ASSOCIATIONS BETWEEN PHYSICAL ACTIVITY, MOTOR SKILLS, EXECUTIVE FUNCTION AND EEG IN PRESCHOOLERS

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ABSTRACT

According to the embodiment theory of development, motor and cognitive development co-occur in early childhood (Gottwald et al., 2016). An abundance of research has especially focused on the co-development of motor skills and executive functioning (Spedden et al., 2017). Executive function refers to a cognitive process that involves the combination of working memory, inhibitory control, and cognitive flexibility and is closely related to attention and problem solving (Diamond & Lee, 2011). Executive function has also been related to electrophysiological data in preschool aged children (e.g., Broomell & Bell, 2018). However, little is known about how physical activity may impact executive function as well as the electrophysiological mechanisms underlying these changes cognition. A systematic review of the literature proposed the idea that the reason physical activity impacts executive functioning skills is that most physical activity involves complex motor tasks (Best, 2010). Other researchers have focused on the influence of physical activity on brain activation as the potential mechanism for improved executive function (Best, 2010; Best & Miller, 2010). There is a lack of consensus on how and why executive function, physical activity, frontal activation, and motor skills relate as well as limited understanding in the literature on how physical activity and motor skills may impact the development of executive function, especially in lower socioeconomic populations. This study aimed to gain insight into the relationship among these variables and determine what mechanisms may be responsible for gains in executive function during this age range. Preschool participants (N=66) were recruited from Head Start programs located in Jackson and Haywood counties. Parents who consented completed the Pre-PAQ, Vineland-3, and a demographic questionnaire while teachers completed the BRIEF-P in February of 2022. In May of 2022, preschool participant’s completed executive function tasks (Dimensional Change Card Sort, Day/Night, and Head-Toes-Knees-Shoulders), and electrophysiological data was collected. Bivariate correlations and hierarchical linear regressions were conducted using the data collected to determine the associations among frontal brain activity, physical activity, EF skills, and motor skills. Teacher-reported BRIEF-P subscales were positively and significantly associated with each other, which suggests BRIEF-P captures a unitary conceptualization of EF. Parent-reported Vineland-3 fine and gross motor skills were also positively and significantly correlated with each other as were the teacher-reported BRIEF-P subscales. EEG alpha at sites F4, F7, and F8 collected during baseline were all positively and significantly correlated. However, parent-report and teacher-report did not significantly predict preschool participant’s laboratory performance or accelerometer, with the exception of the Pre-PAQ predicting Head-Toes-Knees-Shoulders scores. This may be due to Head-Toes-Knees-Shoulders being a motor-based measure of EF. Participant’s performance on laboratory measures of executive were not significantly associated with each other or with EEG data. EEG data did not moderate the relationship between gross motor skills and observed laboratory task performance nor time spend in moderate-to-vigorous physical activity. Based on these findings, study limitations and future directions are discussed.

CHAPTER ONE: INTRODUCTION

According to the embodied theory of development, motor and cognitive development co-occur in early childhood (Gottwald et al., 2016). There are several definitions of embodied cognition, however, the underlying theme of the theory is that sensorimotor input shapes cognitive processing (Shapiro, 2014; Wilson, 2002; Wilson & Golonka 2013). Research investigating the impact of sensorimotor input varies from motor simulation of word meaning and phonological similarities influence on language processing (Wellsby & Pexman, 2014, Wilson, 2002) to physical activity influencing spatial reasoning (Voyer & Jansen, 2017) and locomotion's influence on memory (Gottwald et al., 2016; Herbert et al., 2007; Needham & Libertus, 2011). For instance, Gottwald and colleagues (2016) investigated the bidirectional relationship with prospective motor control and executive functioning in 53 infants aged 18-months. They found that infant's performance on simple inhibition and working memory were related to prospective motor control as measured by peak velocity of the first reaching movement (Gottwald et al., 2016). The preschool years are a time marked by significant and rapid co-development of motor and cognitive skills, and therefore, of particular interest in the embodied cognition literature (Vanhala et al., 2023; Veljkovic et al., 2021). An abundance of embodied cognition research has focused on the co-development of motor skills and executive functioning (Spedden et al., 2017; Gandotra et al., 2021). Executive function (EF) refers to a cognitive process that involves the combination of working memory, inhibitory control, and cognitive flexibility and is closely related to attention and problem-solving (Diamond & Lee, 2011). Findings suggest that the components of EF (e.g., inhibition, cognitive flexibility, working memory) can be measured in preschool populations (Lerner & Lonigan, 2014). EF has also been linked to brain electrical activity, specifically higher electroencephalogram (EEG) frontal alpha power in preschool-aged children (e.g., Broomell & Bell, 2017; Broomell et al., 2019; Hofstee et al., 2022; Whedon et al., 2020; Wolfe & Bell, 2014). However, research suggests that specific constructs are associated with specific brain regions (e.g., cognitive flexibility and the right anterior prefrontal cortex (PFC); Bidzan-Bluma & Lipowska, 2018), and physical activity may differentially influence these EF components (Bidzan-Bluma & Lipowska, 2018; Palmer et al., 2013). EF is associated with motor skills (e.g., Cook et al., 2019) and level of physical activity in both children (e.g., Carson et al., 2016) and adults (e.g., Sanchez-Lopez et al., 2018).

However, little is known about the neural mechanisms underlying the impact of physical activity on measures of EF. Within the theory of embodied cognition, there are proposals that increased respiration impacts cognitive processes by impacting neural synchronization (Varga & Heck, 2017). Specifically, respiration is indirectly related to blood flow changes in the brain via heart-rate variability and/or respiration has been shown to modulate high-frequency neuronal oscillations (e.g., gamma, delta) via sensory input from the olfactory bulb (Varga & Heck, 2017). Others suggest a more bottom-up approach with the activation of the cerebellum, which is a part of the hindbrain involved in coordination of muscle movements, impacting cognitive process selection in the cerebral cortex (Koziol et al., 2011). Other ideas about the underlying biological mechanisms that physical activity impacts EF are that physical activity increases brain-derived neurotropic factor (BDNF), which impacts neuroplasticity, or that physical activity upregulates brain neurotransmitters (Latomme et al., 2022). Specifically, increased aerobic exercise has been linked to increased transmission opportunities for the neurochemical precursors of neurotransmitters like serotonin to cross the blood-brain barrier (Heijnen et al, 2016), which impact executive control (Wiebe & Karbach, 2018).

A further biological mechanism of interest in how motor and physical activity impacts cognitive processes is frontal brain electrophysiological activation. Physical activity can impact frontal brain activity (Best, 2010; Best & Miller, 2010). There is also literature suggesting that cognitively demanding exercise more strongly impacts frontal activation (Best, 2010). It is possible that there is a bidirectional relationship between brain activity and physical activity. Interestingly, increased localized frontal brain activation occurs as individuals age and is associated with increased EF task performance in children (Bell & Wolfe, 2007; Best, 2010). Some studies found that engagement in physical activity improved scores on EF tasks related to inhibition and working memory, and were accompanied by increased frontal activation (Best, 2010). Physical activity that involves complex motor tasks also has more of an impact on EF skills (Best & Miller, 2010). More information is needed to determine how motor skills and physical activity impact the development of EF, and whether there is observable brain activation in conjunction with both cognitive and motor development.

Diamond and Lee (2012) suggest that physical activities like sports might impact EF more than non-goal-oriented exercises as it involves cognitive processes like attention and working memory. There is a lack of consensus on how and why EF, levels of physical activity, frontal brain activity, and different motor skills (e.g., fine motor skills, gross motor skills, visuospatial motor skills) relate to each other. Additionally, there is limited understanding in the literature on how physical activity, fine, and gross motor skills may impact the development of EF, and if frontal brain activation is the mechanism by which it occurs. Based on the significant improvement of both motor (e.g., Gonzalez et al., 2019; Hellendorn et al., 2015) and EF (e.g., Malambo et al., 2022; Vanhala et al., 2023) skills, and the rapid development of the PFC (Diamond, 2002; Swinger et al., 2011) during the preschool years, a preschool population is ideal for examining how these factors are associated with one another and physical activity. This study aims to gain insight into the relationship among these variables, specifically EF, average time spent in moderate-to-vigorous physical activity each day, frontal lobe activation, fine motor skills, and gross motor skills in a preschool population.

Executive function and electrophysiological data

To start, associations between EF and frontal lobe activity are not fully understood. Frontal lobe activation can be measured as metabolic activity, oxygenation levels at the different frontal regions, or electrical activity depending on the neuroimaging techniques used in the study. It is difficult to parse out the relationship between EF skills and brain activity, especially when different neuroimaging techniques are used to assess the biological underpinnings of EF. For example, some studies focus on using EEG (Cuevas et al., 2012; Sanchez-Lopez et al., 2018; Swingler et al., 2011), while others focus on functional magnetic resonance imaging (fMRI; Best, 2010; Chaddock-Heyman et al., 2013; Ezekiel et al., 2013) and yet others still choose to investigate the possible mechanisms using near-infrared spectroscopy (NIRS; Moriguchi & Hiraki, 2013; Tsujimoto, 2008). EEG records electrical activity on an individual’s scalp (Cuevas et al., 2012; Fiske & Holmboe, 2019; Sanchez-Lopez et al., 2018; Swingler et al., 2011) while fMRI measures brain activity by tracking changes in blood flow (Best, 2010; Chaddock-Heyman et al., 2013; Ezekiel et al., 2013; Fiske & Holmboe, 2019) and NIRS measures brain activity by monitoring changes in oxygen saturation of cerebral tissue using near-infrared light (Moriguchi & Hiraki, 2013; Tsujimoto, 2008). Both fMRI and NIRS are hemodynamic neuroimaging techniques that provide information about metabolic activity in localized tissue regions (Fiske & Holmboe, 2019). For the purposes of this study, frontal activation refers to electrical activity measured using an electroencephalogram (EEG). EEG is more portable, less sensitive to interference from motion, and provides information about electrical brain activity (Cuevas et al., 2012; Fiske & Holmboe, 2019; Sanchez-Lopez et al., 2018; Swingler et al., 2011). Thus, EEG was used due to its portability to the preschool sites, and its robustness to motion meaning that if participants move around during data collection it is less likely than other which is another concern when working with preschool populations. Alpha power at frontal sites F3, F4, F7, and F8 were particularly relevant to this study because they are associated with the PFC. Alpha power is a measure of EEG magnitude, specifically associated with waking state, and represents the neural activity at a given scalp location (Broomell & Bell, 2017; Hofstee et al., 2022). More specifically, alpha power occurs at the 6 to 9 Hz frequency in infants and young children is the dominant frequency during this stage of life and is associated with mechanisms of cognitive control (Broomell & Bell, 2017; Hofstee et al., 2022). High alpha power at frontal cortex locations has been associated with EF and self-regulatory behaviors (Hofstee et al., 2022). Moreover, there are ambiguous findings regarding alpha power at frontal lobe sites preceding successful and unsuccessful performance on EF laboratory tasks (Broomell & Bell, 2017; Cuevas et al., 2012; Hofstee et al., 2022). For instance, some studies found increased alpha power was associated with successful performance on EF-related tasks while others found lower frontal alpha power was associated with sustained attention (Hofstee et al., 2022). Additionally, high alpha power is associated with behaivoral tasks and questionnaires, but not computer assessments or laboratory observations (Hofstee et al., 2022).

Alpha power can be measured at baseline in addition to during laboratory tasks (Hofstee et al., 2022; Wolfe & Bell, 2014). Alpha power at baseline has frequently been shown to be associated with higher brain maturation, which is related to better performance on EF-related tasks (Hofstee et al., 2022; Lo et al., 2013). It has also been utilized in research related to the impact of physical activity (Threadgill et al., 2020).

An additional complication to understanding electrophysiological mechanisms involved in EF are that individual differences may uniquely impact the electrophysiological mechanisms observed. The literature on electrophysiological mechanisms involved in EF suggests that potential individual differences outside of age can impact frontal activation, such as shyness (Wolfe & Bell, 2014). These individual differences can also influence whether alpha power increases or decreases from baseline to task (Wolfe & Bell, 2014). For example, children who had higher levels of alpha power in the medial frontal region from baseline to task for those that performed highly on multiple tasks associated with EF skills (e.g., Stroop-like tasks, day-night tasks, and a yes-no task), but in the group that performed low on EF tasks only the shy individuals demonstrated this same increase in alpha power while non-shy individuals did not (Wolfe & Bell, 2014). This finding demonstrates that frontal activation during EF tasks may not be uniform across individuals. It also suggests that individual differences may impact the effect of neural activity on EF task performance. Another cross-sectional study involving 43 4 to 6-year-old participants found that the 6-year-old participants had better response inhibition on a go\no-go task and exhibited higher alpha power on successful trials (Lo et al., 2013). Higher levels of alpha power during idea generation compared to retrieval interval is commonly thought to reflect inhibitory functions (Agnoli et al., 2020). Therefore, alpha power is worthy of further investigation in relation to EF development, especially regarding EF components like inhibition.

However, task-dependent frontal activation is not the only frontal activation associated with EF performance in child populations. Lo and colleagues (2013) found that 6-year-old participants demonstrated higher levels of power at baseline compared to their 5-year-old counterparts suggesting increased brain activity at the PFC on successful go/no-go task trials This indicates that significant development occurs between the ages of 5 and 6 in the brain areas associated with EF. Specifically, this study also found stronger power was associated with successful stop trials compared to unsuccessful stop trials (Lo et al., 2013). Significant improvement in EF-related cognitive abilities occurs during the ages of 3 and 7, but especially during the ages of 3 to 5 (Diamond, 2002). Based on both these observations, it is logical to hypothesize that there would also be observed differences in alpha power in a population of 3-year-olds to 5-year-olds that correlate with gains in EF.

Many of the studies conducted investigating EEG activity and measures of EF are cross-sectional. A recent systematic review reported robust evidence suggesting increased alpha power at baseline-to-task is associated with better performance on Stroop tasks in preschool-aged children (Bhavnani et al., 2021). Cross-sectional studies suggest differential EEG alpha power is associated with differential performance on the Dimensional Change Card Sort (DCCS) tasks, a measure of cognitive flexibility and inhibition, at different ages (Broomell & Bell, 2017; Moriguchi & Hiraki, 2013). The DCCS tests cognitive flexibility by requiring the participant to alternate between two ways of sorting the cards depending on if a border is present or not (Broomell & Bell, 2017; Moriguchi & Hiraki, 2013; Weibe & Karbach, 2018; Zelazo, 2006). Specifically, 5-year-olds and adults that performed well on both congruent and incongruent conditions on the DCCS task demonstrated significant activation in both the right and left inferior PFC whereas 3-year-olds that performed well on the congruent but not incongruent conditions did not exhibit significant activation in the right interior PFC (Moriguchi & Hiraki, 2013). This is important given that the literature suggests that several subregions of the PFC and parietal cortex are involved in EF, specifically those involved in the fronto-parietal network like the dorsolateral PFC, ventrolateral PFC, and posterior parietal cortex (Weibe & Karbach, 2018).

In work using EEG, there are few longitudinal studies examining EF (Cuevas et al., 2012). For instance, Cuevas and colleagues (2012) investigated frontal EEG, parent-reported inhibitory control, and laboratory performance on working memory tasks in participant prior to starting kindergarten to determine if they predicted EF skills in post-kindergarten. Cuevas and colleagues (2012) found that performance on these working memory tasks, parent-reported inhibitory control, and changes in medial frontal activity from baseline to task initiation at pre-kindergarten significantly predicted overall EF skills post-kindergarten. This suggests that significant EF development occurs during this stage and may be related to neurobiological mechanisms.

Many of these studies examined differences in cortical activity from baseline to task but did not investigate the predictive power of baseline EEG data alone. Baseline is imperative particularly in preschool populations as it reduces complications like motor movement that occur during laboratory tasks (Bell & Cuevas, 2012). Infant baseline EEG data has been found to predict EF skills in later childhood (Broomell et al., 2019). This suggests that baseline data is sufficient as a measure of electrophysiological mechanisms in the brain to predict cognitive ability. Baseline data can also be used to detect individual differences in emotional, cognitive, and motor skills (Bell & Cuevas, 2012). Resting-state EEG, another term for baseline, has demonstrated promise as a possible predictor of neurodivergence in preschool populations (Bhavnani et al., 2019). Therefore, this study used baseline EEG data as it may be sufficient in detecting differences and was appropriate for our population of interest, preschoolers.

There have been longitudinal studies investigating EEG activity's predictive power on later EF performance. For example, Kraybill and Bell (2013) found frontal power at 10 months predicted performance on EF tasks at 4-years-old as well as parent report of EF skills. A more recent longitudinal study investigating alpha power and inhibitory control from 10 months of age to 4-years-old in a sample of 364 children, found that frontal alpha power increased over time and was associated with better inhibitory control (Whedon et al., 2020). Gender may also influence development of EF skills and brain maturation. Another longitudinal study by Broomell and colleagues (2019) found that girls, who exhibited larger frontal power at 5-month-olds demonstrated greater preschool performance on EF tasks (e.g., visual search on the NEPSY-II, DCCS, and Pig\bull tasks). These studies corroborate findings from a review by Fiske and Holmboe (2019) that notes the PFC expands from 5 months to 8-years-old. Maturation of the PFC is characterized by myelination, synaptogenesis, and neuron proliferation in early childhood (Fiske & Holmboe, 2019). These structural changes in the PFC can be measured based on inferences from the previously mentioned electrophysiological measures of brain activity from changes in regional activation taken at different time points (e.g., EEG, fMRI, NIRs; Fiske & Holmboe, 2019). Specifically, relevant to this study is that in early childhood there is increased brain activation utilizing frontal region neural network that later becomes more specialized (Fiske & Holmboe, 2019). This is particularly relevant when investigating EF as a unitary construct versus its components of inhibition, working memory, and cognitive flexibility. Alpha power at frontal regions during baseline is the focus for this study and how it relates to better performance on lab measures of EF, gross and fine motor skills, and moderate-to-vigorous physical activity.

Executive function and physical activity

Research conducted with school-age children suggests a link between various types and intensities of physical activity and cognitive abilities (Bidzan-Bluma & Lipowska, 2018). For instance, Becker and colleagues (2018) found a curvilinear relationship between sport intensity and EF skills as assessed using the Tower of Hanoi task. This suggests that the relationship between physical activity and EF is impacted by the intensity of physical activity (Becker et al., 2018). However, Becker and colleagues (2018) found that there was a significant positive association between metabolic equivalent, which is a measure of energy expenditure during physical activity, and EF up to 25 metabolic equivalent intensity value. Important to this study, moderate-to-vigorous physical activity is between 2.9 and 9.3 metabolic equivalent intensity values (Becker et al., 2018). A systematic review noted that cross-sectional studies demonstrated that the intensity and regularity of various types of physical activity from aerobic fitness to sport engagement in later childhood and adolescence consistently relates to their performance on tasks assessing cognitive flexibility (Bidzan-Bluma & Lipowska, 2018). It is important to note that adolescence is another time of sensitive PFC development. Based on Bidzan-Bluma and Lipowska's (2018) findings, it is reasonable to conclude that persistent engagement in physical activity influences EF components. Therefore, it is possible that periods of significant PFC development, which are associated with EF skill development, may be particularly influenced by physical activity.

While most of the literature focuses on adults and older children, research does suggest that acute exercise can impact various aspects of cognitive function in preschool children (Palmer et al., 2013). However, the research is inconclusive as different measures and methodologies were used that measured various aspects of EF, which may impact results. For example, Palmer and colleagues (2013) investigated the impact of acute exercise on a measure of selective attention and response inhibition (e.g., Picture Deletion Task for Preschoolers) in 16 preschool children. Palmer and colleagues (2013) found that acute exercise impacted sustained attention but not response inhibition. Whereas Nieto-Lopez and colleagues (2020) found preschoolers' cardiorespiratory fitness, which is not a measure of physical activity but associated with regularity of engaging in aerobic exercise, significantly predicted their performance on the Flanker task, which measures response inhibition. This further supports the idea that consistent physical activity could influence EF development, particularly regarding inhibition. A recent study also found that for children with low aerobic fitness, time in moderate to vigorous physical activity predicted their performance on a Day-Night Stroop task, however, the same trend was not observed in children with high aerobic fitness (Becker & Nader, 2021). This suggests acute physical activity could impact EF performance. There is limited research investigating the longitudinal impacts of intensity, duration, and frequency of engagement in physical activity on EF (Carson et al., 2016) nor are there many studies investigating how frontal brain activity is related to this association, which will be explored in a later section.

Executive function and motor development

Research on the relationship and co-development of EF and different motor skills across the lifespan has been conducted in a multitude of cultures (Fang et al., 2017) and different age ranges (Musculus et al., 2021). Fang and colleagues (2017) investigated whether working memory, inhibitory control, and cognitive flexibility predicted performance on visual-motor integration, which involves the ability to process visual information and integrate it in such a way that it can be utilized via motor skills, tasks in 151 preschool children aged 4 to 6-years-old in China. They found that 4-years-olds' performance on working memory (self-ordered pointing task paradigm), inhibitory control (Day-Night Stroop task), and cognitive flexibility (DCCS) tasks had a significant effect on visual-motor integration scores on the Beery Developmental Test Package (Fang et al., 2017). Most interestingly, Fang and colleagues (2017) found that specific facets of EF were predictive of visual-motor integration skills at specific ages. For instance, scores on the Day-Night Stroop task significantly predicted visual-motor integration scores but only for 5-year-olds in the first 6 months of their fifth year whereas scores on the DCCS were most predictive for the 4-year-old participants and 6-year-old participants (Fang et al., 2017).

This suggests that Fang and colleagues' (2017) study found the components of EF mature at distinct stages, and may align with rapid maturation of the PFC during these years. While this study focused on visual-motor integration, it begs the question how other broader motor skills (e.g., gross and fine motor skills) are related to EF, especially different components at different ages. There have been other attempts to uncover these aspects of embodied cognition, including the creation of tasks such as the Activate Test for Embodied Cognition which was designed to assess EF, balance, coordination, and motor speed in school-aged population (Bell et al., 2021; Dillhoff et al., 2019). Based on these early attempts to measure EF and motor skills, this study too aims to identify the preschool years as a sensitive stage for EF and motor development that may be susceptible to environmental influences, such as physical activity.

Visual-motor integration skills are not the only motor skills that have demonstrated a connection with EF. Visual-motor integration involves both cognitive integration of visual-spatial perception and coordinated hand-eye movements whereas fine motor skills are defined as small muscle movements in the hands and gross motor skills are skills that involve large muscles and/or whole-body movement. There have been studies and reviews investigating gross and fine motor skills impact on other higher-order cognitive skills like language (Gonzalez et al., 2019;

Hellendoorn et al., 2015). For example, Hellendoorn and colleagues (2015) found that fine motor skills predicted language in a group of 21 children with autism and 29 children with developmental delays. Similar results were found in a systematic review by Gonzalez and colleagues (2019) that both gross and fine motor skills promote language development. However, there is limited research on the relationships between gross motor skills and EF, especially in low socioeconomic populations (Cook et al., 2019). This is imperative as socioeconomic status of parents has been shown to be associated with children's EF skills (Cook et al., 2019; Last et al., 2018; Lawson & Farah, 2017).

Cook and colleagues (2019) also found that gross motor skills assessed in the laboratory predicted performance on the Go/No-go task, a test of inhibition, and performance on the Mr. Ant task, a measure of working memory, in children belonging to low socioeconomic households in both rural and urban areas. This suggests that preschoolers belonging to low socioeconomic status may uniquely benefit from interventions that facilitate motor development. Gandotra and colleagues (2022) conducted a meta-analysis to examine the relationship between various motor skills and EF in typically developing children from ages 3 to 12. They found global motor skill ability was positively associated with EF (Gandotra et al., 2022), but analysis on gross motor specifically was limited. Other research on this topic has been conducted in adults. For instance, Spedden and colleagues (2017) found an association between performance on a complex gross motor task involving dynamic postural balance and performance on a Stroop-like task but only for older adults. This suggests that motor development may impact EF skills only at specific developmental time points. However, very few studies have investigated whether parent-reported motor skills are associated with performance on EF tasks. This is an important area of investigation given that often in clinical settings parent-report measures are used as a screener regarding concerns related to motor skill functioning.

Uncovering an association between gross motor skills and EF may also provide insight into atypical development in both areas that are seen in clinical populations (e.g., Attention-Deficit Hyperactivity Disorder (ADHD) and Autism Spectrum Disorder (ASD); Floris et al., 2016; Miranda et al., 2017, Yu et al., 2019). Motor skill deficits are considered an early indicator of ASD (Floris et al., 2016). Children with ADHD have also demonstrated deficiencies in motor skills (Ziereis & Jansen, 2015). This further demonstrates a possible connection between EF and motor skill in both typically developing and clinical populations. Zieres & Jansens (2015) found children with ADHD's performance on working memory tasks were positively related with their motor performance including tasks like catching, aiming, manual dexterity, and balance. Additionally, Hellendorn and colleagues (2015) found that children with ASD's performance on fine motor functioning was positively related to visuospatial cognition, object exploration, spatial exploration, and social orientation. It is important that this study further explore the relationship between EF and motor skills as it may be relevant for clinical populations, especially given that ASD and ADHD are often diagnosed in preschool and school-aged children.

Very few longitudinal studies have aimed to investigate EF and motor skills (MacDonald et al., 2016). MacDonald and colleagues (2016) collected data with a cohort of 92 3-year-olds to 5-year-olds in preschool from Fall to Spring semester with EF assessed at two time points using the Head-Toes-Knees-Shoulders and the Peabody Developmental Motor Scales, 2nd edition to capture visual-motor integration skills. They found an association between visual-motor integration and later EF skills (MacDonald et al., 2016). However, this finding did not persist when controlling for baseline EF skills (MacDonald et al., 2016). MacDonald and colleagues

(2016) attribute this finding to EF stability from Fall to Spring. This is contradictory to Fang and colleagues' (2017) findings of an association between EF and visual-motor integration. Because of this ambiguity, additional research is needed to determine how motor skills are associated with EF in a longitudinal capacity. This study aims to investigate if both parent-reported fine and gross motor skills in early Spring predict later laboratory performance on EF tasks show, especially whether they are similar findings to MacDonald and colleagues (2016) or Fang and colleagues (2017). Fine and gross motor skills are of interest as they have not been investigated as thoroughly as visual-motor integration and are broader measures of motor skills. A systematic review suggested that there is a connection between EF skills and visual-motor integration in preschool populations, but this may be due to method of measurement (McClelland & Cameron, 2019). This is important to consider as motor-based measures of EF (e.g., Head-Toes-Knees-Shoulders task) may be more strongly associated with children's gross motor skills but not fine motor skills compared to EF tasks that require less advanced motor skill competence (e.g., Day/night task). Smith and colleagues (2022) conducted a cross-sectional study that found children between the ages of 8 and 12 demonstrated different initiation and movement times on a flanker task, and children made more errors compared to adult participants. This finding demonstrates that not only are there developmental differences in response inhibition performance but also that motor differences exist and could impact performance on EF tasks that are motor based. The current study aims to include both more motor-focused EF tasks, as well as those that require less developed motor skills to complete and assess their associations with parent-reported fine and gross motor skills.

Executive function, physical activity, and motor development

Based on the previous sections, further investigation is warranted on the impact of various motor skills and time spent in moderate-to-vigorous physical activity in relation to EF, especially on whether motor skills and physical activity are related to EF via an influence on frontal EEG. Rudd and colleagues (2019) note that motor learning in physical education settings can improve children's EF skills. This suggests that there may be association in which physical activity and motor skills work in tandem to influence EF skills. There is limited literature integrating the impact of physical activity on both EF and motor skills, despite the reasonable theoretical justification for associations between these constructs in preschool children (Cook et al., 2019). School-age children that engaged in either rhythmic or regular physical education program for 12 weeks found that both groups of children demonstrated increased balance and performance on a Flanker task after the physical education program (Vazou et al., 2020). While this study demonstrates connections among the aforementioned variables, it fails to consider whether the physical activity itself or general maturation was responsible for gains in EF, balance, and gross motor skill (Vazou et al., 2020). Furthermore, it fails to consider the longitudinal development of EF skills for preschool-aged children and focuses on a specific intervention of physical activity instead of the potential impact of consistent physical activity engagement on the development of EF and motor skills.

However, there is a lack of consensus in the literature on whether physical activity improves both motor skills and EF, or even if physical activity precedes motor ability. For instance, school-aged children with ADHD were assigned to either a controlled, structured physical activity aimed at improving motor skills, or an unfocused physical activity, then an investigation of their motor skills and EF pre- and post-intervention were assessed (Ziereis & Jansen, 2015). Interestingly, participants in both physical activity interventions showed significant improvements in digit span, a measure of working memory, but not any aspect of motor skills (Ziereis & Jansen, 2015).

Electrophysiological data and physical activity

Few studies investigating the relationship between brain activity and physical activity have been conducted. One study found increased frontal asymmetry ratios when comparing school-aged boys classified as high in physical activity as determined by Movement Skills Assessment to those determined to be in a low physical activity group (Lin, 2007). A more recent study also found a smaller theta alpha ratio for children with ADHD that exhibited higher physical fitness compared to those with lower physical fitness (Huang et al., 2015). Larger theta/alpha ratios are associated with reduced EF skills due to hypoarousal, thus the findings suggest that engagement in physical activity may improve EF via increased alpha power (Huang et al., 2015). These findings strengthen the idea that physical activity impacts brain electrical activity. Because of these observed associations in frontal activity and associations with EF task performance, further investigation is warranted to determine if differential patterns of frontal activation are associated with physical activity especially in more diverse participant samples. Specifically, whether associations between time spent in moderate-to-vigorous physical activity will show positive associations with alpha power at frontal regions in preschool aged children.

Electrophysiological data and motor development

Connections between brain activity and motor skills have been made as early as infancy (Bell & Fox, 1997; Gonzalez et al., 2016; Nishiyori et al., 2021; Xiao et al., 2016). For instance, Bell and Fox (1997) found that 8-month-olds with 1 to 4 weeks of crawling exhibited increase power at medial and lateral frontal and parietal regions. However, there is a lack of consensus on this pattern, especially in clinical populations. Nishiyori and colleagues (2021) compared neural activation at baseline at sites C3, C4, and CZ to both parent-report of motor ability using Bayley Scales and a coded laboratory observation of motor ability of infant grasping in lab. Specifically, Nishiyori and colleagues (2021) compared preterm to typically developing infants. Their results suggest an increasing trend of alpha power and age but no predictive value of any motor variable on EEG activation in preterm infants which differs from the consistent finding that typically developing infants exhibited increased baseline alpha band power (Nishiyori et al., 2021). This is contrary to Xiao and colleagues (2016) finding that resting-state alpha band increased weeks preceding crawling in similar aged, typically developing infants. In slightly older populations of infants compared to adults, Meyer and colleagues (2016) found that regarding motor processing, there was significant overall suppression of Beta-power in adults compared to 14-month-olds.

In addition to data at baseline, there is further electrophysiological evidence linking motor skills with frontal lobe activation (Bootsma et al., 2021; Kao et al., 2022; Wong et al., 2014). In adult populations, decreased frontal activation was observed during task completion (Wong et al., 2014). Similarly. in a preschool population, coordination and dexterity were positively associated with a great upper alpha event-related desynchronization, which indicates decreased activation at onset of engaging in the motor task, between 700 and 1000 milliseconds following stimulus onset after controlling for age and non-aerobic fitness (Kao et al., 2022). This shows that frontal brain activity relates to EF skills across ages. Comparing young adults to older adults, decreases in motor performance was accompanied by more bilateral activity (Bootsma et al., 2021). These task-dependent EEG recordings differ from baseline suggesting a decrease in activity at onset of a motor-based task. However, more information is needed to determine how power at resting-state baseline might provide resources for motor task completion. Taken together, all these studies demonstrate that motor skills are indeed associated with brain activity, and that the link between motor skills and brain activity may be influenced by age. Yet, it also demonstrates the need for clarity on the link between neural activity and motor skill development.

Electrophysiological data, motor development, and physical activity

Given what is known about frontal lobe activity, it is reasonable that cognitive and motor development co-occur as there is a close structural interconnection between the PFC, which relates to EF skills, and the premotor cortex, which relates to motor skills (Diamond, 2000). Along with these cerebral regions, there is a suggestion that the maturation of the cerebellum is also often involved in the co-development of motor and cognitive skills (Diamond, 2000; Koizol et al., 2012). The structural development of these cerebral and subcortical regions in conjunction with the psychological constructions of cognition and motor skill is an apt example of the embodied theory of cognition. It demonstrates a connection between neural activity and behavioral performance. Consider one of the earliest conceptualizations of embodiment theory of cognition that “states of the body modify states of the mind” (Wilson & Golonka, 2013) in a simplified way, this asserts that interactions of the body can impact cognitive constructs. This suggests that an investigation into bodily interactions, such as physical activity, on behavioral responses and electrophysiological mechanisms is warranted.

Studies that investigate electrophysiological data in accordance with motor development and physical activity typically only investigate event-related potentials (ERPs), such as N2 components and P3 waves (Kao et al., 2021; Hseih et al., 2018), which differs from baseline. ERPs involve measuring brain electrical activity on the scalp after the presentation of experimental stimuli (Kao et al., 2021; Hseih et al., 2018). Kao and colleagues (2021) found positive associations among motor competence scores, physical fitness, and task performance.

They also found upper alpha ERP mediated the relationship between motor competence and response time on tasks (Kao et al., 2021). This suggests that electrical activation may be the mechanism by which motor competence impacts EF task performance. Specifically, Kao and colleagues (2021) suggest that the role of attentional process after presentation of a stimulus as measured by the upper alpha ERP desynchronization is the mechanism by which fitness and motor competence influence EF task performance. Another study found that school-age children who engaged in more physical activity demonstrated shorter response times and greater accuracy as well as larger P3 amplitude, which is a part of the ERP that is a positive deflection occurring 300 to 1000 milliseconds after stimulus presentation, during task completion (Hseih et al., 2018). While these studies establish associations among physical activity, motor skills, and electrophysiological activation, it only examines frontal lobe activation during task completion. Therefore, further investigation is warranted of continuous EEG power regardless of presentation of stimuli and its association with physical activity and motor skills.

There is one study that investigated resting-state EEG, motor competence, and physical activity (Yu et al., 2019). Specifically, they found that motor competence moderated the relationship between moderate to vigorous physical activity and resting-state EEG as measured by theta to beta ratio in school-aged children with ADHD (Yu et al., 2019). The study found higher theta to beta ratio is associated with inattention and impaired cognitive processing (Yu et al., 2019). Based on this finding, it is possible that time spent in moderate to vigorous physical activity will only impact electrophysiological brain activity for those with reduced motor competence.

Executive function, physical activity, and electrophysiological data

Most studies investigated connections among physical activity, EF, and electrophysiological brain activity involve school-aged children (Arabi et al., 2023; Chang et al., 2012; Chaddock-Heyman et al., 2013; Davis et al., 2011; Kim & So, 2015) to adolescents (Cox et al., 2020) and adults (Sanchez-Lopez et al., 2018). For instance, Hseih and colleagues (2018) found that the children who engaged in more physical activity demonstrated larger positive slow wave amplitudes and better response accuracy. Chaddock-Heyman and colleagues (2013) found that children in the physical activity group demonstrated improved performance on the Flanker task but decreased brain activation in the right anterior PFC. This may suggest that children who engage in more physical activity might demonstrate lower activation in one hemisphere and higher activation in the other hemisphere or in other words frontal asymmetry. Other research has examined frontal asymmetry as a marker of the impact of physical activity on EF. For instance, Hyodo and colleagues (2015) found that older men who engaged in an acute, aerobic exercise showed increased activation in the left dorsolateral PFC and shorter Stroop time. Additionally, in a young adult population greater self-reported engagement in moderate and vigorous physical activity was associated with great left frontal lobe activation (Threadgill et al., 2020). Increased bilateral activation in the frontal cortex and a 3.8-point increase on performance on an EF task has also been demonstrated in child populations after engaging in an exercise regimen (Davis et al., 2011). This suggests that frontal asymmetry may be important across ages.

Aside from frontal asymmetry, the literature also demonstrates differences in other aspects of brain activation in conjunction with performance on EF tasks and post-engagement in exercise. For instance, a cross-sectional study conducted with 26 healthy kindergarten children found children assigned to a moderately intense soccer program demonstrated improved performance on incongruent trials of the Flanker task and larger P3 amplitude in central and parietal cortices compared to the frontal cortex (Chang et al., 2012). This differs from other studies that found positive associations in a kindergarten population between EF performance and activation at sites Fp1, F3, and C4 after engaging in a prolonged exercise program (Kim & So, 2015). Likewise, another study found positive associations between alpha power, self-reported physical activity, and daily self-reported EF in a school-age population (Arabi et al., 2023). Interestingly, when investigating the impact of physical activity on brain activity and cognitive functioning in older adults, results differ slightly. For instance, Sanchez-Lopez and colleagues (2018) found that highly active adults demonstrated better cognitive abilities yet lower relative alpha power at some frontal sites (e.g., F7, which is associated with the lateral frontal cortex). This may suggest developmental differences in the importance of alpha power as an electrophysiological indicator of EF performance.

Despite this difference, there are few longitudinal studies investigating the relationship between physical activity, cognition, and brain activation (Chaddock-Hayman et al., 2014). To further complicate the conceptualization of how these variables interact, a study of 25 preschool children found no association between scores on a physical fitness test and performance on a cognitive task (Mierau et al., 2016). However, they found locomotor skills were associated with individual peak alpha frequency, which is a measure of only the strongest, most prominent alpha oscillation at rest, and is more associated with occipital and parietal brain regions (Mierau et al., 2016). More information is needed to better understand the relationships between motor development, cognition, physical activity, and electrophysiological activation in the brain. It will also be important to determine whether the format of data collection (e.g., self-report, parent-report, teacher-report, laboratory task) of motor and cognitive development matter in assessing their association with measures of electrophysiological data, especially given the variance in

EEG methodology. The literature investigating the associations between physical activity, EF, motor skills, and EEG, particularly in child and preschool populations, has predominantly focused on alpha power at resting states (Arabi et al., 2023; Broomell & Bell, 2017; Hofstee et al. 2022; Sanchez-Lopez et al., 2018; Whedon et al., 2020; Wolfe & Bell, 2014); however, resting-state ratios (e.g., theta-beta, Yu et al. 2019; theta-alpha, Huang et al., 2015), ERPs from baseline to EF task (Hseih et al., 2018; Kao et al., 2021; Wolfe & Bell, 2014), and frontal asymmetry (Davis et al., 2011; Hyodo et al., 2015; Threadgill et al., 2020) have also been examined, particularly in older populations. Further investigation is warranted into resting-state alpha power to gain clarity into how it relates to physical activity, EF, and motor skills in preschool populations.

The Purpose of the Present Study

Research strongly suggests co-development between cognitive and motor skills in early life (Adolph & Hoch, 2019; Diamond, 2000). Both acute and chronic engagement in physical activity have been shown to improve cognitive functions, with the most robust support for aerobic activity (Diamond & Lee, 2011). Engagement in physical activity also has strong associations with better developed gross motor skills (Kao et al., 2021; Lin, 2007). Although, there is some evidence of an association between cognitive skills and fine motor skills (Gonzalez et al., 2019; Hellendoorn et al., 2015). Studies suggest that engaging in vigorous physical activity can improve children’s performance on EF tasks and increase PFC activity (Davis et al., 2011). However, little is known about the mechanism by which physical activity impacts EF skills and frontal lobe activation, especially in young children nor is the association with gross and fine motor skills clear, especially regarding the forms of measurement of these data. For instance, it is unknown if clinical questionnaires capture motor development and EF skills in a similar way to laboratory measures and electrophysiological data. This study adds to the literature by determining if engagement in moderate-to-vigorous physical activity during unstructured free play in early childhood and the associated advanced motor development predicts EF skills. Specifically, if better performance on EF tasks is due to higher alpha power at frontal regions and frontal asymmetry is related to the increased engagement in moderate-to-vigorous physical activity. This project aims to determine whether the associated gains in EF performance are due to increases in frontal activity as predicted by increased engagement in physical activity. The purpose of this study is to better understand the theory of embodied cognition by identifying the relationship among the aforementioned variables in a preschool population. Based on the current literature, research questions and hypotheses are as follows:

Research Question 1. Do parent and teacher reports predict preschool participants' performance on corresponding laboratory assessments of physical activity and EF?

Hypothesis 1A. Teacher-reported children's EF scores on BRIEF-P subscales will predict children's performance on the following EF tasks, the Day/Night task, Head-Toes-Knees-Shoulders Task, and Dimensional Change Card Sort, where lower scores will predict better children's performance.

Hypothesis 1B. Parent-reported children's physical activity scores will predict children's actigraph data, specifically average time spent in moderate-to-vigorous physical activity.

Hypothesis 1C. Parent-reported children's gross motor skills will positively predict participants' actigraph data, specifically average time spent in moderate-to-vigorous physical activity.

Research Question 2. What are the associations among preschoolers' physical activity, motor skills, frontal activation, and EF skills?

Hypothesis 2A. Parent-reported children's total gross motor and fine motor scores will positively correlate with the frequency and duration of participants' aerobic physical activity as measured by the Preschool Physical Activity Questionnaire (Pre-PAQ).

Hypothesis 2B. Parents reported their children's fine motor skills will be positively correlated with teacher-reported children's EF skills.

Hypothesis 2C. Participants' time spent in moderate-to-vigorous physical activity, as measured by the participants' accelerometer, will positively correlate with alpha band power at frontal sites at baseline (F3, F4, F7, F8).

Hypothesis 2D. Preschool participants' performance on the Day/Night task, Head-Toes-Knees-Shoulders Task, and Dimensional Change Card Sort will all be positively correlated.

Research Question 3. Will electrophysiology data, parent-reported motor skills, and parent-reported physical activity predict performance on laboratory measures of EF?

Hypothesis 3A. Parent-reported children's total fine motor score on the Vineland-3 will positively predict students' performance on the Day/Night and Head-Toes-Knees-Shoulders tasks but not Dimensional Card Sort task, when controlling for age, gender, and familial socioeconomic status.

Hypothesis 3B. Baseline alpha frontal asymmetry (higher left frontal activation) will predict students' overall performance on all laboratory measures of EF. It will predict performance on these measures above and beyond prior teacher-reported students' EF.

Hypothesis 3C. Preschool participants that spend time in moderate-to-vigorous physical activity level will perform better on Day/Night and Dimensional Change Card Sort tasks.

Participants that spend 30 minutes or more in moderate-to-vigorous physical activity will perform better on these measures, even when controlling for age, gender, prior reported EF skills, and prior reported fine motor skills.

Hypothesis 3D. For participants whose parents report that they engage in high levels of physical activity, there will be larger associations between teacher-reported EF and performance on lab measures of EF, especially on the Day/Night and Dimensional Card Sort tasks.

Hypothesis 3E. Gross motor skills on the Vineland-3 will predict average time in moderate-to-vigorous physical activity and performance on Day/Night and Dimensional Card Sort Tasks. The alpha power at frontal sites will moderate these relationships. This will be assessed using a moderation regression analysis.

Figure 1.

EEG Power Moderates the Relationship between Gross Motor Skills and EF Skills

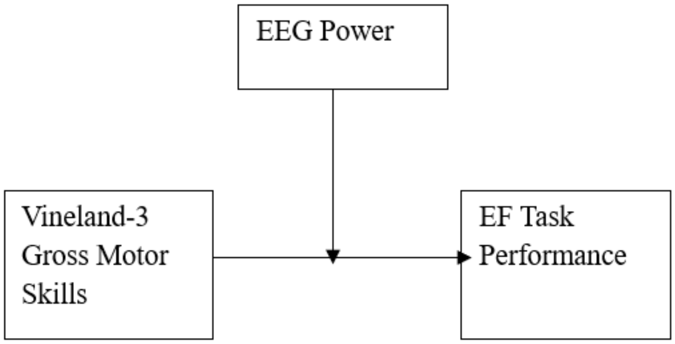
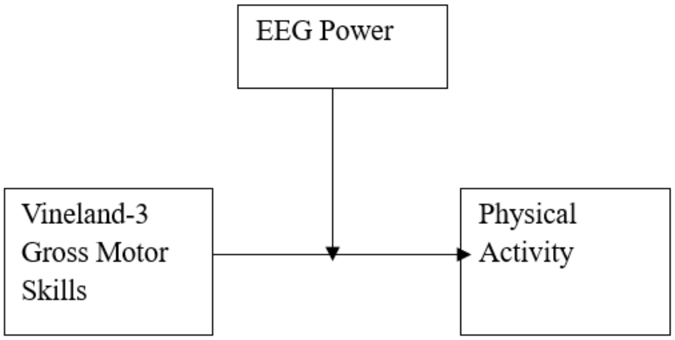


Figure 2.

EEG Power Moderates the Relationship between Gross Motor Skills and Physical Activity



CHAPTER TWO: METHODS

Participants

Participants were recruited from preschools involved in the Mountain Project Head Start Program located at various locations in Western North Carolina (Canton, Cullowhee, Clyde, Sylva, and Waynesville). Consent forms were distributed to parents by preschool teachers at the Mountain Project Head Start program sites. Consents were obtained from parents for a total of 66 preschool participants at the various sites. The total number of possible participants is unknown as this information was not provided. Some aspect of data was collected from all 66 participants. Of the 66 participants, 28 had missing accelerometer data and 27 had missing EEG data for various reasons, including refusal to wear the cap and absences from school on data collection days. Information on sex was missing for 27 participants and information on age was missing for 25 participants due to missing data from either teacher, parent, or both, since parents and teachers were asked for this information. Age data was obtained for 63.63% of the participants. See Table 1 below for demographic characteristics of participants. Regarding participants who identified as biracial, 1 participant was identified as biracial as White and Black or African American, 3 participants were identified as White and Hispanic/Latinx and 1 participant was identified as biracial White and Native American.

Table 1

Demographic Characteristics of the Participants

Sample Characteristics	*n*	%	*M*	*SD*
Gender				
Female	24	36.36		
Male	15	22.72		
Unknown	27	40.91		
Age			4.22	0.61
Race and Ethnicity				
White	29	43.94		
Black/African American	1	1.52		
Hispanic/Latinx	6	9.09		
Biracial	5	7.58		
Unknown	25	37.88		

Note. N=66

Materials

Demographic questionnaires were developed for this study (Appendix A). Parents and teachers completed demographic questionnaires prior to the administration of the other measures. Demographic data were collected from both teachers and parents regarding age, ethnicity, gender, teacher's name, grade, and languages spoken by the participant. Parents were additionally asked to provide information about their income, education level, education level of their spouse, and other questions related to socioeconomic status as well as additional information about family history and the nature of the participant's birth.

Behavior Rating Inventory of Executive-Preschool Version (BRIEF-P; Gioia et al., 2003***)***

The Behavior Rating Inventory of Education-Preschool Version (BRIEF-P) is a single rating scale for parents or teachers to rate a child's EF skills in their everyday environments (Gioia et al., 2003). Teacher rating forms were used for this study. The BRIEF-P consists of 63 items, which measure three broad indices: Inhibitory Self-Control Index, Flexibility Index, and Emergent Metacognition Index (Gioia et al., 2003). The BRIEF-P also consists of six unique subscales: Inhibit, Shift, Working Memory, Emotional Control, and Plan/Organize (Gioia et al., 2003). These subscales were utilized for analysis as a self-report form of the components of EF. Additionally, the BRIEF-P also provides a Global Executive Composite score (Gioia et al., 2003). Total raw score on each index can be converted to *T*-scores and used to interpret the child's level of EF (Gioia et al., 2003). For this study, raw scores were utilized. The BRIEF-P teacher version demonstrates high internal consistency on the scales with $r = 0.90$ to 0.97 (Sherman & Brooks, 2010; Gioia et al., 2003). Test-retest reliability ranges from coefficients 0.94 for the Inhibit subscale to 0.64 for the Shift subscale for teacher rating forms (Sherman & Brooks, 2010; Gioia et al., 2003). The BRIEF-P has demonstrated moderate convergent validity with other parent-report and teacher-report questionnaires such as the Child Behavior Checklist (Gioia et al., 2000; Ezpeleta et al., 2015) while the BRIEF-P's convergent validity with laboratory measures has not been thoroughly investigated (Ezpeleta et al., 2015; Sherman & Brooks, 2010). For this study, all BRIEF-P subscales demonstrated good internal consistency: Inhibit subscale, $\alpha = 0.93$; Shift subscale, $\alpha = 0.88$; Emotional Control subscale, $\alpha = 0.90$; Working Memory subscale, $\alpha = 0.95$; and Plan/Organize, $\alpha = 0.92$.

Vineland Adaptive Behavior Scales, Third Edition (Vineland-3; Sparrow et al., 2016)

Vineland Adaptive Behavior Scales, Third Edition (Vineland-3) is a rating scale that asks caregivers about questions about a child’s adaptive functioning (Sparrow et al., 2016). The Vineland-3 assesses a child’s adaptive functioning in four different domains: Communication, Daily Living Skills, Socialization, and Motor Skills (Sparrow et al., 2016). For the purposes of this study, the Motor Skills Domain of the Vineland-3 and its two subdomains: Gross Motor and Fine Motor skills were the focus. The raw scores on these two subdomains were used for this study. The measure consists of a total of 502 questions but was adapted for the age range of participants (Sparrow et al., 2016). For this study, 189 questions were utilized to include all domains assessed by the Vineland-3 with age-appropriate cut-offs. The full Vineland-3 is validated for individuals 0 to 99 years old (Sparrow et al., 2016). Coefficient alphas that determine the internal consistency of the Vineland-3 range from 0.94 to 0.99 for the Comprehensive Form and 0.86 to 0.97 for the Domain-level Form (Sparrow et al., 2016). Additionally, the Vineland-3 demonstrates good test-retest reliability with corrected *r* values of between 0.64 and 0.94 for the Comprehensive Form and between 0.62 and 0.92 for the Domain-Level Form (Sparrow et al., 2016). The concurrent validity of the parent/Caregiver forms and teacher forms of the Vineland-3 demonstrate corrected *r* values ranging from 0.41 to 0.98 showing moderate to high correlations with other adaptive forms (Sparrow et al., 2016). All domains up until the age-appropriate cut-off point on the parent/Caregiver Domain-Level Form were used; however, the fine and gross motor domains were the only domains used in this study. Cronbach alphas were unable to be calculated for this study due to missing items.

Preschool-age Children’s Physical Activity Questionnaire (Pre-PAQ)

The Preschool-age Children’s Physical Activity Questionnaire (Pre-PAQ) is a questionnaire that asks parents about their child’s physical activity over 3 days, one weekday and two weekend days (Dwyer et al., 2011). The Pre-PAQ consists of 36 questions over 4 broad sections involving demographic information, the parents’ own physical activity, the child’s home environment, and the child’s physical activity (Dwyer et al., 2011). This measure has been shown to be adequately reliable and valid across different genders in preschool-aged populations (Dwyer et al., 2011). The reliability of Pre-PAQ questions range from an ICC of 0.31 to 1.00 (Dwyer et al., 2011). The Pre-PAQ has also shown moderate concurrent validity with accelerometer data (Dwyer et al., 2011; Phillips et al., 2021). This study utilized one item that asked about children’s time spent playing outside over a weekend.

Dimensional Change Card Sort (DCCS ; Zelazo, 2006)

Dimensional Change Card Sort (DCCS) is an easily administered measure of EF, specifically shifting, that has been validated for preschool-aged children (Zelazo, 2006). The DCCS is administered face-to-face using 14 standard test cards that have different shapes in different colors and 7 cards that contain borders (Zelazo, 2006). Participants were asked to place the cards in two different trays based on instructions from the assessors (Zelazo, 2006). Participants were first asked to sort the cards by color, then after 6 trials they were asked to sort the cards based on shape for 6 trials (Zelazo, 2006). If the participant were able to sort at least 5 out of 6 in both the pre- and post-switch phases, then the participant moved on to the border cards (Zelazo, 2006). The border card section consists of 12 trials and is scored by the number of cards the participant sorts correctly based on a new rule (Zelazo, 2006). For this study, the first dimension for the pre-switch condition was counterbalanced. Also, for the purposes of this study, the post-switch condition is a measure of cognitive flexibility (Zelazo, 2006) and provides more variance than the border condition. For this reason, the participants' raw scores on the post-switch condition were used as a measure of cognitive flexibility. The DCCS task demonstrates good test-retest reliability (ICC=0.92; Zelazo & Bauer, 2013). The DCCS task also demonstrated good convergent validity with the WPPSI-III Block Design task in a sample of 3- to 6-year-olds (Zelazo & Bauer, 2013). Furthermore, the DCCS task exhibited strong construct validity in a sample of prekindergarten participants and strong predictive validity of their academic achievement in kindergarten (McClelland et al., 2014). Additionally, prior studies demonstrated strong internal reliability with Cronbach's alphas ranging from 0.90 to 0.93 (McClelland et al., 2014) as well as strong internal consistency (Cronbach's alphas = 0.85-0.94) in a preschool sample (Gonzales et al., 2021). For this study, interrater reliability was unable to be conducted as the camera used for recording purposes either cut-off during administration or were accidentally deleted from the storage card upon transfer of data. See Appendix B for coding information.

Day/Night Task (Day/Night; Gerstadt et al., 1994)

The Day/Night Task (Day/Night) is a measure of cognitive inhibitory control that has been shown to be reliable and valid when used with preschool populations (Gerstadt et al., 1994; Broomell & Bell, 2017). The Day/Night Task has three different assessment blocks: a congruent version, an incongruent version, and a mixed conditions block (Gerstadt et al., 1994). In the congruent version, participants were asked to say 'day' when shown a picture of a sun and 'night' when shown pictures of a moon (Gerstadt et al., 1994). During the incongruent block, participants were asked to say 'night' when they saw the sun card and 'day' when they saw the moon card (Gerstadt et al., 1994). In the mixed condition, participants were asked to follow the congruent rule when there is no border on the card and follow the incongruent rule when there is a border on the card (Gerstadt et al., 1994). Each block will consist of two practice trials and 12 test trials (Gerstadt et al., 1994). Because of this study’s interest in inhibition, the proportion correct on the Stroop trials of the Day/Night Task were used for analysis. The Day/Night Task has demonstrated reliability in preschool populations (Carlson, 2005). The Day/Night Task demonstrated good internal reliability with prior Cronbach’s alphas ranging from 0.93 to 0.99 (McClelland et al., 2014) as well as strong internal consistency in a preschool sample with Cronbach’s alphas ranging from 0.84 to 0.91 (Gonzales et al., 2021). The Day/Night task demonstrated good construct validity as well as predictive validity in a prekindergarten population examining future academic achievement in kindergarten (McClelland et al., 2014). For this study, interrater reliability was unable to be conducted as the camera used for recording purposes either cut-off during administration or were accidentally deleted from the storage card upon transfer of data. See Appendix B for coding information.

Head-Toes-Knees Shoulders Task (HTKS)

The Head-Toes-Knees Shoulders Task is a measure of EF that involves all three facets of EF: cognitive flexibility, working memory, and inhibitory control (McClelland et al., 2014). There are a total of 30 test items with scores of 0 (incorrect), 1 (self-correct), or 2 (correct) for each item (McClelland et al., 2015). In the HTKS, participants were given up to four commands (e.g., "touch your head," "touch your toes," "touch your knees" and "touch your shoulders"), and then asked to do the opposite of each command (McClelland et al., 2014). During the first trial, children were instructed to follow the rules (McClelland et al., 2014). In this study, the first trial conditions were counterbalanced either starting with head and toes or shoulders and knees. During the second trial, the children were asked to act in opposition of what they were told (McClelland et al., 2014). For the subsequent third and fourth trials, the instructions for the first trial and second trial were repeated respectively but with the condition not previously administered (McClelland et al., 2014). For the second part of the task, the rules for both head-toes and shoulders-knees were combined with the first trial requiring children to listen to the instructions whereas the second trial requiring children to do the opposite of the instructions (McClelland et al., 2014). The third part of the task involved switching the rules from the second part, such that toes were the opposite of shoulders and knees were the opposite of head (McClelland et al., 2014). Due to the all-encompassing nature of the HTKS task, the overall scores on all three trials were used for analysis. In previous studies, HTKS demonstrated good internal consistency in diverse preschool samples (ICC=0.71, Wanless et al., 2011; Gonzales et al., 2013). The HTKS task also exhibited strong inter-rater reliability with Cronbach's alphas ranging from 0.97 to 0.98 in a preschool sample (Becker & Nader, 2021). Additionally, the HTKS task demonstrated good construct validity when tested in international, preschool populations (McClelland et al., 2014; von Suchodoletz et al., 2012) as well as demonstrated predictive validity related to academic achievement (McClelland et al., 2014; Wanless et al., 2011). For this study, interrater reliability was unable to be conducted as the camera used for recording purposes either cut-off during administration or were accidentally deleted from the storage card upon transfer of data.

Electroencephalogram (EEG)

Electroencephalogram (EEG) is a non-invasive neuroimaging tool that involves placing a cap with electrodes on participants' scalp to record the electrical activity of the brain. For this study, EEG data was collected using the IX-EEG (iWorx Systems Inc., 2016). IX-EEG is a 24-channel recorder with a 10-20 silver/silver chloride 16 electrode EEG cap (iWorx Systems Inc., 2016). After assent was obtained, EEG caps were placed on participants' head and water-based gel was applied to the EEG electrodes using a dull syringe. A Q-tip was then used to ensure that the gel covered the electrode (iWorx Systems Inc., 2016). Impedances were measured and checked visually to ensure signal quality. EEG caps and electrodes were disinfected after used with each participant. EEG baseline was recorded while participants watched an age-appropriate 2-minute video clip with no sound. After data was collected, it was analysed using LabScribe software (iWorx Systems Inc., 2016) in which data was collected during the baseline video, was isolated, and absolute power was analysed at 6 to 9 Hz. The data was corrected by using a scaled scoring provided by the LabScribe manufacturers. The data was then converted to the EEGLab format to be spliced for baseline before reconverting these new spliced files. The spliced files were then converted to a LabScribe file where the Artifact Removal function was utilized prior to calculating alpha power.

ActiGraph Wgt3x-bt Acceleromenters

ActiGraph Wgt3x-bt accelerometers were used to measure preschool participants' level of physical activity (Sasaki et al., 2011) as it is reliable and valid with preschool populations (O'Brien et al., 2018; Trost et al., 2005). The accelerometer was attached to a participant's hip and detected vertical accelerations involved in day-to-day movement (Becker & Nader, 2021). These measures were taken during recess over a course of one to four days depending on participants' attendance (Sasaki et al., 2011). Participants wore the accelerometer for the entirety of recess, which ranged from 10 minutes to 1 hour with an average on each day of approximately 30 minutes. Average time spent in moderate-to-vigorous physical activity was the variable of interest used. The actigraph wgt3x-bt accelerometers were initialized to take data at 15-second epics (Becker & Nader, 2021; Trost et al., 2005). Accelerometers were calibrated such that moderate physical activity was defined as 1680 to 3367 counts per minute and vigorous physical activity as 3368 counts per minute and above.

Procedure

After the proposal for this study was approved by Western Carolina University's IRB review board, faculty connected to the programs contacted the director of the Mountain Projects Head Start Program, who gave permission to contact sites to ask about participating in the study. Each of the five sites to discuss the study and plan to visit to provide information to teachers about participation. Once sites and teachers at the sites had agreed, consent forms were given to each site's director and teachers, who then distributed the consent forms to parents in February of 2022. Consents were collected in February and early March of 2022. Once consents were collected, flyers with links to the Qualtrics questionnaires were distributed to the Head Start teachers along with a list of participating students' names. One flyer contained a link with the BRIEF-P for teachers to complete, and the other set of flyers contained a link to the Vineland-3 and pre-PAQ for parents to complete. Teachers at each site in each classroom were given a list of the students whose parents had consented to the study and were able to use the same Qualtrics links for separate students. The parent and teacher data were collected in February and March of 2022. However, teachers at some of the sites did not complete all their surveys until April 2022. Electrophysiological data and laboratory assessments were administered in-person on-site at the various Mountain Project Head Start program locations in late May of 2022. Verbal assent was obtained from students prior to collecting any electrophysiological data or administering laboratory assessments.

Data Analyses

Using IBM SPSS Statistics 25 (IBM Corporation, 2017), bivariate correlations were conducted to answer research questions regarding the associations among physical activity, EF, motor skills, and frontal activation (i.e., see Hypotheses 2A-2D). The bivariate correlations were conducted to determine whether there were associations among the variables. Hierarchical multiple regression analyses were conducted to determine the predictive value of parent and teacher questionnaires (i.e., parent-reported raw scores on the Pre-PAQ and Vineland 3; teacher-reported raw scores on the BRIEF-P) on children's performances on laboratory measures (i.e., physical activity level as determined by the ActiGraph Wgt3x-bt accelerometers, raw scores on DCCS, Day/Night Stroop, and HTKS), controlling for age (i.e., see Hypotheses 1A-1C). For many of the regression analyses, classroom was also used to control for the nested aspects of the study sample. There were two classes at the two larger sites that were divided by age with a 3-year-old classroom and a 4-to-5-year-old classroom, whereas there was only classroom for each of the other three sites. This led to 7 possible categories. The largest sites classrooms were coded first then the smaller sites were assigned the subsequent codes. A hierarchical regression was also conducted to determine the predictive value of parent-reported fine motor raw score on children's performance on the Day/Night, DCCS, and HTKS tasks, when controlling for age (i.e., Hypothesis 3A). As a measure of socioeconomic status, maternal education status was used. Previous studies have shown maternal education as a measure of socioeconomic status related to childhood EF (Cuevas et al., 2014; Hackman et al., 2015). Another hierarchical regression was performed to assess the predictive value of alpha frontal asymmetry (i.e., alpha power at site F7) on children's laboratory performance on all EF tasks (i.e., Day/Night, DCCS, and HTKS), when controlling for teacher-reported EF on the BRIEF-P, age (i.e., Hypothesis 3B).

Additional analyses included subsequent *t*-tests comparing EF performance scores (i.e., raw Day/Night and DCCS scores) for participants that average time spent in moderate-to-vigorous physical activity levels reached 30 minutes or more in physical activity compared to those participants who did not reach that level of physical activity (i.e., Hypothesis 3C). Another hierarchical regression was conducted to assess the predictive value of in vivo physical activity on EF task performance (i.e., raw scores on Day/Night Stroop and DCCS) when controlling for prior EF skills and prior reported physical activity.

Finally, analyses were performed to determine the predictive value of gross motor skills on physical activity level and performance on EF tasks (i.e., raw scores on Day/Night Stroop and DCCS). Interaction variables were computed and hierarchical regressions were run for the additional moderation analyses to assess whether alpha power moderates the relationship between gross motor skills and physical activity level and performance on EF tasks (i.e., raw scores on Day/Night Stroop and DCCS), respectively (i.e., Hypothesis 3D).

CHAPTER THREE: RESULTS

Only 8 parents completed a portion of the Pre-PAQ, Vineland-3, and demographics. Of these 8 responses, there were missing items for all except one response. The high number of missing responses from parents likely impacted the findings leaving each of the analyses related to parent data as significantly underpowered. Because the missing variables are all related to parent-reported data, the pattern of missingness meets criteria for missing not at random. Due to the limited number of parent respondents, multiple imputation was not utilized, and listwise deletion was used as it is likely that the results are uninterpretable for all analyses with parent-report measures.

Hypothesis 1A. Teacher-reported children's EF scores on BRIEF-P subscales will predict children's performance on the following EF tasks, the Day/Night task, Head-Toes-Knees-Shoulders Task, and Dimensional Change Card Sort, where lower scores will predict better children's performance.

Preschool classroom numbers were entered in the first step of the model, and raw scores on the BRIEF-P subscales were entered in the second step. The first step of the model accounted for 4% of the variance, $R^2 = 0.04$, $F(1, 34) = 1.53$, $p = 0.225$. In this first step, classroom was not significantly associated with the proportion correct on Day/Night Stroop trials, $B = 3.41$, $\beta = 0.21$, $t(35) = 4.76$, $p = .225$, 95% CI [-2.203, 9.032]. Adding the BRIEF-P scales accounted for an additional 19% of the variance, $\Delta R^2 = 0.19$, $F(6, 29) = 1.46$, $p = .226$. In the second step, teacher-reported total score on the BRIEF-P subscale Inhibit was not significantly associated with proportion correct on Day/Night Stroop trials, $B = -0.62$, $\beta = 1.63$, $t(35) = -0.38$, $p = .707$, 95% CI [-3.942, 2.709]. Teacher-reported total score on the BRIEF-P subscale Shift was also not significantly associated with proportion correct on Day/Night Stroop trials, $B = -0.99$, $\beta = 0.11$, *t*(35) = 0.46, *p* = .650, 95% CI [-3.436, 5.419], nor was teacher-reported total score on the BRIEF-P subscale Emotional Control, *B* = 2.27, β = 0.23, *t*(35) = 0.89, *p* = .380, 95% CI [-2.937, 7.479]. However, teacher-reported total score on the BRIEF-P subscale Working Memory did significantly predict proportion correct on Day/Night Stroop trials, *B* = -5.99, β = -1.31, *t*(35) = -2.39, *p* = .024, 95% CI [-2.937, 7.479]. Teacher-reported total score on the BRIEF-P subscale Plan/Organize was, however, not significantly associated with proportion correct on Day/Night Stroop trials, *B* = 8.83, β = 1.23, *t*(35) = 1.91, *p* = .066, 95% CI [-0.615, 18.273]. In sum, after controlling for classroom, results indicated that only the total score on the BRIEF-P subscale working memory was predictive of task performance on Day/Night Stroop trials, however, it is uninterpretable as the model was not statistically significant (see Table 2).

Table 2

Regression Analysis Predicting Day/Night Proportion Correct on Stroop Trials from BRIEF-P Subscales

	B	*SE*	β	*t*	*p*	95% CI for *B* Lower	95% CI for *B* Upper	R²
Step 1								0.04
Classroom	3.41	2.76	0.21	4.76	0.225	-2.203	9.032	
Step 2								0.23
Classroom	3.70	2.89	0.23	1.28	0.211	-2.214	9.620	
Total Inhibit	-0.62	1.63	-0.13	-0.38	0.707	-3.942	2.709	
Total Shift	0.99	2.17	0.11	0.46	0.650	-3.436	5.419	
Total Emotional Control	2.27	2.55	0.23	0.89	0.380	-2.937	7.479	
Total Working Memory	-5.99	2.51	-1.31	-2.39	0.024	-11.111	-0.864	
Total Plan/Organize	8.83	4.62	1.23	1.91	0.066	-0.615	18.273	

Notes: CI = confidence interval. *N* = 38.

Preschool classroom numbers were entered in the first step of the model, and raw scores on the BRIEF-P subscales were entered in the second step. The first step of the model accounted for 4% of the variance, R^2 = 0.09, *F*(1, 33) = 3.12, *p* = 0.087. In this first step, classroom was not significantly associated with participants' scores on the post-switch trial of the DCCS task, *B* = 0.43, β = 0.29, *t*(34) = 1.77, *p* = .087, 95% CI [-0.066, 0.920]. Adding the BRIEF-P scales accounted for an additional 15% of the variance, ΔR^2 = 0.15, *F*(6, 28) = 1.45, *p* = .233. In the second step, teacher-reported total score on the BRIEF-P subscale Inhibit was not significantly associated with scores on the post-switch trial of the DCCS task, *B* = 0.19, β = 0.45, *t*(34) = 1.31, *p* = .200, 95% CI [-0.109, 0.495]. Teacher-reported total score on the BRIEF-P subscale Shift was also not significantly associated with scores on the post-switch trial of the DCCS task, *B* = 0.03, β = 0.03, *t*(34) = 0.14, *p* = .890, 95% CI [-0.374, 0.429], nor was teacher-reported total score on the BRIEF-P subscale Emotional Control, *B* = -0.27, β = -0.31, *t*(34) = -1.16, *p* = .255, 95% CI [-0.741, 0.204]. Teacher-reported total score on the BRIEF-P subscale Working Memory also did not significantly predict proportion correct on the post-switch trial of the DCCS task, *B* = -0.16, β = -0.40, *t*(34) = -0.71, *p* = .485, 95% CI [-0.625, 0.304]. Additionally, teacher-reported total score on the BRIEF-P subscale Plan/Organize was not significantly associated with the post-switch trial of the DCCS task, *B* = -0.04, β = -0.06, *t*(34) = -0.09, *p* = .926, 95% CI [-0.896, 0.818]. In sum, after controlling for classroom, results indicated that none of the BRIEF-P subscales were predictive of task performance on DCCS post-switch trials (Table 3).

Table 3

Regression Analysis Predicting Dimensional Change Card Sort Score on Post-switch Trials from BRIEF-P Subscales

	B	*SE*	β	*t*	*p*	95% CI for *B* Lower	Upper	R²
Step 1								0.09
Classroom	0.43	0.25	0.29	1.77	0.087	-0.886	2.861	
Step 2								0.24
Classroom	0.24	0.26	0.16	0.90	0.378	-0.302	0.771	
Total Inhibit	0.19	0.15	0.45	1.31	0.200	-0.109	0.495	
Total Shift	0.03	0.20	0.03	0.14	0.890	-0.374	0.429	
Total Emotional Control	-0.27	0.23	-0.31	-1.16	0.255	-0.741	0.204	
Total Working Memory	-0.16	0.23	-0.40	-0.71	0.485	-0.625	0.304	
Total Plan/Organize	-0.04	0.42	-0.06	-0.09	0.926	-0.896	0.818	

Notes: CI = confidence interval. *N* = 36.

A hierarchical regression was conducted to determine if the teacher-reported BRIEF-P scales would predict participant's performance on HTKS while controlling for the classroom that they were in. Preschool classroom numbers were entered in the first step of the model, and raw scores on the BRIEF-P subscales were entered in the second step. The first step of the model accounted for 0.6% of the variance, $R^2 = 0.01$, $F(1, 34) = 0.22$, $p = 0.643$. In the first step, classroom did not significantly predict overall HTKS scores, $B = 0.44$, $\beta = 0.08$, $t(35) = 0.47$, $p = .643$, 95% CI [-1.463, 2.337]. Adding the BRIEF-P scales accounted for an additional 7% of the variance, $\Delta R^2 = 0.07$, $F(6, 29) = 0.42$, $p = .862$. In the second step, teacher-reported total score on the BRIEF-P subscale Inhibit was not significantly associated with overall HTKS scores, *B* = -0.41, β = -0.26, *t*(35) = -0.69, *p* = .664, 95% CI [-1.689, 2.613]. Teacher-reported total score on the BRIEF-P subscale Shift was also not significantly associated with overall HTKS scores, *B* = -0.14, β = -0.05, *t*(35) = -0.18, *p* = .861, 95% CI [-1.749, 1.470], nor was teacher-reported total score on the BRIEF-P subscale Emotional Control, *B* = 1.21, β = 0.37, *t*(35) = 1.31, *p* = .202, 95% CI [-0.684, 3.102]. Teacher-reported total score on the BRIEF-P subscale Working Memory also did not significantly predict overall HTKS score, *B* = 0.15, β = 0.10, *t*(35) = 0.17, *p* = .867, 95% CI [-1.709, 2.016]. Additionally, teacher-reported total score on the BRIEF-P subscale Plan/Organize was not significantly associated with overall HTKS score, *B* = -0.45, β = -0.19, *t*(34) = -0.27, *p* = .789, 95% CI [-3.887, 2.979]. In sum, after controlling for classroom, results indicated that none of the BRIEF-P subscale working memory was overall HTKS score. See Table 4.

Table 4

Regression Analysis Predicting Overall Head-Toes-Knees-Shoulders Score from BRIEF-P Subscales

	B	*SE*	β	*t*	*p*	95% CI for *B*		R²
						Lower	Upper	
Step 1								0.01
Classroom	0.44	0.94	0.08	0.47	0.643	-1.463	2.337	
Step 2								0.08
Classroom	0.46	1.05	0.08	0.44	0.664	-1.689	2.613	
Total Inhibit	-0.41	0.59	-0.26	-0.69	0.494	-1.619	0.799	
Total Shift	-0.14	0.79	-0.05	-0.18	0.861	-1.749	1.470	
Total Emotional Control	1.21	0.93	0.37	1.31	0.202	-0.684	3.102	
Total Working Memory	0.15	0.91	0.10	0.17	0.867	-1.709	2.016	
Total Plan/Organize	-0.45	1.68	-0.19	-0.27	0.789	-3.887	2.979	

Notes: CI = confidence interval. *N* = 39.

Hypothesis 1B. Parent-reported children's physical activity scores will predict children's actigraph data, specifically average time spent in moderate-to-vigorous physical activity.

Regarding the predictive ability of parent-report, a hierarchical regression was conducted to determine if the pre-PAQ predicted in vivo physical activity while controlling for classroom. Preschool classroom numbers were entered in the first step, and parent-reported time spent outside on the pre-PAQ was entered in the second step. The first step of the model accounted for 77% of the variance, $R^2 = 0.80$, $F(1, 4) = 15.65$, $p = 0.017$. In the first step, preschool classroom did significantly and positively predict the average amount of time participants spent in MVPA, *B* = 12.27, β = 0.89, *t*(5) = 3.96, *p* = .017, 95% CI [3.606, 20.888]. Adding the Pre-PAQ accounted for an additional 7% of the variance, $\Delta R^2 = 0.07$, *F*(2, 3) = 9.76, *p* = .049. In the second step, parent-reported time spent engaging in physical activity in a day was not significantly associated with average amount of time spent in MVPA, *B* = 2.12, β = 0.28, *t*(5) = 1.26, *p* = .297, 95% CI [-3.240, 7.480]. In sum, after controlling for classroom, results indicated that parent-reported time spent engaging in physical activity on the pre-PAQ was not predictive of participants' time spent in MVPA at recess. See Table 5.

Table 5

Regression Analysis Predicting Average Time Spent in Moderate-to-Vigorous Physical Activity from Parent-Reported Pre-PAQ

						95% CI for *B*		
	B	*SE*	β	*t*	*p*	Lower	Upper	R^2
Step 1								0.80
Classroom	12.27	3.10	0.89	3.96	0.017	3.660	20.888	
Step 2								0.87
Classroom	11.07	3.05	0.81	3.63	0.036	1.353	20.782	
Pre-PAQ	2.12	1.68	0.28	1.26	0.297	-3.240	7.480	

Notes: CI = confidence interval. *N* = 6.

Hypothesis 1C. Parent-reported children's gross motor skills will positively predict participants' actigraph data, specifically average time spent in moderate-to-vigorous physical activity.

Regarding the predictive ability of parent-report, a hierarchical regression was conducted to determine if total gross motor score on the Vineland-3 predicted in vivo physical activity while controlling for classroom. Preschool classroom numbers were entered in the first step, and parent-reported gross motor total score was entered in the second step. The first step of the model accounted for 80% of the variance, $R^2 = 0.80$, $F(1, 4) = 16.30$, $p = 0.016$. In the first step, preschool classroom did significantly and positively predict the average amount of time participants spent in MVPA, $B = 11.97$, $\beta = 0.90$, $t(5) = 4.04$, $p = .016$, 95% CI [3.736, 20.200]. Adding the gross motor total accounted for an additional 7% of the variance, $\Delta R^2 = 0.08$, $F(2, 3) = 11.10$, $p = .041$. In the second step, total gross motor score was not significantly associated with average time spent in MVPA, $B = 0.13$, $\beta = 0.34$, $t(5) = 1.10$, $p = .255$, 95% CI [-0.171, 0.439]. In sum, after controlling for classroom, results indicated that parent-reported total gross motor score was not predictive of participants' time spent in MVPA at recess. See Table 6.

Table 6

Regression Analysis Predicting Average Time Spent in Moderate-to-Vigorous Physical Activity from Parent-Reported Gross Motor Raw Score on Vineland-3

						95% CI for *B*		
	B	*SE*	β	*t*	*p*	Lower	Upper	R²
Step 1								0.80
Classroom	11.97	2.96	0.90	4.04	0.016	3.736	20.200	
Step 2								0.88
Classroom	9.30	3.27	0.70	2.85	0.065	-1.102	19.708	
Gross Motor Total	0.13	0.10	0.34	1.40	0.255	-0.171	0.439	

Notes: CI = confidence interval. *N* = 6.

Hypothesis 2A. Parent-reported children's total gross motor and fine motor scores will positively correlate with the frequency and duration of participants' aerobic physical activity as measured by the Preschool Physical Activity Questionnaire (Pre-PAQ).

Parent-reported total score on Gross Motor skills was not significantly correlated with parent-reported pre-PAQ total time spent in physical activity in a day, $r = 0.45$, $p = 0.55$. See Table 6. In other words, parents who reported their children had good gross motor did not engage more or less in physical activity as reported by their parents. However, parent-reported total raw gross motor skills and fine motor skills on the Vineland-3 were significantly and positively correlated, $r = 0.97$, $p < 0.01$. This indicates that if parents reported that their children had good gross motor skills, then they also reported their children had good fine motor skills.

Table 7

Pearson's Correlation between Vineland 3 Raw Motor Scores and Pre-PAQ

Variables	Correlations	
	1	2
1. Fine Motor Total	---	---
2. Gross Motor Total	0.97**	---
3. PRE-PAQ Time Spent Outside in a Day	0.44	0.45

*Notes. N*s = 6. * $p < 0.05$. ** $p < 0.01$

Hypothesis 2B. Parents reported their children's fine motor skills will be positively correlated with teacher-reported children's EF skills.

Parent-reported total score on fine motor skills was not significantly correlated with any of the teacher-reported BRIEF-P subscales. See Table 8. In other words, children whose parents reported better fine motor skills did not demonstrate better or worse EF skills as reported by their teachers. However, all of the teachers reported BRIEF-P raw scores on the subscales were significantly and positively correlated.

Table 8

Pearson's Correlation Between Fine Motor Score on the Vineland-3 and BRIEF-P Subscales

Variable	Correlations				
	1	2	3	4	5
1. Fine Motor Total	---	---	---	---	---
2. Total Inhibit	-0.36				
3. Total Shift	-0.36	0.37*			
4. Total Emotional Control	0.35	0.58**	0.70**		
5. Total Working Memory	-0.72	0.72**	0.62**	0.62**	
6. Total Plan/Organize	-0.27	0.79**	0.61**	0.65**	0.95**

*Notes. N*s = 5 for Fine Motor Skills; 41 for BRIEF-P Subscales. * $p < 0.05$. ** $p < 0.01$.

Hypothesis 2C. Participants' time spent in moderate-to-vigorous physical activity, as measured by the participants' actigraph, will positively correlate with alpha band power at frontal sites at baseline (F3, F4, F7, F8).

Participants' time spent in moderate-to-vigorous physical activity (MVPA) was not significantly correlated with alpha power at F7, $r = 0.23$, $p = 0.18$, F8, $r = 0.25$, $p = 0.16$, and F4, $r = 0.24$, $p = 0.17$ (Table 8). Alpha power at F4 was significantly and positively correlated with F7, $r = 0.93$, $p < 0.01$, and F8, $r = 0.97$, $p < 0.01$. Alpha power at F7 and F8 were also significantly and positively correlated, $r = 0.98$, $p < 0.01$. See Table 9 below for other correlations, which were not significant.

Table 9

Pearson's Correlation Between Time Spent in MVPA and Alpha Power at Frontal EEG Sites

Variable	Correlations			
	1	2	3	4
1. Average Time in MVPA	---	---	---	---
2. Alpha Power at F7	0.23			
3. Alpha Power at F8	0.25	0.98**		
4. Alpha Power at F3	0.01	-0.31	-0.30	
5. Alpha Power at F4	0.24	0.93**	0.97**	-0.28

Notes. $N = 35$ * $p < 0.05$. ** $p < 0.01$.

Hypothesis 2D. Preschool participants' performance on the Day/Night task, Head-Toes-Knees-Shoulders Task, and Dimensional Change Card Sort will all be positively correlated.

Participants' overall score on HTKS did not significantly correlate with participants' score on DCCS post-switch trials, $r = 0.07$, $p = 0.67$, nor did it significantly correlate with participants' proportion correct on Day/Night Stroop trials, $r = 0.21$, $p = 0.21$. Participants' score on DCCS post-switch trials also did not significantly correlate with participants' proportion correct on Day/Night Stroop trials, $r = 0.06$, $p = 0.74$. See Table 10.

Table 10

Pearson's Correlation Between All Lab Measure of EF

Variable	Correlations	
	1	2
1. HTKS Overall Total	---	---
2. DCCS POST Total	0.07	
3. DN Stroop Proportion	0.21	0.06

*Notes. N*s = 36-39. * $p < 0.05$. ** $p < 0.01$, DCCS = Dimensional Change Card Sort Task; DN = Day Night Task; HTKS= Head-Toes-Knees Shoulders Task.

Hypothesis 3A. Parent-reported children's total fine motor score on the Vineland-3 will positively predict students' performance on the Day/Night and Head-Toes-Knees-Shoulders tasks but not Dimensional Card Sort task, when controlling for age, gender, and familial socioeconomic status.

Regarding the predictive ability of parent-report, a hierarchical regression was conducted to determine if total fine motor score on the Vineland-3 predicted proportion correct on Day/Night Stroop trials, while controlling for age, sex, and maternal education. Age, sex, and maternal education were entered in the first step, and parent-reported fine motor total score was entered in the second step. The first step of the model accounted for 68% of the variance, $R^2 = 0.68$, $F(1, 4) = 0.71$, $p = .680$. In the first step, age did not significantly predict proportion correct on the Day/Night Stroop trials, $B = 8.33$, $\beta = 0.20$, $t(4) = 0.23$, $p = .856$, 95% CI [-453.209, 469.879], nor did sex, $B = -45.83$, $\beta = -0.59$, $t(4) = -.99$, $p = .503$, 95% CI [-632.994, 541.328], nor did maternal education, $B = 4.17$, $\beta = 0.28$, $t(4) = 0.30$, $p = .814$, 95% CI [-171.424, 179.757]. Adding the parent-reported fine motor skills accounted for an additional 32% of the variance, $\Delta R^2 = 0.32$. In sum, after controlling for age, sex, and maternal education, results indicated that parent-reported total fine motor score was not predictive of proportion correct on Day/Night Stroop trials.

Regarding the predictive ability of parent-report, a hierarchical regression was conducted to determine if total fine motor score on the Vineland-3 predicted overall HTKS score while controlling for classroom and age. Age, sex, and maternal education were entered in the first step, and parent-reported fine motor total score was entered in the second step. The first step of the model accounted for 97% of the variance, $R^2 = 0.97$, $F(1, 3) = 9.89$, $p = 0.229$. In the first step, age did not significantly predict overall HTKS score, $B = 16.36$, $\beta = 1.45$, $t(4) = 5.16$, $p = .122$, 95% CI [-23.916, 56.644], nor was a sex, $B = -9.91$, $\beta = -0.47$, $t(4) = -2.46$, $p = .246$, 95% CI [-61.152, 41.334], nor was maternal education, $B = -5.00$, $\beta = -1.21$, $t(4) = -4.15$, $p = .151$, 95% CI [-20.324, 10.324]. Adding parent-reported fine motor skills accounted for an additional 3% of the variance, $\Delta R^2 = 0.03$. In the second step, parent-reported total fine motor score was not significantly associated with overall HTKS score, $B = -1.33$, $\beta = -0.58$, 95% CI [-1.333, -1.333]. In sum, after controlling for classroom and age, results indicated that parent-reported total fine motor score was not predictive of participants' overall HTKS score.

Regarding the predictive ability of parent-report, a hierarchical regression was conducted to determine if total fine motor score on the Vineland-3 predicted score on the DCCS post-switch trials while controlling for age, sex, and maternal education. Age, sex, and maternal education were entered in the first step, and parent-reported fine motor total score was entered in the second step. The first step of the model accounted for 100% of the variance, $R^2 = 1.00$. In the first step, age did not significantly predict DCCS post-switch trials, $B = -1.15\text{E-}15$, $\beta = 0.00$, 95% CI [0.000, 0.000], nor was sex, $B = -6.00$, $\beta = -1.00$, 95% CI [-6.000, -6.000] nor was maternal education, *B* = -1.44E-15, β = 0.00, 95% CI [0.000, 0.000]. Adding the parent-reported fine motor skills accounted for no additional variance. Parent-reported fine motor skills did not significantly predict DCCS post-switch trials. In sum, after controlling for age, sex, and maternal education, results indicated that parent-reported total fine motor score was not predictive of participants' score on the DCCS post-switch trial.

Hypothesis 3B. Baseline alpha frontal asymmetry (higher left frontal activation) will predict students' overall performance on all laboratory measures of EF. It will predict performance on these measures above and beyond prior teacher-reported students' EF.

A hierarchical regression was conducted to determine the predictive ability of classroom, age, BRIEF-P subscales, and frontal asymmetry on scores of the DCCS post-switch trials. Preschool classroom and age were entered in the first step of the model, and raw scores on the BRIEF-P subscales were entered in the second step while frontal asymmetry was entered in the third step of the analyses. The first step of the model accounted for 16% of the variance, R^2 = 0.16, *F*(2, 32) = 3.04, *p* = 0.062. In this first step, classroom was not significantly associated with participants' scores on the post-switch trial of the DCCS task, *B* = 0.26, β = 0.18, *t*(34) = 1.01, *p* = .319, 95% CI [-0.226, 0.790], nor was age, *B* = 1.37, β = 0.82, *t*(34) = 1.67, *p* = .105, 95% CI [-0.301, 3.039]. In the second step, teacher-reported score on the BRIEF-P subscale Inhibit was not significantly associated with scores on the post-switch trial of the DCCS task, *B* = 0.18 β = 0.41, *t*(34) = 1.20, *p* = .239, 95% CI [-0.124, 0.474]. Adding the BRIEF-P scales accounted for an additional 13% of the variance, ΔR^2 = 0.13, *F*(7, 27) = 1.54, *p* = .196. Teacher-reported total score on the BRIEF-P subscale Shift was also not significantly associated with scores on the post-switch trial of the DCCS task, *B* = 0.03, β = 0.03, *t*(34) = 0.13, *p* = .898, 95% CI [-0.371, 0.421], nor was teacher-reported total score on the BRIEF-P subscale Emotional Control, *B* = -

0.31, β = -0.36, *t*(34) = -1.36, *p* = .187, 95% CI [-0.781, 0.160]. Teacher-reported total score on the BRIEF-P subscale Working Memory also did not significantly predict proportion correct on the post-switch trial of the DCCS task, *B* = -0.09, β = -0.23, *t*(34) = -0.37, *p* = .712, 95% CI [-0.558, 0.387]. Additionally, teacher-reported total score on the BRIEF-P subscale Plan/Organize was not significantly associated with the post-switch trial of the DCCS task, *B* = -0.09, β = -0.41, *t*(34) = -0.22, *p* = .828, 95% CI [-0.940, 0.758]. Adding frontal asymmetry accounted for an additional 0% of the variance, $\Delta R^2 = 0.00$, *F*(8, 26) = 1.30, *p* = .288. In the third step of the hierarchical regression, frontal asymmetry was not predictive of performance on post-switch trials on DCCS, *B* = -0.02, β = -0.01, *t*(34) = -0.06, *p* = .957, 95% CI [-0.825, 0.782]. In sum, after controlling for classroom, age, and BRIEF-P subscales, results indicated that frontal asymmetry was not predictive of task performance on DCCS post-switch trials. See Table 11.

Table 11

Regression Analysis Predicting Dimensional Change Card Sort Score on Post-switch Trials from Frontal Asymmetry, When Controlling for Classroom, Age, and BRIEF-P Subscales

						95% CI for *B*		
	B	*SE*	β	*t*	*p*	Lower	Upper	R²
Step 1								0.16
Classroom	0.26	0.26	0.18	1.012	0.319	-0.266	0.790	
Age	1.37	0.82	0.29	1.670	0.105	-0.301	3.039	
Step 2								0.29
Classroom	0.12	0.27	0.08	0.42	0.677	-0.445	0.675	
Age	1.19	0.88	0.26	1.36	0.186	-0.610	2.997	
Total Inhibit	0.18	0.15	0.41	1.20	0.239	-0.124	0.474	
Total Shift	0.03	0.19	0.03	0.13	0.898	-0.371	0.421	
Total Emotional Control	-0.31	0.23	-0.36	-1.36	0.187	-0.781	0.160	
Total Working Memory	-0.09	0.23	-0.21	-0.37	0.712	-0.558	0.387	
Total Plan/Organize	-0.09	0.41	-0.14	-0.22	0.828	-0.940	0.758	
Step 3								0.29
Classroom	0.12	0.29	0.08	0.42	0.681	-0.468	0.706	
Age	1.18	0.91	0.26	1.31	0.205	-0.688	3.056	
Total Inhibit	0.17	0.17	0.40	1.03	0.313	-0.171	0.514	
Total Shift	0.02	0.20	0.03	0.12	0.906	-0.385	0.432	
Total Emotional Control	-0.31	0.25	-0.35	-1.25	0.222	-0.810	0.197	
Total Working Memory	-0.09	0.24	-0.21	-0.36	0.719	-0.568	0.397	
Total Plan/Organize	-0.09	0.43	-0.14	-0.20	0.841	-0.968	0.795	
Frontal Asymmetry	-0.02	0.39	-0.01	-0.06	0.957	-0.825	0.782	

Notes: CI = confidence interval. *N* =36.

A hierarchical regression was conducted to determine the predictive ability of classroom, age, BRIEF-P subscales, and frontal asymmetry on scores of Day/Night proportion correct on Stroop trials. Preschool classroom and age were entered in the first step of the model, and raw scores on the BRIEF-P subscales were entered in the second step while frontal asymmetry was entered in third step. The first step of the model accounted for 28% of the variance, $R^2 = 0.28$, $F(2, 33) = 6.29$, $p = .005$. In this first step, classroom was not significantly associated with the proportion correct on Day/Night the Stroop trials, $B = 0.01$, $\beta = 0.00$, $t(35) = 0.01$, $p = .996$, 95% CI [-5.384, 5.413]. Age was significantly and positively predictive of performance on Day/Night Stroop trials, $B = 27.38$, $\beta = 0.53$, $t(35) = 3.26$, $p = .003$, 95% CI [10.293, 44.456]. Adding the

BRIEF-P scales accounted for an additional 11% of the variance, $\Delta R^2 = 0.11$, $F(7, 28) = 2.56$, $p = .036$. In the second step, teacher-reported total score on the BRIEF-P subscale Inhibit was not significantly associated with proportion correct on Day/Night the Stroop trials, $B = -0.97$, $\beta = -0.20$, $t(35) = -0.66$, $p = .516$, 95% CI [-4.007, 2.059]. Teacher-reported score on the BRIEF-P subscale Shift was also not significantly associated with proportion correct on Day/Night the Stroop trials, $B = 0.95$, $\beta = 0.10$, $t(35) = 0.48$, $p = .634$, 95% CI [-3.076, 4.969], nor was teacher-reported score on the BRIEF-P subscale Emotional Control, $B = 1.42$, $\beta = 0.15$, $t(35) = 0.61$, $p = .549$, 95% CI [-3.360, 6.190]. BRIEF-P subscale Working Memory did not significantly predict proportion correct on Day/Night the Stroop trials, $B = -4.48$, $\beta = -0.98$, $t(35) = -1.91$, $p = .066$, 95% CI [-9.272, 0.315]. Teacher-reported score on the BRIEF-P subscale Plan/Organize was not significantly associated with proportion correct on Day/Night the Stroop trials, $B = 7.79$, $\beta = 1.09$, $t(35) = 1.85$, $p = .075$, 95% CI [-0.829, 16.402]. Adding frontal asymmetry accounted for an additional 4% of the variance, $\Delta R^2 = 0.04$, $F(8, 27) = 2.53$, $p = .034$. In the third step of the hierarchical regression, frontal asymmetry was not predictive of performance on Day/Night Stroop trials, $B = -5.15$, $\beta = -0.23$, $t(35) = -1.34$, $p = .192$, 95% CI [-13.036, 2.744]. In sum, after controlling for classroom, age, and BRIEF-P subscales, results indicated frontal asymmetry was predictive of task performance on Day/Night Stroop trials. See Table 12.

Table 12

Regression Analysis Predicting Day/Night Proportion Correct on Stroop Trials from Frontal Asymmetry, When Controlling for Classroom, Age, and BRIEF-P Subscales

						95% CI for *B*		
	B	*SE*	β	*t*	*p*	Lower	Upper	R^2
Step 1								0.28
Classroom	0.01	2.65	0.00	0.01	0.996	-5.384	5.413	
Age	27.38	8.40	0.53	3.26	0.003	10.293	44.456	
Step 2								0.39
Classroom	1.29	2.77	0.08	0.47	0.645	-4.389	6.970	
Age	24.06	8.93	0.46	2.69	0.012	5.756	42.353	
Total Inhibit	-0.97	1.48	-0.20	-0.66	0.516	-4.007	2.059	
Total Shift	0.95	1.96	0.10	0.48	0.634	-3.076	4.969	
Total Emotional Control	1.42	2.33	0.15	0.61	0.549	-3.360	6.190	
Total Working Memory	-4.48	2.34	-0.98	-1.91	0.066	-9.272	0.315	
Total Plan/Organize	7.79	4.21	1.09	1.85	0.075	-0.829	16.402	
Step 3								0.43
Classroom	2.15	2.81	0.13	0.77	0.450	-3.611	7.917	
Age	21.88	8.96	0.42	2.44	0.021	3.496	40.259	
Total Inhibit	-1.97	1.64	-0.41	-1.20	0.240	-5.330	1.393	
Total Shift	0.60	1.95	0.07	0.31	0.762	-3.411	4.607	
Total Emotional Control	2.39	2.41	0.24	0.99	0.331	-2.560	7.335	
Total Working Memory	-4.40	2.31	-0.97	-1.91	0.067	-9.135	0.339	
Total Plan/Organize	8.81	4.22	1.23	2.09	0.046	0.155	17.462	
Frontal Asymmetry	-5.15	3.85	-0.23	-1.34	0.192	-13.036	2.744	

Notes: CI = confidence interval. *N* = 38.

A hierarchical regression was conducted to determine the predictive ability of classroom, age, BRIEF-P subscales, and frontal asymmetry on overall scores on HTKS. Preschool classroom and age were entered in the first step of the model, and raw scores on the BRIEF-P subscales were entered in the second step while frontal asymmetry was entered in third step. The first step of the model accounted for 7% of the variance, $R^2 = 0.07$, $F(2, 33) = 1.30$, $p = 0.286$. In the first step, classroom did not significantly predict overall HTKS scores, $B = -0.17$, $\beta = -0.03$, $t(35) = -0.17$, $p = .868$, 95% CI [-2.194, 1.862], nor was age, $B = 4.86$, $\beta = 0.28$, $t(35) = 1.54$, $p = .133$, 95% CI [-1.555, 11.279]. Adding the BRIEF-P scales accounted for an additional 7% of the variance, $\Delta R^2 = 0.07$, $F(7, 28) = 0.66$, $p = .704$. In the second step, teacher-reported score on the BRIEF-P subscale Inhibit was not significantly associated with overall HTKS scores, $B = -0.48$, $\beta = -0.30$, $t(35) = -0.83$, $p = .414$, 95% CI [-1.679, 0.711]. Teacher-reported score on the BRIEF-P subscale Shift was also not significantly associated with overall HTKS scores, $B = -0.15$, $\beta = -0.05$, $t(35) = -0.19$, $p = .849$, 95% CI [-1.733, 1.436], nor was teacher-reported score on the BRIEF-P subscale Emotional Control, $B = 1.03$, $\beta = 0.32$, $t(35) = 1.12$, $p = .271$, 95% CI [-0.850, 2.912]. Teacher-reported score on the BRIEF-P subscale Working Memory also did not significantly predict overall HTKS score, $B = 0.47$, $\beta = 0.31$, $t(35) = 0.51$, $p = .616$, 95% CI [-1.421, 2.355]. Additionally, teacher-reported score on the BRIEF-P subscale Plan/Organize was not significantly associated with overall HTKS score, $B = -0.67$, $\beta = -0.28$, $t(35) = -0.31$, $p = .688$, 95% CI [-4.065, 2.722]. Adding frontal asymmetry accounted for an additional 8% of the variance, $\Delta R^2 = 0.07$, $F(8, 27) = 0.94$, $p = .504$. In the third step of the hierarchical regression, frontal asymmetry was not predictive of performance on HTKS total score, $B = -2.41$, $\beta = -0.32$, $t(35) = -1.62$, $p = .118$, 95% CI [-5.478, 0.650]. In sum, after controlling for classroom, age, and BRIEF-P subscales, results indicated frontal asymmetry was predictive of task performance on Day/Night Stroop trials. See Table 13.

Table 13

Regression Analysis Predicting Overall Head-Toes-Knees-Shoulders Score from Frontal Symmetry, When Controlling for Classroom, Age, and BRIEF-P Subscales

						95% CI for *B*		
	B	*SE*	β	*t*	*p*	Lower	Upper	R²
Step 1								0.07
Classroom	-0.17	1.00	-0.03	-0.17	0.868	-2.194	1.862	
Age	4.86	3.15	0.28	1.54	0.133	-1.555	11.279	
Step 2								0.14
Classroom	-0.04	1.09	-0.01	-0.04	0.971	-2.277	2.197	
Age	5.01	3.52	0.29	1.42	0.166	-2.202	12.212	
Total Inhibit	-0.48	0.77	-0.30	-0.63	0.539	-2.120	1.151	
Total Shift	-0.15	0.77	-0.05	-0.19	0.849	-1.733	1.436	
Total Emotional Control	1.03	0.92	0.32	1.12	0.271	-0.850	2.912	
Total Working Memory	0.47	0.92	0.21	0.51	0.616	-1.412	2.355	
Total Plan/Organize	-0.67	1.66	-0.28	-0.41	0.688	-4.065	2.722	
Step 3								0.22
Classroom	0.37	1.09	0.07	0.33	0.741	-1.874	2.603	
Age	3.98	3.48	0.23	1.15	0.262	-3.155	11.122	
Total Inhibit	-0.95	0.64	-0.59	-1.49	0.147	-2.256	0.355	
Total Shift	-0.31	0.76	-0.10	-0.41	0.684	-1.869	1.245	
Total Emotional Control	1.49	0.94	0.46	1.59	0.124	-0.434	3.409	
Total Working Memory	0.51	0.90	0.33	0.56	0.578	-1.335	2.345	
Total Plan/Organize	-0.19	1.64	-0.08	-0.12	0.908	-3.553	3.169	
Frontal Asymmetry	-2.41	1.49	-0.32	-1.62	0.118	-5.478	0.650	

Notes: CI = confidence interval. *N* =39.

Hypothesis 3C. Preschool participants that spend time in moderate-to-vigorous physical activity level will perform better on Day/Night and Dimensional Change Card Sort tasks. Participants that spend 30 minutes or more in moderate-to-vigorous physical activity will perform better on these measures, even when controlling for age, gender, prior reported EF skills, and prior reported fine motor skills.

Time spent in MVPA did not significantly predict performance on Day/Night Stoop Stroop trials, *B* = 0.62, β = 0.25, *F*(1, 32) = 2.15, *p* = .153, 95% CI [-0.242, 1.480]. However, time spent in MVPA did significantly and positively predicted performance on DCCS post-switch trials, *B* = 0.07, β = 0.33, *F*(1,30) = 3.69, *p* = .0.064, 95% CI [-0.005, 0.150].

Independent samples *t*-tests were conducted using 2-tailed tests with scores on EF lab measures as continuous variables. An independent samples *t*-test to compare the mean scores on HTKS tasks for participants who spent 30 minutes or more in MVPA (*M* = 10.63, *SD* = 8.31, *N* = 8) and participants who spent less than 30 minutes in MVPA (*M* = 6.74, *SD* = 10.13, *N* = 27). There was no difference in overall HTKS scores between participants who spent 30 minutes or more in MVPA and participants who spent less than 30 minutes in MVPA, *t*(14.05) = 1.10, *p* =.29, 95% $\text{CI}_{\text{Difference}}$ [-3.72,11.49]. Additionally, an independent samples *t*-test was conducted to compare scores on DCCS post-switch trial for participants who spent 30 minutes or more in MVPA (*M* = 3.00, *SD* = 3.21, *N* = 8) and participants who spent less than 30 minutes in MVPA (*M* = 2.54, *SD* = 2.87, *N* = 24). There was no difference in scores on the DCCS post-switch trial between participants who spent 30 minutes or more in MVPA and participants who spent less than 30 minutes in MVPA, *t*(11.01) = 0.36, *p* =.73, 95% $\text{CI}_{\text{Difference}}$ [-2.35,3.27]. Finally, an independent samples *t*-test was conducted to compare proportion correct on Day/Night Stroop trials for participants who spent 30 minutes or more in MVPA (*M* = 69.79%, *SD* = 22.69%, *N* = 8) and participants who spent less than 30 minutes in MVPA (*M* = 52.56%, *SD* = 32.64%, *N* = 26). There was no difference in the proportion correct on Day/Night Stroop trials between participants who spent 30 minutes or more in MVPA and participants who spent less than 30 minutes in MVPA, *t*(16.84) = 1.68, *p* =.11, 95% $\text{CI}_{\text{Difference}}$ [-4.44%,38.89%].

Hypothesis 3D. For participants whose parents report that they engage in high levels of physical activity, there will be larger associations between teacher-reported EF

and performance on lab measures of EF, especially on the Day/Night and Dimensional Card Sort tasks.

A hierarchical regression was conducted to determine the predictive ability of the total raw score of the global executive control (GEC) on the BRIEF-P and Pre-PAQ on Day/Night proportion correct on the post-switch trial. Pre-PAQ was entered in the first step of the model, and the raw score for GEC on the BRIEF-P was entered in the second step. The first step of the model accounted for 11% of the variance, $R^2 = 0.11$, $F(1, 4) = 0.05$, $p = 0.836$. In the first step, Pre-PAQ did not significantly predict the Day/Night proportion correct, $B = 1.84$, $\beta = 0.11$, $t(5) = 0.22$, $p = .836$, 95% CI [-21.250, 24.925]. Adding BRIEF-P GEC accounted for an additional 13% of the variance, $\Delta R^2 = 0.13$, $F(2, 3) = 0.25$, $p = .795$. In the second step, teacher-reported GEC did not significantly predict Day/Night proportion correction, $B = 2.12$, $\beta = 0.28$, $t(5) = 1.26$, $p = .297$, 95% CI [-3.240, 7.480]. In sum, after controlling for Pre-PAQ, results indicated that teacher-reported BRIEF-P GEC scores were not predictive of participants’ Day/Night proportion correct. See Table 14.

Table 14

Regression Analysis Predicting Day/Night Proportion Correct on Post-switch Trials from Pre-PAQ and BRIEF-P

						95% CI for *B*		
	B	*SE*	β	*t*	*p*	Lower	Upper	R²
Step 1								0.11
Pre-PAQ	1.84	8.32	0.11	0.22	0.836	-21.250	24.925	
Step 2								0.24
Pre-PAQ	6.12	10.98	0.37	0.56	0.616	-28.812	41.042	
BRIEF-P GEC	0.60	0.89	0.44	0.67	0.549	-2.220	3.411	

Notes: CI = confidence interval. *N* = 6.

A hierarchical regression was conducted to determine the predictive ability of total raw score of the GEC on the BRIEF-P and Pre-PAQ on raw score on post-switch trial of the DCCS task. Pre-PAQ was entered in the first step of the model, and raw score for GEC on the BRIEF-P was entered in the second step. The first step of the model accounted for 0% of the variance, R^2 = 0.00, *F*(1, 4) = 0.00, *p* = 1.000. In the first step, Pre-PAQ did not significantly predict performance on post-switch trial of the DCCS task, *B* = 0.00, β = 0.00, *t*(5) = 0.00, *p* = 1.000, 95% CI [-3.228, -3.228]. Adding BRIEF-P GEC accounted for an additional 8% of the variance, ΔR^2 = 0.08, *F*(2, 2) = 0.09, *p* = 9.16. In the second step, teacher-reported GEC did not significantly predict performance on post-switch trial of the DCCS task, *B* = -0.06, β = -0.33, *t*(4) = -0.43, *p* = .710, 95% CI [-0.608, 0.498]. In sum, after controlling for pre-PAQ, results indicated that teacher-reported BRIEF-P GEC scores did not predict participants' performance on post-switch trial. See Table 15.

Table 15

Regression Analysis Predicting Score on Dimensional Change Card Sort Task on Post-switch Trials from Pre-PAQ and BRIEF-P

						95% CI for *B*		
	B	*SE*	β	*t*	*p*	Lower	Upper	R^2
Step 1								0.00
Pre-PAQ	0.00	1.01	0.00	0.00	1.000	-3.228	3.228	
Step 2								0.08
Pre-PAQ	-0.29	1.37	-0.17	-0.21	0.851	-6.181	5.599	
BRIEF-P GEC	-0.06	0.13	-0.33	-0.43	0.710	-0.608	0.498	

Notes: CI = confidence interval. *N* = 4.

A hierarchical regression was conducted to determine the predictive ability of total raw score of the GEC on the BRIEF-P and Pre-PAQ on overall HTKS score. Pre-PAQ was entered in the first step of the model, and raw score for GEC on the BRIEF-P was entered in the second step. The first step of the model accounted for 74% of the variance, $R^2 = 0.74$, $F(1, 5) = 11.64$, $p = .027$. In the first step, Pre-PAQ did significantly and positively predict performance on overall HTKS score, $B = 4.17$, $\beta = 0.86$, $t(5) = 3.41$, $p = 0.27$, 95% CI [0.777, 7.570]. Adding BRIEF-P GEC accounted for an additional 3% of the variance, $\Delta R^2 = 0.03$, $F(2, 5) = 5.13$, $p = .108$. In the second step, teacher-reported GEC did not significantly predict performance on overall HTKS, $B = -0.08$, $\beta = -0.21$, $t(5) = -62$, $p = .577$, 95% CI [-0.500, 0.336]. In sum, after controlling for pre-PAQ, results indicated that teacher-reported BRIEF-P GEC scores did not predict participants' performance on overall HTKS score. See Table 16.

Table 16

Regression Analysis Predicting HTKS Overall Total from Pre-PAQ and BRIEF-P

						95% CI for *B*		
	B	*SE*	β	*t*	*p*	Lower	Upper	R^2
Step 1								0.74
Pre-PAQ	4.17	1.22	0.86	3.41	0.027	0.777	7.570	
Step 2								0.77
Pre-PAQ	3.58	1.63	0.74	2.20	0.115	-1.602	8.770	
BRIEF-P GEC	-0.08	0.13	-0.21	-0.62	0.577	-0.500	0.336	

Notes: CI = confidence interval. *N* = 5.

Hypothesis 3E. Gross motor skills on the Vineland-3 will predict average time in moderate-to-vigorous physical activity and performance on Day/Night and Dimensional Card Sort Tasks. The alpha power at frontal sites will moderate these relationships. This will be assessed using a moderation regression analysis.

To test hypothesis 3E, interaction variables for alpha power at F4 and gross motor skills were calculated. Interaction variables for alpha power at F3 and gross motor skills were also calculated. A hierarchical regression was conducted to determine the predictive ability of gross motor total, alpha power at F4, and the interaction of alpha power at F4 on gross motor total on performance on Day/Night Stroop trials. Gross motor total and alpha power at F4 were entered in the first step of the model, and the interaction of alpha power at F4 on gross motor total was entered in the second step. The first step of the model accounted for 1% of the variance, R^2 = 0.01, $F(2, 3) = 0.02$, $p = 0.979$. In the first step, gross motor total did not significantly predict the Day/Night proportion correct, $B = -0.02$, $\beta = -0.02$, $t(5) = -0.03$, $p = .977$, 95% CI [-2.017, 1.978] nor was alpha power at F4, *B* = -7.45, β = -0.11, *t*(5) = -0.17, *p* = .879, 95% CI [-150.605, 135.712]. Adding the interaction of alpha power at F4 on gross motor total accounted for an additional 58% of the variance, ΔR^2 = 0.57, *F*(3, 2) = 0.97, *p* = .543. In the second step, the interaction did not significantly predict Day/Night proportion correct, *p* = .234.

A hierarchical regression was conducted to determine the predictive ability of gross motor total, alpha power at F3, and the interaction of alpha power at F3 on gross motor total on performance on Day/Night Stroop trials. Gross motor total and alpha power at F3 were entered in the first step of the model, and the interaction of alpha power at F3 on gross motor total was entered in the second step. The first step of the model accounted for 10% of the variance, R^2 = 0.10, *F*(2, 3) = 0.02, *p* = 0.986. In the first step, gross motor total did not significantly predict the Day/Night proportion correct, *B* = -0.02, β = -0.02, *t*(5) = -0.03, *p* = .980, 95% CI [-2.234, 2.196] nor was alpha power at F3, *B* = -5.00, β = -0.09, *t*(5) = -0.12, *p* = .914, 95% CI [-139.887, 129.888]. Adding the interaction of alpha power at F3 on gross motor total accounted for an additional 76% of the variance, ΔR^2 = 0.76, *F*(3, 2) = 2.22, *p* = .325. In the second step, the interaction did not significantly predict Day/Night proportion correct, *p* = .124.

A hierarchical regression was conducted to determine the predictive ability of gross motor total, alpha power at F4, and the interaction of alpha power at F4 on gross motor total on raw score on the post-switch trial of the DCCS task. Gross motor total and alpha power at F4 were entered in the first step of the model, and the interaction of alpha power at F4 on gross motor total was entered in the second step. The first step of the model accounted for 91% of the variance, R^2 = 0.91, *F*(2, 2) = 4.71, *p* = 0.175. In the first step, gross motor total did not significantly predict performance on the post-switch trials of the DCCS task, *B* = 0.08, β = 0.91, *t*(4) = 2.90, *p* = .101, 95% CI [-0.040, 0.204] nor was alpha power at F4, *B* = -3.96, β = -0.61, *t*(4) = -1.93, *p* = .194, 95% CI [-12.825, 4.897]. Adding the interaction of alpha power at F4 on gross motor total accounted for an additional 13% of the variance, $\Delta R^2 = 0.13$, *F*(3, 1) = 6.76, *p* = .247. In the second step, the interaction did not significantly predict performance on the post-switch trials of the DCCS task, *p* = .346.

A hierarchical regression was conducted to determine the predictive ability of gross motor total, alpha power at F3, and the interaction of alpha power at F3 on gross motor total on raw score on the post-switch trial of the DCCS task. Gross motor total and alpha power at F3 were entered in the first step of the model, and the interaction of alpha power at F3 on gross motor total was entered in the second step. The first step of the model accounted for 89% of the variance, $R^2 = 0.89$, *F*(2, 2) = 3.80, *p* = 0.208. In the first step, gross motor total did not significantly predict performance on the post-switch trials of the DCCS task, *B* = 0.09, β = 1.02, *t*(4) = 2.74, *p* = .112, 95% CI [-0.053, 0.237] nor was alpha power at F3, *B* = -3.46, β = -0.63, *t*(4) = -1.67, *p* = .236, 95% CI [-12.364, 5.443]. Adding the interaction of alpha power at F3 on gross motor total accounted for an additional 20% of the variance, $\Delta R^2 = 0.20$, *F*(3, 1) = 39.66, *p* = .116. In the second step, the interaction did not significantly predict performance on the post-switch trials of the DCCS task, *p* = .128.

A hierarchical regression was conducted to determine the predictive ability of gross motor total, alpha power at F4, and the interaction of alpha power at F4 on gross motor total on average time spent in moderate-to-vigorous physical activity. Gross motor total and alpha power at F4 were entered in the first step of the model, and the interaction of alpha power at F4 on gross motor total was entered in the second step. The first step of the model accounted for 76% of the variance, $R^2 = 0.76$, *F*(2, 3) = 2.08, *p* = 0.271. In the first step, gross motor total did not significantly predict performance on average time spent in moderate-to-vigorous physical activity, *B* = 0.32, β = 0.83, *t*(5) = 1.95, *p* = .147, 95% CI [-0.205, 0.852] nor was alpha power at F4, *B* = -4.633, β = -0.17, *t*(5) = -0.40, *p* = .723, 95% CI [-42.527, 33.262]. Adding the interaction of alpha power at F4 on gross motor total accounted for an additional 2% of the variance, $\Delta R^2 = 0.02$, *F*(3, 2) = 0.99, *p* = .539. In the second step, the interaction did not significantly predict performance on average time spent in moderate-to-vigorous physical activity, *p* = .804.

A hierarchical regression was conducted to determine the predictive ability of gross motor total, alpha power at F3, and the interaction of alpha power at F3 on gross motor total on average time spent in moderate-to-vigorous physical activity. Gross motor total and alpha power at F3 were entered in the first step of the model, and the interaction of alpha power at F3 on gross motor total was entered in the second step. The first step of the model accounted for 75% of the variance, $R^2 = 0.75$, *F*(2, 3) = 1.95, *p* = 0.287. In the first step, gross motor total did not significantly predict performance on average time spent in moderate-to-vigorous physical activity, *B* = 0.32, β = 0.80, *t*(5) = 1.68, *p* = .191, 95% CI [-0.281, 0.911] nor was alpha power at F3, *B* = -2.19, β = -0.09, *t*(5) = -0.19, *p* = .860, 95% CI [-38.481, 34.101]. Adding the interaction of alpha power at F3 on gross motor total accounted for an additional 4% of the variance, $\Delta R^2 = 0.04$, *F*(3, 2) = 1.02, *p* = .529. In the second step, the interaction did not significantly predict performance on average time spent in moderate-to-vigorous physical activity, *p* = .696.

Post-hoc analyses

Post-hoc analyses were conducted to determine if age and frontal asymmetry predicted performance on EF laboratory measures. A hierarchical regression was conducted to determine the predictive ability of participant age and frontal asymmetry on Day/Night proportion correct on the post-switch trial. Participant age was entered in the first step of the model, and frontal asymmetry was entered in the second step. The first step of the model accounted for 28% of the variance, $R^2 = 0.28$, $F(1,34) = 12.97$, $p < .001$. In the first step, participant did significantly predict the Day/Night proportion correct, $B = 28.79$, $\beta = 0.55$, $t(35) = 3.60$, $p = .001$, 95% CI [12.543, 45.033]. Adding frontal asymmetry accounted for an additional 2% of the variance, $\Delta R^2 = 0.02$, $F(2, 33) = 6.84$, $p = .003$. In the second step, frontal asymmetry did not significantly predict Day/Night proportion correct, $p = .381$. In sum, after controlling for age, results indicated that frontal asymmetry was not predictive of participants' Day/Night proportion correct.

A hierarchical regression was conducted to determine the predictive ability of participant age and frontal asymmetry on raw score on the post-switch trial of the DCCS task. Participant age was entered in the first step of the model, and frontal asymmetry was entered in the second step. The first step of the model accounted for 36% of the variance, $R^2 = 0.36$, $F(1,33) = 5.05$, $p < .05$. In the first step, participant did significantly predict performance on post-switch trial of the DCCS task, $B = 1.86$, $\beta = 0.36$, $t(34) = 2.25$, $p = .031$, 95% CI [0.177, 3.545]. Adding frontal asymmetry accounted for an additional 10% of the variance, $\Delta R^2 = 0.10$, $F(2, 32) = 2.82$, $p = .075$. In the second step, frontal asymmetry did not significantly predict performance on post-switch trial of the DCCS task, $p = .431$, 95% CI [-0.903, 0.394]. In sum, after controlling for age, results indicated that frontal asymmetry was not predictive of participants' performance on post-switch trial of the DCCS task.

A hierarchical regression was conducted to determine the predictive ability of participant age and frontal asymmetry on overall scores on HTKS. Participant age was entered in the first step of the model, and frontal asymmetry was entered in the second step. The first step of the model accounted for 27% of the variance, $R^2 = 0.27$, $F(1,34) = 2.65$, $p = .113$. In the first step, participant did not significantly predict overall scores on HTKS, *B* = 4.90, β = 0.27, *t*(35) = 1.63, *p* = .113, 95% CI [-1.215, 11.015]. Adding frontal asymmetry accounted for an additional 2% of the variance, $\Delta R^2 = 0.02$, *F*(2, 33) = 1.75, *p* = .189. In the second step, frontal asymmetry did not significantly predict overall scores on HTKS, *B* = -1.14, β = -0.16, *t*(35) = -0.93, *p* = .359, 95% CI [-3.649, 1.361]. In sum, after controlling for age, results indicated that frontal asymmetry was not predictive of participants' overall scores on HTKS.

Additional post-hoc analyses were conducted to determine if frontal asymmetry would moderate the relationship time spent in moderate-to-vigorous physical activity and performance on EF laboratory measures. A hierarchical regression was conducted to determine the predictive ability of average time spent in MVPA, frontal asymmetry, and the interaction of frontal asymmetry on average time spent in MVPA on performance on Day/Night Stroop trials. Average time spent in MVPA and frontal asymmetry were entered in the first step of the model, and the interaction of frontal asymmetry on average time spent in MVPA was entered in the second step. The first step of the model accounted for 36% of the variance, $R^2 = 0.36$, *F*(2, 31) = 2.32, *p* = 0.115. In the first step, average time spent in MVPA did not significantly predict the Day/Night proportion correct, *B* = 0.64, β = 0.25, *t*(33) = 1.49, *p* = .45, 95% CI [-0.234, 1.517] nor was frontal asymmetry, *B* = -5.30, β = -0.26, *t*(33) = -1.55, *p* = .132, 95% CI [-12.231, 1.685]. Adding interaction of frontal asymmetry on average time spent in MVPA accounted for an additional 0.4% of the variance, $\Delta R^2 = 0.004$, *F*(3, 30) = 1.54, *p* = .223. In the second step, the interaction did not significantly predict Day/Night proportion correct, *p* = .723.

A hierarchical regression was conducted to determine the predictive ability of average time spent in MVPA, frontal asymmetry, and the interaction of frontal asymmetry on average time spent in MVPA on raw score on the post-switch trial of the DCCS task. Average time spent in MVPA and frontal asymmetry were entered in the first step of the model, and the interaction of alpha power at F4 on gross motor total was entered in the second step. The first step of the model accounted for 39% of the variance, $R^2 = 0.39$, $F(2, 29) = 2.61$, $p = 0.091$. In the first step, average time spent in MVPA did not significantly predict performance on the post-switch trials of the DCCS task, $B = 0.08$, $\beta = 0.33$, $t(31) = 1.94$, $p = .063$, 95% CI [-0.004, 0.159] nor was frontal asymmetry, $B = -0.38$, $\beta = -0.21$, $t(31) = -1.21$, $p = .236$, 95% CI [-1.033, 0.264]. Adding the interaction of frontal asymmetry on average time spent in MVPA accounted for an additional 1% of the variance, $\Delta R^2 = 0.01$, $F(3, 28) = 1.86$, $p = .159$. In the second step, the interaction did not significantly predict performance on the post-switch trials of the DCCS task, $p = .498$.

A hierarchical regression was conducted to determine the predictive ability of average time spent in MVPA, frontal asymmetry, and the interaction of frontal asymmetry on average time spent in MVPA on overall HTKS. Average time spent in MVPA and frontal asymmetry were entered in the first step of the model, and the interaction of frontal asymmetry on average time spent in MVPA was entered in the second step. The first step of the model accounted for 42% of the variance, $R^2 = 0.42$, $F(2, 32) = 3.41$, $p = 0.045$. In the first step, average time spent in MVPA did significantly predict performance on overall HTKS, $B = 0.27$, $\beta = 0.33$, $t(34) = 2.04$, $p = .049$, 95% CI [0.001, 0.542], but frontal asymmetry did not significantly predict performance on overall HTKS, $B = -1.72$, $\beta = -0.26$, $t(34) = -1.63$, $p = .114$, 95% CI [-3.883, 0.435]. Adding the interaction of frontal asymmetry on average time spent in MVPA accounted for an additional 3% of the variance, $\Delta R^2 = 0.03$, $F(3, 31) = 2.74$, $p = .060$. In the second step, the interaction did not significantly predict performance on overall HTKS, $p = .258$.

CHAPTER FOUR: DISCUSSION

For the Discussion, the main findings of the study will be summarized. After the main findings are summarized, the interpretation of the findings and how they relate to the current literature will be presented. To conclude, the Discussion will identify the study limitations and suggest areas for future research.

Teacher-reported BRIEF-P subscales were significantly and positively associated with each other. This likely indicates that the teacher reporters were consistent in their conceptualizations of each student's level of EF. Likewise, parent-reported Vineland-3 gross motor scores were significantly and positively associated with fine motor scores. This finding demonstrates that parents' conceptualizations of their children's fine and gross motor skills are highly aligned. While the sample size is small, this finding demonstrates that the Vineland-3 has potential as a broad measure of motor development as it was able to show consistency within the larger motor domain. This is unexpected given that Vineland-3 is typically used as a measure of adaptive functioning. The consistencies of the motor subscales suggests that these questionnaires represent reliable measures of development. While consistency was observed within the questionnaire data collection, performance on DCCS, HTKS, and Day/Night were not significantly associated. This suggests that laboratory tasks do in fact represent different components of EF. For example, DCCS as a measure of cognitive flexibility (Zelazo, 2006; Fang et al., 2017), the Day/Night task as a measure of inhibition (Broomell & Bell, 2017; Fang et al., 2017), and the HTKS task as a more cohesive measure of all components of EF (McClelland & Cameron, 2012). The difference in EF lab task performance is interesting, especially given that research suggests a less differentiated EF in preschool populations (Wiebe & Karbach, 2018).

When examining the predictive ability of parent-reported and teacher-reported questionnaires, these measures were not found to be significantly predictive of laboratory measures. These are unexpected results as it suggests either the questionnaires are not valid measures of the constructs they intend to capture, or that previous EF skill and time spent engaging in physical activity is not predictive of later EF skills or engagement in moderate-to-vigorous physical activity during unstructured recess. The BRIEF-P has demonstrated past reliability and validity with EF laboratory measures (Duku & Vaillancourt, 2014). Likewise, the Pre-PAQ has demonstrated validity in capturing preschooler's frequency of engagement in physical activity when compared with naturalistic observations (Dwyer et al., 2011). There were a limited number of questionnaires returned by parents. This may in part be due to fatigue as the 189 questions were included from the Vineland-3 (Sparrow et al., 2016) and the pre-PAQ contains 36 questions (Dwyer et al., 2011).

Parents' limited responses may have impacted the analyses. Interestingly though, the pre-PAQ was predictive of performance on HTKS. This aligns with previous research suggesting that physical activity can predict later EF performance (Becker & Nader, 2021; Bidzan-Bluma & Lipowska, 2018). This finding may be due in part to the fact that the HTKS involves more motor movement and activity compared to the DCCS and Day/Night EF tasks, which only require the participant to respond verbally or via pointing. It is possible that associations between the BRIEF-P and the laboratory EF measures were not seen due to their development from differing theoretical conceptualizations of EF. For instance, it has been highly debated whether EF is a unitary construct in preschool populations or can be deconstructed into components or that the components proposed by Diamond develop sequentially, and there is still no clarity within the literature (Griffin et al., 2016). This conceptualization of these findings also suggests that there is a disconnect in the laboratory measures of EF, which focuses on components that are utilized in research compared to observer-reports and self-reports that are utilized clinically. Additionally, the rapid changes in EF as preschool children age make it difficult to capture longitudinal differences using certain measures (Griffin et al., 2016). Measures that have continuous scores are more sensitive (Griffin et al., 2016). HTKS scores are based on scale of 0, 1, and 2 (Griffin et al., 2016) whereas the other EF tasks were scored using a binary scale. In this study, this may be why HTKS demonstrated the best insight into EF. The BRIEF-P has only demonstrated modest correlations with laboratory EF measures in previous studies (Griffin et al., 2016), which indicates that perhaps these analyses were underpowered to detect smaller correlations. Another reason why the BRIEF-P does not align with laboratory EF measures might be that the BRIEF-P was constructed based on measures that were developed for school children. For example, the BRIEF-P was constructed via factor analysis and modeled after the BRIEF, which is for older children, thus there are additional subscales like Emotional Control and Inhibit that combine to make the construct Inhibitory (Skogan et al., 2016). This may explain why associations were not seen between the BRIEF-P and the laboratory measures of EF.

Teacher-reported BRIEF-P and parent-reported fine and gross motor skills were also not predictive of time spent engaging in MVPA or performance on laboratory measures of EF. This finding may be in part due to the nature of the BRIEF-P as mentioned above does not fully align with the three subconstruct of EF proposed and was modified based on older populations (Skogan et al., 2016). The age range of our population was also a bit older than previous studies that have demonstrated the influence of cognitive development on motor development. For instance, cognitive skills at age 2 have predicted motor skills at 4 (Cameron, 2018). It is possible that during the developmental stages of 4 to 6, as most of this sample was, that either cognitive skills are not as predictive of later activity and motor skills or, more likely, the 3-month period between teacher ratings and lab performances was too limited time frame to see these associations. The lack of association of the Vineland-3 motor subscales to MVPA may be due to the limited number of questionnaires returned as mentioned above, thus failing to provide enough power to detect its ability to predict MVPA. While the Vineland-3 does contain these motor indices, it is more often used as a measure of adaptive functioning (Sparrow et al., 2016). This may suggest that the Vineland-3 measures motor skills associated with day-to-day functioning but fails to capture motor skill acquisition in less structured, physical activity (e.g., recess for the preschool participants).

Associations between EEG and EF Laboratory Tasks

Additionally, frontal asymmetry was not predictive of performance on EF laboratory tasks. Contradicting previous findings that alpha frontal asymmetry is associated with EF task performance (Moriguchi & Hiraki, 2011; Wolfe & Bell, 2014; Wiebe & Karbach, 2018). Perhaps a third variable that was not measured could explain the inability for frontal asymmetry to predict EF task performance. For instance, Wolfe and Bell (2014) found higher alpha power in in the left hemisphere compared to the right only in the shy preschool participants that performed well on EF tasks. Additionally, it is possible that our sample did not vary enough in age to detect a difference. For instance, in a longitudinal study, Moriguchi and Hiraki (2011) found that frontal hemispheric activation differed from ages 3 to 4, but where at 3 years old, children that performed better on DCCS had higher right frontal activity and higher bilateral frontal activity at 4 years old. Notably, our sample had few participants that were 3 years old. It is also worth noting that these regression analyses were run when controlling for classroom, which was used as a stand in for age. These classrooms consisted of children of various ages as they were determined by age category (e.g., 4 to 5 years old, 2 to 3 years old). Regarding the other EF tasks, studies have found increased left lateral PFC associated with both performance on Stroop tasks and age (Wiebe & Karbach, 2018). However, these studies were conducted with school-age children and adults (Wiebe & Karbach, 2018), so it is possible that the same pattern is not observed in preschool populations. No significant, positive associations were observed with participants' time spent in MVPA at recess and the alpha power at any of frontal electrodes. This is contrary to Sanchez-Lopez and colleagues' (2018) findings of a lower baseline alpha power at F7 and F3 for older adults who were sedentary. It is possible that sedentary behavior uniquely impacts older adult populations, and thus would not be found in preschool populations. It is also possible brain region differentiation in association with EF constructs is not seen until later in childhood (Griffin et al., 2016).

Associations between Physical Activity, Motor Skills, Frontal Lobe Activity, and Executive Functioning

Regarding the moderation analyses, alpha power of F3 demonstrated no significant impact on the relationship between gross motor skills and performance on Day/Night did nor did it demonstrate a significant influence on the relationship between gross motor skill and engagement in MVPA. Likewise, alpha power at F4 also did not significantly impact or moderate the relationship between gross motor skills and time spent engaging in MVPA. Additionally, alpha power at F4 did not significantly impact the relationship between gross motor skills and performance on the Day/Night task. The limited number of parent responses resulted in underpowered analyses. It is also possible that frontal power at baseline does not effectively capture the influence of MVPA on executive function. It is possible that MVPA more directly impacts subcortical regions, such as the cerebellum, especially in relation to cognitive development like EF (Diamond, 2000). Another explanation of this finding might be that physical activity does not begin to influence cortical activity until later in life as most studies demonstrated associations among physical activity, EF, and electrophysiological brain activity in older populations involve school-aged children (Arabi et al., 2023; Chang et al., 2012; Chaddock-Heyman et al., 2013; Cox et al., 2020; Davis et al., 2011; Kim & So, 2015; Sanchez-Lopez et al., 2018). Additionally, it is possible that physical activity more directly impacts task-dependent EEG recordings (Kao et al., 2021). These findings are preliminary and based on an observational study. Further research is needed, particularly experimental studies that employ physical activity as an intervention. Additional investigation is needed to determine how motor development is associated with cognitive development and neural development in preschool populations, specifically a longitudinal study that involves a longer timeframe between points of data collection to better identify how these constructs interact.

Limitations

A major limitation of this study is that few parents (5) completed the Vineland-3 and Pre-PAQ. With a limited number of parents completing the questionnaires, the analyses aimed at understanding the associations between motor skills, physical activity, and EF were underpowered. In addition to the limited number of returned questionnaires, a couple of the parents of participants failed to complete every question. This likely impacted overall scores on the gross and fine motor subscales, and thus did not provide the entire picture of that child’s abilities. It is possible that the instructions were unclear, or that the parents experienced technical difficulties accessing each question. The Vineland-3 is a lengthy measure, which may have impacted parent engagement. However, since the reason for these missing questionnaires and questions is unknown, and they exclusively impacted only the parent reports it does hinder the study in considering the data missing at random and led to underpowered analyses that involved parent data.

Additionally, only teachers at the two largest Head Start sites completed the teacher-reported questionnaires, namely the BRIEF-P. It is possible that this skewed the results by possibly impacting the variance within the sample. Furthermore, while most teachers sent in their response prior to May. There were questionnaires for a few students that were returned later while collecting the lab measures, which may have impacted the results. While teachers were provided questionnaires in February, it is not a guarantee that they completed it at this time as the instructions on the link stated for them to complete at their earliest convenience. This would mean that results for some students were obtained closer to the in vivo data collection date, which would mean that insufficient time passed between time points for the longitudinal data. This reduces the potential predictive capacity of the teacher reports. This would also shorten the already short timeframe further as the timeframe between February 2022 and May 2022 is only 3 months. Even without considering that teachers returned questionnaires closer to the second time, there was already a limited timeframe between data collection points, which may have failed to capture significant cognitive or motor development. There were difficulties in scheduling in vivo data collection as the Head Start programs ended earlier than initially anticipated. This led to an accelerated timeframe that reduced time between data collection to 3 months or less, which may not have been a sufficient time to see significant developmental changes in EF, motor skills, or physical activity.

Another major limitation of the study is the limited reliability coding of the laboratory tests available. While all research team members were trained to administer HTKS, DCCS, and Day/Night tasks and completed live scoring of the tasks, there were technical issues with the cameras used during data collection, such that video review and reliability coding were unable to be completed for 20% of the measures. Because of this, it is difficult to assess the reliability of the EF laboratory measures.

Future Directions

While this study aimed to determine the relationship between engagement in moderate-to-vigorous physical activity and motor development with EF development and frontal activation, it failed to capture mechanistically the influence of engagement in physical activity on motor and cognitive development. This was an observational study, so it cannot ensure any causative relationship of physical activity on cognitive, neural, or motor development. Future studies should aim to determine if mechanistically physical activity impacts frontal activation and thus cognitive development using an experimental study.

Additionally, relying on parental report of motor skills may not have fully captured preschool students' motor abilities. Therefore, a future study may aim to use a motor assessment tool, such as the Movement Skills Assessment (Lin, 2007). This could be used as a screening procedure that separates participants into high and low motor skill ability. Future studies should employ both laboratory measures of motor development in addition to parent-report motor development questionnaires. This would allow for determination if the Vineland-3 is sufficient in capturing the observed motor abilities of preschool children. It would provide researchers information about the validity and reliability of parent-report motor development questionnaires that are often used clinically.

Future studies should also focus on gathering both cross-sectional and longitudinal EEG data at various times points to better capture how chronic engagement in physical activity impacts throughout the preschool years may be related to brain development. Specifically, this study had a limited timeframe. To understand the development of cognitive and motor skills better during the preschool stage and their relationship to level of physical activity and alpha power at frontal electrode sites, distinct time points need to be isolated to provide information about how the relationship between these constructs change over time.

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APPENDIX A: DEMOGRAPHICS QUESTIONNAIRE

Teacher Questionnaire:

Instructions: Please complete the following questions to help us learn about the many factors related to this child's development. Your participation is voluntary, and you are free to skip any question you do not wish to answer. All information will be kept confidential and will not be associated with your name.

1. The name of the child for whom you are completing the survey (both first and last):____________________
2. Child's age: ________________
3. Childs date of birth: ______________________
4. Child's gender
    - ○ Boy
    - ○ Girl
    - ○ Other
5. Child's race/ethnicity (select all that apply)
    - ○ American Indian or Native Alaskan
    - ○ Asian
    - ○ Black or African American
    - ○ Hispanic or Latinx
    - ○ Middle Eastern or North African
    - ○ Native Hawaiian or Pacific Islander
    - ○ White
    - ○ Another race, ethnicity, or origin (please define): ______________________________
6. Is there a second language that this child is exposed to? If so, what is it?
   ____
   ____
7. What is your relation to the child? ____

APPENDIX B: PARENT QUESTIONNAIRES

Please complete the following questions to help us learn about the many factors related to your child’s development. Your participation is voluntary and you are free to skip any question you do not wish to answer. All information will be kept confidential and will not be associated with your name.

Child's date of birth

Child's gender

- ○ Male
- ○ Female
- ○ Intersex

Child's race/ethnicity (select *all that apply*):

- ☐ American Indian or Native Alaskan
- ☐ Asian
- ☐ Black or African American
- ☐ Hispanic or Latinx
- ☐ Middle Eastern or North African
- ☐ Native Hawaiian or Pacific Islander
- ☐ White
- ☐ Another race, ethnicity, or orgin (please define):

What is the primary language spoken at home?

Is there a second language that your child is exposed to? If so, what is it?

At how many weeks gestation was your child born?

How much did your child weigh? (please answer in pounds and ounces)?

Was your child given oxygen at birth?

- ○ Yes
- ○ No

Were there any complications with delivery?

- ○ Yes
- ○ No

Is yes, please explain.

Has your child been diagnosed with any developmental delays?

- ○ Yes
- ○ No

Is yes, please explain.

Has your child been diagnosed with any medical conditions?

- ○ Yes
- ○ No

If yes, please explain.

Does an immediate family member (birth mother, birth father, biological sibilings) has a diagnosis of Autism Spectrum Disorder (including Asperger's Syndrome)?

- ○ Yes
- ○ No

If yes, which relative?

Please answer the following questions about the adults in the child's life.

What is your relation to the child?

What was the age of the birth mother at the time of your child's birth?

What was the age of the birth father at the time of your child's birth?

Please indicate the level of education that you have **completed.** (*select one)*

- ○ Some high school
- ○ High School Graduate/GED
- ○ Associates degree/two-year degree or program
- ○ BA/BS or other four-year degree

- ○ Masters degree
- ○ Doctorate degree
- ○ Other (please specify)

What is your annual gross household income?

- ○ less than $12,000
- ○ $12,000-$22,000
- ○ $22,001-$42,000
- ○ $42,001-$62,000
- ○ $62,001-$100,00
- ○ More than $100,001

Has your family qualified for public assistance such as SNAP or WIC in the last four years?

- ○ Yes
- ○ No

If yes, which program?

APPENDIX C: CODING FOR LABORATORY TASKS

Coding Sheet for 4-year-old Day/Night Task

ID #: **Visit Date:**
Cap: Yes No

Coder: **Time of Visit:**

Day/Night Task STRAIGHT

Stimulus	**Appropriate Response**	**Actual Response**			***Notes:***
		Correct	**Partial**	**Incorrect**	
D	**D**				
N	**N**				
N	**N**				
D	**D**				
N	**N**				
D	**D**				
D	**D**				
N	**N**				
D	**D**				
N	**N**				
N	**N**				**Number correct**
D	**D**				**Total Correct Proportion**

Day/Night Task STROOP

Stimulus	**Appropriate Response**	**Actual Response**			***Notes:***
		Correct	**Partial**	**Incorrect**	
D	**N**				
N	**D**				
N	**D**				
D	**N**				
N	**D**				
D	**N**				
D	**N**				
N	**D**				
D	**N**				
N	**D**				
N	**D**				**Number correct**
D	**N**				**Total Correct Proportion**

Coding Sheet for 4-year-olds
DCCS

First dimension (circle one): color shape Pre-switch Score: Post-switch Score:

	Correct	**Incorrect**		**Correct**	**Incorrect**
Pre-switch			**Post-switch**		
1			**1**		
2			**2**		
3			**3**		
4			**4**		
5			**5**		
6			**6**		

Notes:

CODER'S IMPRESSION:
Does the child understand the rules? (i.e., Are the data useable?)

Yes No

Dimensional Change Card Sort Border Version:

Borders Score:

	Card Shown	**Correct Bin Placement: Colors**	**Correct Bin Placement: Shapes**	**Response**	
				Correct	**Incorrect**
1	Blue Flower **w/Border**	Car Bin	Flower Bin		
2	Blue Flower **No Border**	Flower Bin	Car Bin		
3	Red Car **No Border**	Car Bin	Flower Bin		
4	Red Car **w/Border**	Flower Bin	Car Bin		
5	Blue Flower **No Border**	Flower Bin	Car Bin		
6	Blue Flower **w/Border**	Car Bin	Flower Bin		
7	Red Car **w/Border**	Flower Bin	Car Bin		
8	Red Car **No Border**	Car Bin	Flower Bin		
9	Blue Flower **w/Border**	Car Bin	Flower Bin		
10	Blue Flower **No Border**	Flower Bin	Car Bin		
11	Red Car **No Border**	Car Bin	Flower Bin		
12	Red Car **w/Border**	Flower Bin	Car Bin		

Notes:

CODER'S IMPRESSION:
Does the child understand the rules? (i.e., Are the data useable?)

Yes No