design and methods are described below.

Study Design

The Institutional Review Board at the University of Illinois approved the FITKids study protocol. The purpose of the FITKids intervention is to provide occasion for children to engage in moderate to vigorous physical activity for more than 90 minutes per day for 9-months with the intention of improving cardiorespiratory fitness. This was accomplished by randomizing all consenting participants into either the intervention or the wait-list control group following baseline assessment. Those randomized into the wait-list group were guaranteed placement in the after-school intervention the following school year. Group assignment was blinded to all staff members involved with data collection. Baseline and 9-month follow-up post-testing measures were collecting over a 2-day testing period that circumscribed academic years from 2009 to 2015. Monetary compensation was provided to all children for participation upon completion of their involvement with the study (Hillman et al., 2014).
Participants

Eight hundred thirty-two children were screened and 384 children were randomly assigned to either the treatment or wait-list group. All participants provided written assent and their legal guardians provided written informed consent in accordance with the Institutional Review Board (IRB) of the University of Illinois at Urbana-Champaign. Prior to testing, legal guardians completed a battery of health history and demographic questionnaires on behalf of the participant. Based on these questionnaires all participants included in the analyses did not receive special educational services from their school in connection with learning or attentional disorders, are free of neurological or physical disabilities, have (corrected-to)-normal vision based on the minimal 20/20 standard, and indicate English as their primary language.

Procedure

Baseline and post-intervention testing protocols were identical with each assessment divided across two separate days. All participants, on their first visit to the lab, completed informed assent/consent, preliminary screening, demographic information, intelligent quotient (IQ) assessment, and the cardiorespiratory fitness assessment. No cognitive testing took place following cardiorespiratory fitness assessments, thus avoiding any confounding effects related to acute physical activity on cognitive performance (Drollette et al., 2014; Drollette, Shishido, Pontifex, & Hillman, 2012; Pontifex, Saliba, Raine, Picchietti, & Hillman, 2013). On the second visit to the lab, participants were fitted with an EEG cap and seated in a quiet testing chamber to complete the cognitive tasks. All participants were instructed on appropriate completion of the tasks and given practice trials prior to testing. Upon completion of testing, participants were briefed on the purpose of the study and received remuneration for their participation.
Demographic assessment

Multiple SES measures were collected including household income, free or reduced-priced lunch, parent’s education, and the number of parents living in the household. Additionally, a dichotomous SES index was used based on highest level of education obtained by the female guardian. Low SES was determined if the female guardian had no high school degree, a high school degree, or some college experience. High SES was determined if the female guardian obtained a bachelor or advanced degree. Hand dominance was determined by the Edinburgh Handedness Inventory (Oldfield, 1971). Pubertal timing was determined using the Tanner Staging System Questionnaire (Tanner, 1962; Taylor, Whincup, Hindmarsh, Lampe, Odoki et al., 2001), which was completed by a legal guardian in cooperation with the participant. Body mass index (BMI) was calculated as weight divided by the square of height (i.e., kg/m^2). Lastly, an estimate of IQ was collected based on an age-normed standardized IQ exam, which was administered by a trained experimenter. IQ was assessed using either the Kaufman Brief Intelligence Test (K-BIT; Kaufman & Kaufman, 1990) or the Woodcock-Johnson III Test of Cognitive Abilities (WJ-III; Woodcock, McGrew, & Mather, 2001).

Cardiorespiratory fitness assessment

Each participant was fitted with a Polar heart rate (HR) monitor (Polar WearLink®+ 31, Polar Electro, Finland) and measurements of height and weight were recorded (stadiometer and a Tanita WB-300 Plus digital scale) prior to the fitness assessment test. A modified Balke Protocol (American College of Sports Medicine, 2014) was used while participants ran on a motor driven treadmill (Life Fitness 93T classic; Brunswick Corporation, Schiller Park, IL, USA) at a constant speed. Sequentially, at two-minute intervals, treadmill incline increased 2.5% and the OMNI scale was used to assess rating of perceived exertion (RPE) (Utter, Robertson, Nieman, & Kang,
Running was maintained until volitional exhaustion was achieved. Maximal aerobic capacity (\(\text{VO}_{2\text{peak}}\)) was measured during treadmill running by a computerized indirect calorimetry system (ParvoMedics True Max 2400) with averages of respiratory exchange ratio (RER) and oxygen uptake (\(\text{VO}_{2}\)) assessed every 20 seconds. Relative peak oxygen consumption was expressed in milliliters of oxygen consumed per kilogram of body weight per minute. \(\text{VO}_{2\text{peak}}\) was based upon maximal effort as evidenced by a minimum of two of the following four criteria: 1) a plateau in oxygen uptake corresponding to an increase of less than 2 ml/kg·min\(^{-1}\) despite an increase in exercise workload; 2) a peak heart rate \(\geq 185\) beats per minute (ACSM, 2014) and a heart rate plateau (Freedson & Goodman, 1993); 3) RER \(\geq 1.0\) (Bar-Or, 1983); and/or 4) ratings on the children’s OMNI scale of perceived exertion \(\geq 8\) (Utter et al., 2002).

**Cognitive Task**

Participants completed a modified version of the Eriksen flanker task (Eriksen & Eriksen, 1974). All stimuli were presented focally on a computer screen at a distance of approximately 1 m using Neuroscan Stim software (Compumedics NeuroScan, Charlotte, NC). Participants were instructed to respond with a thumb press on a response pad (Neuroscan STIM system response pad) as quickly and accurately as possible to the direction of the centrally presented target (3 cm tall goldfish on a blue background) amid either congruent (e.g., <<<<< or >>>>>) or incongruent (e.g., <<<< or >>>) flanking non-targets (identical goldfish). Prior to testing, participants were given 40 practice trials in order to control for potential practice effects. Participants completed 2 blocks of 75 trials presented for 200 milliseconds with a fixed inter-trial interval (ITI) of 1700 milliseconds with equiprobable congruency (i.e., 50% congruent trials) and directionality (50% of targets facing right).
ERP Recording

Electroencephalographic (EEG) activity was recorded from 64 Ag/AgCl sintered electrode sites (FPz, Fz, FCz, Cz, CPz, Pz, POz, Oz, FP1/2, F7/5/3/1/2/4/6/8, FT7/8, FC3/1/2/4, T7/8, C5/3/1/2/4/6, M1/2, TP7/8, CB1/2, P7/5/3/1/2/4/6/8, PO7/5/3/4/6/8, O1/2) arranged in an extended montage according to the international 10-10 system (Chatrian, Lettich, & Nelson, 1985) using Neuroscan Quickcap (Compumedics NeuroScan, Charlotte, NC). Prior to EEG recordings, electrode impedance was maintained at less than 10 kΩ. Online, continuous data were referenced to a midline electrode placed at midpoint between Cz and CPz with AFz serving as the ground electrode. Additional electrodes were placed above and below the left orbit and outer canthus of each eye to monitor electrooculographic (EOG) activity with separate bipolar recordings to monitor vertical (VEOG) and horizontal (HEOG) activity. Continuous data were digitized at a sampling rate of 500 Hz, amplified 500 times with a DC to 70 Hz filter, and a 60-Hz notch filter was applied using Neuroscan SynAmps2 amplifier.

Offline, data were re-referenced to averaged mastoids (M1, M2) using Matlab (R2012b) and various toolbox plugins including EEGLAB (Delorme & Makeig, 2004) and ERPLAB (Lopez-Calderon & Luck, 2010). Independent component analysis (ICA) was conducted to identify stereotypical eye-blink artifact (Comon, 1994) followed by an auto-correlation procedure developed for rejecting ICA components related to VEOG activity. This was accomplished by correlating point-by-point raw VEOG data with separate ICA activation waveforms (i.e., EEG.icaact matrix generated by the ICA procedure). No more than two ICA components with a correlation coefficient greater than .35 were removed.

Stimulus-locked epochs were extracted for correct trials (-200 to 1200 milliseconds relative to stimulus presentation), baseline corrected (-200 to 0 ms), and low-pass filtered (zero phase
shift 30 Hz with 24 dB/octave roll-off). Response-locked epochs were extracted for correct and commission-error trials (-600 to 1000 ms relative to response onset), baseline corrected (-400 to -200 ms), and bandpass filtered (zero phase shift 1 to 12 Hz with 24 dB/octave roll-off). Epochs were rejected if a moving window peak-to-peak amplitude exceeded 100 µV (100 ms window width and 50 ms window step) and if the overall variance of the epoch exceeded ± 3 SDs of the mean of local (by electrode site) and global (all electrode sites) accepted epochs. Average ERP waveforms were created separately for stimulus- and response-locked epochs with response-locked waveforms averaged across congruency. Response-locked components were characterized as the mean voltage amplitude within a 0 to 150 ms latency window relative to response onset for commission-error (ERN) and correct (CRN) waveform averages. For stimulus-locked components, 50% fractional area latency and mean amplitude measures were utilized to quantify each ERP component within a 200-400 ms (N2) latency window and 400-800 ms latency window (P3).

**Physical Activity Program Description**

The FITKids trials have adopted the Community Access to Child Health (CATCH) program developed in 1985 by the National Institutes of Health. This program follows daily lessons organized to provide bouts of integrated physical activities with intermittent educational lessons designed to foster healthy lifestyle behaviors beyond the program. Additionally, the CATCH program has been demonstrated in prior research to reduce unhealthy weight status (Coleman, Tiller, Sanchez, Heath, Sy et al., 2005) and facilitate persistent physical activity behaviors among school-aged children (Luepker, Perry, McKinlay, Nader, Parcel et al., 1996).

Utilizing the CATCH curriculum, the FITKids interventions take place every weekday (in accordance with the annual academic calendar for local public school districts) following
completion of regular school hours. Children are either bussed or driven to a designated gymnasium rented from the University of Illinois Campus Recreation. During the intervention, children are provided a sum of 90 minutes of moderate to vigorous physical activity per day. Intensity of the exercise bouts was monitored utilizing Polar heart rate (HR) monitors (Polar E600, Polar Electro, Finland) worn for the duration of the program. These monitors are designed to collect continual HR data with a 30 second sampling rate while worn during group physical activity lessons. Data were downloaded weekly utilizing Polar E Series software.

**Exclusionary Criteria and Matching**

Thirty-one children discontinued the intervention or lost to follow-up assessment. Furthermore, the incompatible condition of the flanker task was removed from further analyses given that performance for a significant sample of children fell below 50%. Lastly, following baseline ERP and cognitive assessment, 65 participants were excluded for task performance below 50% accuracy, insufficient stimulus-locked trials necessary to characterize ERP components, and dependent measures exceeding ± 3 SD. Thus, the proceeding analyses were conducted on the remaining children (see Table 1) following these exclusion criterions (n = 288).

Preliminary analysis of pre-test cardiorespiratory fitness revealed that 70% (n = 203) of participants were below the 30th percentile (i.e., lower-fit) and only 12% (n = 35) were above the 70th percentile (i.e., higher-fit) based on national norms in prepubertal children. As such, the sample size for higher-fit children was insufficient to distribute across separate groups within the remaining factors of SES and sex. Thus, fitness percentile was utilized as a matching variable in order to control for any confounding effects related to fitness level. IQ was also utilized as a matching variable based on further demographic analyses demonstrating greater IQ scores for higher-SES (113.0 ± 0.9) compared to lower-SES (105.9 ± 1.3), F (1, 285) = 20.1, p ≤ 0.01,
children. As such, 172 participants \((n = 86 \text{ treatment}; n = 86 \text{ wait-list}; \text{ see Table 3.1})\) were successfully matched across eight separate groups (males and female groups were matched across SES and treatment groups separately) with the remaining un-matched participants excluded from further analyses \((n = 116; \sim 80\% \text{ of un-matched participants were higher-SES children})\).

**Statistical Analysis**

Statistical procedures were conducted using SPSS (SPSS v. 22, Chicago, IL) with a family-wise alpha threshold for all tests set at \(p = .05\). Demographic, fitness, and baseline behavior/ERP measures were evaluated using one-way analysis of variance (ANOVAs) with SES and sex as the between-subject factors. Similarly, multivariate repeated measures ANOVA were performed to evaluate the efficacy of the intervention with SES, sex, and treatment groups as the between-subject factors. Findings are reported using the Greenhouse-Geisser correction statistic for violations of sphericity. Subsidiary univariate ANOVAs and Bonferroni corrected \(t\)-tests were used for post hoc comparisons and reported using mean and standard error of the mean (±SEM). Further reporting included partial \(\eta^2\) and estimated effect size for main effects and interactions. Flanker performance (accuracy, median reaction time) were separately analyzed utilizing a 2 (Group: treatment, wait-list) \(\times\) 2 (Time: pre-test, post-test) \(\times\) 2 (Sex: males, females) \(\times\) 2 (SES: high, low) \(\times\) 2 (Congruency: congruent, incongruent) statistical model. Remaining behavioral analyses (i.e., accuracy interference, reaction time interference, post error accuracy, post error latency) were separately analyzed utilizing a 2 (Group: treatment, wait-list) \(\times\) 2 (Time: pre-test, post-test) \(\times\) 2 (Sex: males, females) \(\times\) 2 (SES: high, low) statistical model. ERP analyses were performed at single electrode sites for each component of interest in order to limit additional levels in the factorial models. Electrode sites for each component were chosen based
on scalp distribution and previous research indicating component maximum in fronto-central (FCz) for N2 and ERN, and central-parietal (CPz) for P3 (Clayson, & Larson, 2012; Nieuwenhuis et al., 2003). Analyses of stimulus-locked N2 and P3 fractional area latency and mean amplitude were analyzed separately utilizing a 2 (Group: treatment, wait-list) × 2 (Time: pre-test, post-test) × 2 (Sex: males, females) × 2 (SES: high, low) × 2 (Congruency: congruent, incongruent) statistical model. Analyses of response-locked ERN and CRN mean amplitude were analyzed separately utilizing a 2 (Group: treatment, wait-list) × 2 (Time: pre-test, post-test) × 2 (Sex: males, females) × 2 (SES: high, low) statistical model.
Table 1. Inclusion criteria for participants included in the current dissertation.
Chapter 4 – RESULTS

Participant demographics are provided in Table 2. Preliminary analyses were performed to test the efficacy of the participant matching procedure. Pre-test ANOVAs revealed no significant main effects or interactions between groups (sex, SES, and treatment groups) for IQ and VO$_2$ percentile [$F$’s (1, 164) ≤ 3.5, $p_s$ ≥ 0.06, $\eta^2_p$ ≤ 0.02]. Further, no significant main effects or interactions were observed across additional demographic factors including age, pubertal timing, and BMI percentile [$F$’s (1, 164) ≤ 3.4, $p_s$ ≥ 0.07, $\eta^2_p$ ≤ 0.02]. However, as expected, analyses of relative VO$_2$ and BMI revealed a main effect of Sex,$[F$’s (1, 164) ≥ 5.4, $p_s$ ≤ 0.02, $\eta^2_p$ ≥ 0.03], demonstrating greater fitness (40.0 ± 0.7 ml/kg/min) and a lower BMI (19.1 ± 0.5 kg/m$^2$) for males compared to females (VO$_2$: 35.3 ± 0.7 ml/kg/min, BMI: 20.7 ± 0.5 kg/m$^2$). BMI analysis further revealed a main effect of SES [$F$ (1, 164) = 4.1, $p = 0.05$, $\eta^2_p$ = 0.02], demonstrating lower BMI for higher-SES (19.2 ± 0.5 kg/m$^2$) compared to lower-SES children (20.6 ± 0.5 kg/m$^2$). Lastly, analyses for ERPs were conducted on the number of correct- and error-trials to ensure that group differences were not influenced by trial count included in stimulus- and response-locked averages. Analyses revealed no significant main effects or interactions for stimulus-locked [$F$’s (1, 164) ≤ 3.0, $p_s$ ≥ 0.08, $\eta^2_p$ ≤ 0.02], or response-locked trial count [$F$’s (1, 133) ≤ 3.2, $p_s$ ≥ 0.08, $\eta^2_p$ ≤ 0.02], suggesting equivalent trial count across groups.
Table 2. Mean (±1 SEM) values for demographic and fitness measures.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Treatment</th>
<th></th>
<th></th>
<th>Wait-list</th>
<th></th>
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<tr>
<td></td>
<td>High SES</td>
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<tr>
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<tr>
<td>N</td>
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<td>21</td>
<td>22</td>
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<tr>
<td>Age (years)</td>
<td>8.7 ± 0.1</td>
<td>8.9 ± 0.1</td>
<td>8.7 ± 0.1</td>
<td>8.8 ± 0.1</td>
<td>8.7 ± 0.1</td>
<td>8.8 ± 0.1</td>
</tr>
<tr>
<td>Grade</td>
<td>3.1 ± 0.2</td>
<td>3.0 ± 0.2</td>
<td>3.1 ± 0.1</td>
<td>3.2 ± 0.1</td>
<td>2.9 ± 0.1</td>
<td>3.3 ± 0.1</td>
</tr>
<tr>
<td>Pubertal timing</td>
<td>1.5 ± 0.1</td>
<td>1.3 ± 0.1</td>
<td>1.4 ± 0.1</td>
<td>1.6 ± 0.1</td>
<td>1.4 ± 0.1</td>
<td>1.5 ± 0.1</td>
</tr>
<tr>
<td>IQ</td>
<td>113.7 ± 2.9</td>
<td>106.5 ± 2.8</td>
<td>108.8 ± 3.1</td>
<td>103.5 ± 2.9</td>
<td>110.6 ± 3.0</td>
<td>107.6 ± 2.2</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>17.9 ± 0.8</td>
<td>20.2 ± 0.9</td>
<td>19.4 ± 1.1</td>
<td>20.2 ± 1.1</td>
<td>18.4 ± 0.9</td>
<td>20.1 ± 0.9</td>
</tr>
<tr>
<td>BMI percentile (%)</td>
<td>59.1 ± 7.3</td>
<td>77.1 ± 5.2</td>
<td>71.1 ± 5.4</td>
<td>73.5 ± 6.2</td>
<td>66.8 ± 6.7</td>
<td>74.2 ± 6.0</td>
</tr>
<tr>
<td>VO2max (ml/kg/min)</td>
<td>40.1 ± 1.6</td>
<td>35.9 ± 1.2</td>
<td>39.3 ± 1.7</td>
<td>35.1 ± 1.6</td>
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<td>35.8 ± 1.1</td>
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<tr>
<td>VO2max percentile (%)</td>
<td>18.9 ± 5.3</td>
<td>16.7 ± 3.8</td>
<td>19.1 ± 5.1</td>
<td>21.3 ± 5.3</td>
<td>18.3 ± 3.8</td>
<td>17.6 ± 4.2</td>
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</table>
Baseline Assessment

Individual Differences in Task Performance and ERPs

Analyses of baseline task performance revealed a main effect of Sex across latency measures \([F’s (1, 168) \geq 3.8, p_s \leq 0.05, \eta_p^2 \geq 0.02]\), revealing shorter incongruent median reaction time (RT) for males \((519.1 \pm 13.1 \text{ ms})\) compared to females \((555.1 \pm 12.8 \text{ ms})\) and shorter post-error latency for males \((528.2 \pm 15.6 \text{ ms})\) compared to females \((593.0 \pm 15.3 \text{ ms})\) (see Figure 1). No further main effects or interactions regarding sex or SES were observed for task performance and stimulus-locked ERP measures \([F’s (1, 168) \leq 3.3, p_s \geq 0.07, \eta_p^2 \leq 0.02]\). However, analysis of response-locked ERN mean amplitude revealed a main effect of Sex \([F (1, 129) = 5.5, p = 0.02, \eta_p^2 = 0.04]\), demonstrating larger mean amplitude for males \((-0.4 \pm 0.5 \mu \text{V})\) compared to females \((1.1 \pm 0.4 \mu \text{V})\).
Figure 1. Median (±SEM) incongruent and post-error RT at pre-test for males and females collapsed across SES.
Intervention Assessment

Changes in Weight Status and Aerobic Fitness

The omnibus analysis for BMI percentile revealed no main effects or interactions \([F (1, 164) \leq 3.4, p \geq 0.06, \eta^2_p \leq 0.02]\). However, analysis for VO_2 percentile revealed an interaction of Group \(\times\) Time \([F (1, 164) = 4.3, p = 0.04, \eta^2_p = 0.03]\), demonstrating increased change in VO_2 percentile at post-test \((24.7 \pm 2.9\%)\) compared to pre-test \((18.9 \pm 2.5\%)\), but only for the treatment group \([t (85) = 2.3, p = 0.02]\), with no such effect observed for the wait-list control group \([t (85) = 0.2, p = 0.82\) (see Figure 2)]. In addition, an interaction of Time \(\times\) SES was observed, \(F (1, 164) = 6.9, p \leq 0.01, \eta^2_p = 0.04\). Decomposition of the interaction revealed increase VO_2 percentile at post-test \((24.4 \pm 2.6\%)\) compared to pre-test \((17.9 \pm 2.1\%)\), but only for higher-SES children, \(t (85) = 3.1, p \leq 0.01\).
Figure 2. Mean (±SEM) VO₂ percentile (%) at pre- and post-test for each group collapsed across SES and sex.
Changes in Inhibitory Control

Flanker Median Reaction Time

The omnibus analysis for flanker median RT revealed a main effect of Time [$F(1, 164) = 29.9, p \leq 0.01, \eta_p^2 = 0.02$], demonstrating shorter RT at post-test (480.4 ± 7.1 ms) compared to pre-test (515.9 ± 8.5 ms). In addition, a main effect of Type was observed [$F(1, 164) = 263.2, p \leq 0.01, \eta_p^2 = 0.61$], demonstrating shorter RT for congruent (477.2 ± 6.9 ms) compared to incongruent (519.1 ± 7.6 ms) trials. No further main effects or interactions were observed for median RT [$F's(1, 164) \leq 2.6, p_s \geq 0.11, \eta_p^2 \leq 0.02$].

Flanker Response Accuracy

The omnibus analysis for flanker accuracy revealed a main effect of Time [$F(1, 164) = 26.0, p \leq 0.01, \eta_p^2 = 0.14$], that was superseded by a Group × Time interaction, $F(1, 164) = 11.6, p \leq 0.01, \eta_p^2 = 0.07$. Decomposition of the interaction revealed increased response accuracy at pre-test for the wait-list group (79.4 ± 1.1%) compared to the treatment group (75.0 ± 1.2%), $t(170) = 2.8, p \leq 0.01$. Additional decomposition revealed increased accuracy at post-test (82.3 ± 1.0%) compared to pre-test (75.0 ± 1.2%) but only for the treatment group [$t(85) = 6.0, p \leq 0.01$], with no such trend observed for the wait-list group [$t(85) = 1.2, p = 0.24$ (pre-test: 79.4 ± 1.1%, post-test: 80.8 ± 1.3%; see Figure 3)]. A main effect of Congruency [$F(1, 164) = 308.9, p \leq 0.01, \eta_p^2 = 0.65$] was also observed that was superseded by a Sex × SES × Congruency interaction [$F(1, 164) = 4.0, p = 0.05, \eta_p^2 = 0.02$]. However, decomposition of the interaction assessing Sex × SES within each congruency condition revealed no significant interactions [$F’s(1, 168) \leq 1.4, p_s \geq 0.23, \eta_p^2 \leq 0.01$].
Figure 3. Mean (±SEM) response accuracy at pre- and post-test for each treatment group collapsed across SES, sex, and congruency.
**Interference RT and Accuracy**

No significant main effects or interactions were observed for flanker interference RT \[ F'(s) (1, 164) \leq 2.7, p_s \geq 0.10, \eta^2_p \leq 0.02 \]. The omnibus analysis for flanker accuracy interference revealed an interaction of Sex × SES \[ F(1, 164) = 26.0, p \leq 0.01, \eta^2_p = 0.14 \]. Decomposition of the interaction revealed increased interference for lower-SES male children (8.9 ± 0.8%) compared to lower-SES female children (6.2 ± 0.8%), \( t(84) = 2.4, p = 0.02 \). No further main effects or interactions were observed for flanker accuracy interference \[ F'(s) (1, 164) \leq 2.7, p_s \geq 0.10, \eta^2_p \leq 0.02 \].

**P3 Latency**

The omnibus analysis for P3 latency revealed a main effect of Congruency \[ F(1, 164) = 21.3, p \leq 0.01, \eta^2_p = 0.12 \], and an interaction of Sex × Congruency \[ F(1, 164) = 6.9, p \leq 0.01, \eta^2_p = 0.04 \], that were superseded by a Group × Sex × Congruency interaction \[ F(1, 164) = 8.5, p \leq 0.01, \eta^2_p = 0.05 \]. Decomposition of the 3-way interaction revealed shorter latency for females (564.0 ± 4.8 ms) compared to males (581.7 ± 6.2 ms) in the wait-list group, but only for congruent trial types \( t(84) = 2.3, p = 0.03 \). However, the results were non-significant following Bonferroni correction. Further decomposition revealed shorter latency for congruent compared to incongruent trial types, but only for males in the treatment group (congruent: 579.5 ± 4.7 ms, incongruent: 588.0 ± 4.7 ms), \( t(41) = 2.4, p = 0.02 \), and females in the wait-list control group (564.0 ± 4.8 ms, incongruent; 583.8 ± 4.7 ms), \( t(43) = 5.8, p \leq 0.01 \). Lastly, a main effect of Time \[ F(1, 164) = 17.0, p \leq 0.01, \eta^2_p = 0.09 \], revealed shorter latency at post-test (573.6 ± 3.0 ms) compared to pre-test (587.2 ± 3.0 ms).
**P3 Mean Amplitude**

The omnibus analysis for P3 mean amplitude revealed a main effect of Congruency \([F (1, 164) = 55.7, p \leq 0.01, \eta^2_p = 0.25]\), demonstrating larger mean amplitude for incongruent \((12.7 \pm 0.5 \, \mu V)\) compared to congruent trials \((10.8 \pm 0.5 \, \mu V)\). In addition, an interaction of Group \(\times\) Time \(\times\) Sex \([F (1, 164) = 4.6, p = 0.03, \eta^2_p = 0.03]\), was observed. However, decomposition of the interaction assessing Group \(\times\) Time within each sex only approached significance for females \([F (1, 84) = 3.4, p = 0.07, \eta^2 = 0.04]\), suggesting greater change from pre- to post-test in the treatment \((1.7 \pm 1.2 \, \mu V)\) compared to the wait-list group \((-1.2 \pm 1.0 \, \mu V)\), \(t (86) = 1.9, p = 0.07\) (see Figure 4).
Figure 4. Stimulus-locked grand-average waveforms separated by time and treatment groups at site CPz for males (A) and females (B) collapsed across SES and congruency.
Changes in Error Processing and Conflict Adaptation

N2 Latency

The omnibus analysis for N2 latency revealed an interaction of SES × Congruency, \( F(1, 164) = 4.4, p = 0.04, \eta^2_p = 0.03 \). Decomposition of the interaction revealed shorter latency for incongruent trials (298.8 ± 2.2 ms) compared to congruent trials (303.6 ± 2.4 ms), but only for higher-SES children \( [t(85) = 2.4, p = 0.02] \), with no such trend observed for lower-SES children \( [t(85) = 0.5, p = 0.59] \). In addition, a Group × Time × Congruency interaction was observed \( [F(1, 164) = 3.9, p = 0.05, \eta^2_p = 0.02] \), revealing shorter latency for incongruent trials (298.5 ± 3.0 ms) compared to congruent trials (305.3 ± 3.2 ms) at post-test, but only for the wait-list group \( [t(85) = 2.3, p = 0.03] \). However, the results were non-significant following Bonferroni correction. Lastly, a Group × Sex interaction was observed \( [F(1, 164) = 10.2, p \leq 0.01, \eta^2_p = 0.06] \), revealing shorter latency for males in the control group (295.3 ± 2.7 ms) compared to females in the control group (307.4 ± 3.2 ms) \( t(84) = 2.9, p \leq 0.01 \), and males in the treatment group (306.6 ± 3.0 ms), \( t(82) = 2.8, p \leq 0.01 \).

N2 Mean Amplitude

The omnibus analysis for N2 mean amplitude revealed an interaction of Group × Time \( [F(1, 164) = 4.5, p = 0.04, \eta^2_p = 0.03] \), and an interaction of Group × Sex \( [F(1, 164) = 3.8, p = 0.05, \eta^2_p = 0.02] \), both of which were superseded by a Group × Time × Sex interaction \( [F(1, 164) = 4.5, p = 0.04, \eta^2_p = 0.03] \). Decomposition of the 3-way interaction revealed larger N2 amplitude for females in the treatment group at pre-test (-5.8 ± 1.1 µV) compared to post-test (-3.0 ± 1.1 µV), \( t(43) = 3.0, p \leq 0.01 \) (see Figure 5 & 6), and compared to females in the wait-list control group at pre-test (-1.5 ± 0.7 µV), \( t(86) = 3.2, p \leq 0.01 \). Further decomposition revealed larger N2 amplitude for females in the treatment group at pre-test (-5.8 ± 1.1 µV) compared to
males (-2.7 ± 1.0 µV); however, the results were non-significant following Bonferroni correction $[t (84) = 2.1, p = 0.04]$. Lastly, a main effect of Congruency $[F (1, 164) = 15.0, p \leq 0.01, \eta^2_p = 0.08]$ was observed revealing larger N2 amplitude for incongruent (-3.6 ± 0.4 µV) compared to congruent trial types (-2.8 ± 0.5 µV).
Figure 5. Stimulus-locked grand-average waveforms at site FCz separated by time and treatment groups for males (A) and females (B) collapsed across SES and congruency.
Figure 6. N2 mean amplitude change (post-pre) by sex collapsed across SES and congruency.
**ERN and CRN**

Thirty-five participants were removed from ERN analyses due to insufficient response-locked commission errors (less than six trials) necessary to characterize an ERN component (see Olvet & Hajcak, 2009; Pontifex et al., 2010). Accordingly, the preceding analyses were conducted on the remaining subset of 137 children ($n = 70$ intervention; $n = 67$ wait-list). Furthermore, given previous results (behavior and ERP) revealing no significant treatment interactions related to SES, the analyses were collapsed across SES groups.

The omnibus analysis for ERN mean amplitude revealed a main effect of Sex [$F (1, 133) = 6.1, p = 0.02, \eta_p^2 = 0.04$] and an interaction of Group × Time [$F (1, 133) = 5.1, p = 0.03, \eta_p^2 = 0.04$], which were superseded by a Group × Time × Sex interaction [$F (1, 133) = 4.4, p = 0.04, \eta_p^2 = 0.03$]. Decomposition of the interaction revealed larger ERN mean amplitude for females in the wait-list group at post-test (-0.8 ± 0.5 µV) compared to pre-test (1.3 ± 0.6 µV), $t (33) = 3.0, p \leq 0.01$ (see Figure 7A & C). Further decomposition revealed larger ERN for males at post-test (-0.8 ± 0.6 µV) compared to females [$t (68) = 2.9, p \leq 0.01$], but only in the intervention with no such effect observed for the wait-list group [$t' s (65) \leq 1.6, p \geq 0.12$]. Lastly, the omnibus analysis for CRN mean amplitude revealed no main effects or interactions [$F' s (1, 133) \leq 2.8, p, \geq 0.09, \eta_p^2 \leq 0.02$ (see Figure 7B & D)].
Figure 7. Response-locked grand-average waveforms at site FCz separated by time and treatment groups for male commission errors (A), male correct trials (B), female commission errors (C), and female correct trials (D).
Post-error Flanker Performance

The omnibus analysis for post-error RT revealed a main effect of Time \([F (1, 164) = 37.2, p \leq 0.01, \eta_p^2 = 0.19]\), demonstrating shorter RT at post-test \((501.4 \pm 9.3 \text{ ms})\) compared to pre-test \((560.6 \pm 10.9 \text{ ms})\). In addition, a main effect of Sex was observed \([F (1, 164) = 7.3, p \leq 0.01, \eta_p^2 = 0.04]\), demonstrating shorter RT for males \((507.0 \pm 12.7 \text{ ms})\) compared to females \((555.1 \pm 12.4 \text{ ms})\). The omnibus analysis for post-error accuracy revealed a main effect of Time \([F (1, 164) = 8.3, p \leq 0.01, \eta_p^2 = 0.05]\) that was superseded by a Group \(\times\) Time interaction \([F (1, 164) = 3.9, p = 0.05, \eta_p^2 = 0.02]\). Decomposition of the interaction revealed increase accuracy at post-test \((82.2 \pm 1.6\%)\) compared to pre-test \((74.7 \pm 1.9\%)\), but only for the treatment group, \(t (85) = 3.4, p \leq 0.01\), with no such trend observed for the wait-list control group, \(t (85) = 0.7, p = 0.51\) (pre-test: \(78.2 \pm 1.8\%,\) post-test: \(79.6 \pm 1.9\%)\).

Relation of Fitness Change to ERPs

Planned correlations were performed to evaluate the relation of fitness change to cognitive and ERP changes observed in the treatment group. The results demonstrate that increasing fitness in the treatment group was positively associated with reductions in N2 amplitude from pre- to post-test for all children \((r = .21, p = 0.05)\). Further decomposition revealed selective findings only for females \((r = .31, p = 0.04)\), with no such relation observed for males \((r = .11, p = 0.49);\) see Figure 8A) as well as males \((r = .08, p = 0.64)\) and females \((r = .12, p = 0.45)\) in the wait-list group (see Figure 8B). No further main effects were observed for behavior and ERP results \((r_s \leq .18, p \geq 0.09)\).
Figure 8. Scatter plots for bivariate correlations between change in cardiorespiratory fitness and change in N2 mean amplitude separated by intervention (A) and wait-list groups (B).
Chapter 5 – DISCUSSION

The present dissertation demonstrated that a 9-month physical activity intervention significantly improved behavioral indices of inhibitory control in preadolescent children. Additional neuroelectric findings demonstrated sexual dimorphic facilitation in error processing networks and conflict adaptation selective for females. Specifically, children in the intervention demonstrated improvements in flanker accuracy and post-error accuracy performance from pre- to post-test compared to the wait-list children, which remained following adjustments for fitness level and IQ. Additionally, this dissertation is the first to report that such behavioral benefits are afforded to all children regardless of individual differences associated with SES and sex. Additionally, underlying neuroelectric patterns demonstrated sexual selective modulation of neural networks associated with error processing and conflict adaptation specific for females. That is, only females in the treatment group demonstrated decreased N2 amplitude while females in the wait-list group demonstrated increased ERN amplitude from pre- to post-test. Together, the results of the present dissertation have considerable implications for promoting organized physical activity interventions for all children, regardless of SES or sex, with further implications for sexual selective benefits to performance monitoring in preadolescent females.

Baseline Individual Differences

Baseline results demonstrated decreased incongruent RT, post-error RT, and ERN amplitude for females compared to males. These results replicate prior work revealing unique sexual dimorphic differences in performance monitoring strategies (Der & Deary, 2006; Lahat, Lamm, Chronis-Tuscano, Pine, Henderson et al., 2014; Larson, South, & Clayson, 2010). Specifically, slowing of RT among females, especially following commission errors, suggests a greater degree of up-regulation in cognitive control mechanisms (Carter & van Veen, 2007;
Gehring & Fencsik, 2001) in order to ‘buy time’ necessary to regulate subsequent performance. However, RT slowing did not improve performance as no differences were observed for accuracy measures between males and females. One possibility might relate to differences in compensatory neural patterns that facilitate performance adjustments. Notably, the ERN results suggest that females are more responsive (i.e., neural efficiency) to erroneous events in the environment as evidenced by a reduction in conflict threshold for error signaling in neural networks mediating cognitive control. Conversely, males appear to compensate for more speeded responding by necessitating the up-regulation and implementation of cognitive control error-monitoring systems as evidence by increase ERN amplitude compared to females (Gehring et al., 2012; Gehring & Knight, 2000). It could be speculated that such differences are due to developmental differences given earlier development is typical in females. However, prior research demonstrates similar ERN differences in adults (Crowley, Crutcher, Bailey, Lejuez, & Mayes, 2009; Davies, Segalowitz, & Gavin, 2004; Larson et al., 2010) with fMRI investigations further demonstrating reduced ACC activity (significant contributing neural generator of the ERN) in females compared to males (Li, Huang, Constable, & Sinha, 2006). Thus, the observed sexual dimorphic differences in RT and ERN suggest that males and females, at an early age, develop separate and unique performance monitoring strategies necessary for cognitive control operations that remain into adulthood.

Contrary to the a priori hypothesis, no significant differences associated with SES were observed for behavior and ERP outcomes. One possibility for the lack of significant findings might be the matching procedure, which controlled for fitness and IQ across higher- and lower-SES groups. Given that prior investigations demonstrate cognitive differences associated with fitness, the present results for SES may have been attenuated by systematically controlling for
such factors. Consonant with this assumption, observations prior to matching demonstrated that higher-SES children were also significantly greater aerobic capacity (28.9 ± 2.0%) compared to lower-SES children (20.7 ± 2.2%). As such, these findings have considerable implications regarding future cross-sectional comparisons interested in cognitive differences associated with SES and the importance of fitness as a potential moderating factor.

**Weight Status and Aerobic Fitness**

Although BMI did not reveal any significant changes over time, cardiorespiratory fitness improved to a greater degree for the intervention group (6%) compared to the wait-list group (<1%) from pre- to post-test. These results highlight the fidelity of the FITKids program for successfully improving physiological markers of cardiorespiratory health in preadolescent children. Further, fitness improvements were observed for all children in the intervention regardless of sex or SES. These findings are encouraging for future physical activity interventions given that females and lower-SES children demonstrate greater inactivity trends that remain into adulthood (Brodersen, Steptoe, Boniface, Wardle, & Hillsdon, 2007). Therefore, physical activity interventions aimed at preadolescent youth may be an effective means for not only improving cardiorespiratory health in all children, but also for providing occasions for facilitating lifetime habits relative to active behaviors among children who need it most.

**Inhibitory Control**

The present dissertation extends prior investigations such that greater improvements in flanker accuracy were observed for children in the treatment group compared to the wait-list group (Chaddock-Heyman et al., 2013; Hillman et al., 2014). These findings add to the growing literature by demonstrating cognitive health benefits associated with daily physical activity participation. The results further demonstrate that such benefits are afforded to all children
regardless of sex or SES. These patterns of improved cognitive performance, taken together with fitness changes, advocate the importance of interventions aimed at all preadolescent children, both males and females as well as socially disadvantaged children, not only for overall health but also for improving attentional faculties necessary for effective learning in a classroom environment.

Examination of ERP analysis demonstrated no differences in P3 amplitude or latency for the treatment group compared to the wait-list group, and only a marginal increase in amplitude from pre- to post-test for females in the treatment group. These results appear inconsistent with prior work (Hillman et al., 2014). That is, Hillman and colleagues demonstrated decreased P3 latency and increased P3 amplitude from pre- to post-test for the treatment group with no such effects observed for the wait-list group. One possibility for the observed differences might be the matching criteria that not only controlled for fitness, SES and IQ across groups, but further excluded a demographic consisting of predominantly higher-SES (~80%) children. Prior research suggests that higher-SES children demonstrate greater maturational development in neuroelectric indices of cognitive control and greater recruitment of pre-frontal attentional mechanisms (Kishiyama et al., 2009; Otero, 1997), whereas lower-SES children demonstrate left-frontal hypoactivity (Hermann & Guadagno, 1997) and greater activation for unattended stimuli (Stevens et al., 2009). These and other investigations (see Hackman & Farah, 2008 for review) clearly demonstrate dimorphic ERP patterns associated with SES. As such, the matching procedure may have arbitrarily removed a significant sample of higher-SES children, possibly contributing to the observed differences. However, the research is limited regarding SES and fitness interactions on cognition. Future research aimed at elucidating such effects should
incorporate methods to assess individual differences and the potential modulating effect of such factors on important outcome variables related to cognition and brain health.

Another possibility might be methodological differences in the reduction of ERP data. For example, the present dissertation utilized an independent component analysis (ICA) for detection and removal of eye-blink artifact. Recent investigations suggest that ICA methods are just as effective, if not more succinct, at removing eye-blink artifact compared to more traditional methods (Ghaderi, Kim, & Kirchner, 2014; Hoffmann & Falkenstein, 2008; Lee, Girolami, & Sejnowski, 1999). Although the superiority of one method compared to the multitude of available methods is certainly a matter of debate, and beyond the scope of the present dissertation, it should be noted that ERP morphological differences are evident between the two investigations such that P3 amplitude at CPz revealed an ~8 µV difference. However, without further research assessing the reliability of various reduction techniques it is difficult to conclude the superiority of conflicting methods, especially in young children. Regardless, it is possible that small nuances in ERP reduction techniques observed between these investigations contribute to the observed P3 differences. As such, it is vital for future ERP research in this domain to carefully consider appropriate reduction techniques and provide sufficient methodological detail in order to facilitate replication and extension of novel ERP research ideas.

**Error Processing and Conflict Adaptation**

A significant contribution of the present dissertation are the results demonstrating sexual selective modulation of error processing networks in relation to a physical activity intervention. Specifically, N2 results demonstrate a reduction in amplitude from pre- to post-test only for females in the treatment group. Additionally, planned correlation analyses further demonstrated a dose-response relation such that greater increases in fitness were related to greater reductions in
N2 amplitude, but only for females in the treatment group. These data are broadly similar to previous investigations in children demonstrating healthy developmental processes as a result of participating in an exercise intervention (Chaddock-Heyman et al., 2013). Specifically, Chaddock-Heyman and colleagues (2013) demonstrated an adult-like decrease in activation within the anterior prefrontal brain region (part of the cognitive control network) for children who participated in a physical activity intervention. Together, these data provide compelling evidence suggesting that improvement in fitness through daily physical activity facilitates adjustments in conflict adaptation that are reflective of healthy neurocognitive development in female children.

The modulatory patterns of the ERN provide further support for healthy brain development approach. That is, the treatment group maintained ERN amplitude and demonstrated greater improvements in post-error accuracy from pre- to post-test compared to the wait-list group. Conversely, ERN amplitude for females in the wait-list group increased, with no such effect observed for males. However, when compared to the treatment group, this directionality suggests a maladaptive adjustment in neural efficiency given that post-error behavior did not change. Furthermore, taken together with pre-test results suggesting that females demonstrate greater neural efficiency, the wait-list results suggest that failure to engage in daily physical activity routines may be indicative of atypical development of performance monitoring mechanisms selective for females. Interestingly, previous research investigating ERN as a biomarker of abnormal personality and psychological disorders revealed larger ERN in children and adolescents with symptoms of obsessive-compulsive disorder (Hajcak & Simons, 2002; Hajcak & Simons, 2008; Santesso, Segalowitz, & Schmidt, 2006) and anxiety (Ladouceur, Dahl, Birmaher, Axelson, & Ryan, 2006; Meyer, Weinberg, Klein, & Hajcak, 2011) compared to
healthy cohorts. Thus, although highly speculative, the present results suggest that inactivity may facilitate atypical cognitive and psychological development selective for female populations. Clearly, this is an area of research that warrants further consideration as to how inactivity behavior might influence abnormal development in brain and behavior especially in young children.

Mechanisms

Collectively, these results have implications for the importance of regular physical activity on brain health in preadolescent children, and further provide novel links for future research aimed at elucidating mechanisms of physical activity effects on brain and cognition. That is, prior research demonstrates a positive relation between increased brain derived neurotrophic factors and insulin like growth factor-1 (IGF-1) with increases in chronic physical activity (see Knaepen, Goekint, Heyman, & Meeusen, 2010 for review). These neural processes facilitate neuronal proliferation and cell survival in various brain structures associated with cognitive control and memory operations (van Praag et al., 1999). Interestingly, estradiol levels (i.e., estrogen) also exert a neuroprotective effect and promote neuronal regeneration in a similar manner to IGF-1 (Azcoitia, Sierra, & Garcia-Segura 1999). Thus, this co-expression within the same neural cells suggests coordinated actions between these two factors (Azcoitia et al., 1999). Furthermore, the beneficial effects of physical activity have been shown to rely on such coordinated actions. That is, physical activity effects on the up-regulation of neurotrophic factors are reduced in the absence of estrogen (Berchtold, Kesslak, Pike, Adlard, & Cotman, 2001). Therefore, estrogen appears to play a key role in the modulation and expression of these healthy brain processes. Furthermore, prior research indicates that prepubertal females (of a similar age to the present investigation) have significantly higher levels of estrogen compared to age-
matched males (Courant, Aksglaede, Antignac, Monteau, Sorensen et al., 2010). Estrogen, therefore, may be a common variable related to sexual dimorphic patterns in error-processing and conflict adaptation observed in the present dissertation. Thus, although circulating sex hormones were not measured, future research should consider assessing hormonal changes in relation to physical activity and cognitive performance.

Another possible mechanism underlying these physical activity induced enhancements in performance monitoring may be gender socialization patterns and gender stereotype. Specifically, prior research reveals sexual dimorphism in parental childcare schemas. These patterns are typically observed in Western cultures and are evident as early as infancy (Dedovic, Wadiwalla, Engert, & Pruessner, 2009; Ruble, Greulich, Pomerantz, & Gochberg, 1993). For example, one study had female guardians of 11-month old infants adjust a walkway ramp to an estimated safe slope for their infant to successfully crawl up and down without falling or sliding. Results revealed that mothers tended to overestimated slope angle for male infants and underestimated slope angle for females (Mondschein, Adolph, & Tamis-LeMonda, 2000). These and other data (Ruble et al., 1993) demonstrate the unique gender socialization patterns that differentiate expectations regarding male and female behavior at an early age. As such, some researchers attribute these socialization effects to sex differences observed later in life regarding the perception of threatening or stressful environments (Dedovic et al., 2009; Stroud, Salovey, & Epel, 2002), emotional reactivity to unpleasant events (Kring & Gordon, 1998), and increased rate of anxiety and depression in females compared to males (Sachs-ericsson & Ciarlo, 2000). As such, these dimorphic socialization patterns might have significant implication for the observed differences in the present dissertation. That is, daily physical activity facilitates cortical and subcortical processes underlying performance-monitoring behaviors that may be utilized to a
greater degree by females as a result of the above-mentioned socialization effects. However, no prior research has investigated sexual dimorphic socialization effects on brain and cognition, thus, additional research is warranted in this domain.

**Conclusions**

Given the lack of physical activity interventions, particularly in youth, there remains untapped possibilities for isolating unique individual difference factors that potentially alter cognition and brain health associated with daily physical activity participation. Further, the extent to which these results are observed in other domains of cognition as well as across developmental age groups remains unknown until further investigations pursue this course of study. As such, certain limitations are worth noting. Most importantly, a non-active control group was not utilized as part of the intervention. That is, it is difficult to attribute the observed effects in inhibitory control and performance monitoring to physical activity while other factors were present including social interaction, the educational component, and continual positive affirmation from adult figures. Some of these factors have been shown to have a positive effect on psychological well-being and self-efficacy and could certainly influence the outcome measures of interest. Furthermore, a developmental perspective may provide additional insight into the cognitive response to physical activity interventions. Specifically, the age range was restricted to 8 and 9-year-old children. Future research could benefit by the inclusion of additional age groups in the study design.

The findings of the present dissertation provide further evidence for the utility of physical activity interventions as a means of facilitating healthy cognitive development in young children, with selective effects facilitating performance monitoring in females. Collectively, the results substantiate organized active breaks encompassing classroom learning, and further demonstrate
the importance of such interventions on individuals who are characterized by unique biological and environmental differences. Therefore, if the goal of physical activity research is to understand the populations that will benefit most, and how best to implement physical activity in school settings, then accounting for individual differences should be a considerable factor in future research aimed at improving brain health and functioning in school aged children.
REFERENCES


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