THE IMMEDIATE IMPACT OF COGNITIVELY ENGAGING PHYSICAL ACTIVITY ON PRESCHOOL CHILDREN'S EXECUTIVE FUNCTION

by

Marcia L. Preston

A dissertation submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Education

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ABSTRACT

Executive function (EF) skills are important for a wide-range of outcomes, including academic achievement and socio-emotional development. These outcomes promote a call to action to better understand EF and the factors that may influence its development in young children. Previous research with adolescents and adults provides support for a connection between physical activity and improvements in EF (e.g. Best, 2010), though little is known about the impact of physical activity for preschool children. Utilizing a pre-test, intervention, post-test design, the current study examined the immediate impact of cognitively engaging physical activity on three components of preschool children's executive function skills. Based on previous research, this study hypothesized that a combination of physical activity and cognitive engagement (Best, 2010; Diamond, 2015) would result in the greatest improvements on preschool children's working memory, inhibition, and shifting ability compared to activities high in physical activity but low in cognitive engagement, activities low in physical activity but high in cognitive engagement, and activities low in both.

As expected, the cognitively engaging physical activity condition resulted in the greatest immediate improvements in EF, though in some circumstances, the physical activity condition and the cognitive engagement condition were also effective. In addition to confirming the study hypothesis, this study also adds to the existing literature in several ways: the intervention was effective for preschool children and the effects were found immediately after a short intervention. This study was limited by challenges typical of a dissertation study including potential bias from the lead researcher conducting the interventions, small sample sizes in each condition,

and the difficulty of selecting measures appropriate for a 2-year age range. Future research should continue to expand on these findings by investigating the cumulative effects of cognitively engaging physical activity, considering the role of these activities in combination with or instead of other preschool curriculum programs that have been shown to benefit executive function skills, and examining the transfer of these immediate improvements in executive function to school-readiness behaviors and academic achievement. While there are questions that remain unanswered, the findings here are especially promising in that children benefitted from the intervention after only twelve minutes of activity, thereby providing further justification for increasing daily opportunities for physical activity and exercise play for preschool children.

Chapter 1

INTRODUCTION

Executive function (EF) skills are important for a wide-range of outcomes, including academic achievement and socio-emotional development. These skills organize and control goal-directed behavior (Best, 2010; Zelazo et al., 2016) and together influence attentional, emotional, and physiological responses to stimulation (Blair & Raver, 2014) thereby supporting more effective learning (Zelazo et al., 2016). A wide variety of concepts have been grouped into EF, although recent research has focused on three primary constructs: working memory, inhibition, and shifting. Despite this simplification, there are many complexities involving how these constructs manifest throughout development (Huizinga et al., 2006), how EF is measured (Peterson & Welsh, 2014), and the difference between EF skills in a controlled laboratory setting versus the real world (Isquith et al., 2013).

Regardless of these difficulties, well-established relations have been found between EF and outcomes such as language and math ability (Blair & Razza, 2007; Bull et al., 2008; Diamond & Lee; 2011; Verdine et al., 2014; Zelazo et al., 2016); long-term physical and mental health (Diamond & Lee, 2011; Zelazo et al., 2016) and positive social relationships (Diamond, 2012; Diamond & Lee, 2011). These outcomes promote a call to action to better understand EF and the factors that may influence its development in young children.

Factors that impact EF can be divided into two main categories, stable individual differences such as gender, temperament, and genes and malleable factors such as stress (Raver et al., 2013; Shonkoff, 2011), early caregiving experiences (Bernier et al., 2010), mindfulness practices (Diamond & Lee, 2011; Gallant, 2016; Tang et al., 2012), and physical activity (Best, 2010; Carson et al., 2015; Tomporowski et al., 2015; Verburgh et al., 2014). Malleable factors have been researched more extensively in the literature, perhaps because the stable differences, although potentially influencing susceptibility to EF interventions, cannot be changed and therefore are typically considered for controls. The malleable factors, however, each have their own extensive lines of research.

Physical activity is a factor of particular interest because many recent societal trends, such as the increasing amount of time children spend at daycare, increases in television viewing, and children having fewer siblings than previous generations, may be reducing children's physical activity (Tucker, 2008). Exactly how much less activity children engage in today compared to previous years is difficult to quantify due to lack of suitable baseline data, methodological limitations, and changing methods of assessment (Dollman et al., 2005). However, evidence clearly illustrates that children's participation in physical activity is now constrained by school curricula, parental limits, and safety concerns (Dollman et al., 2005). The majority of preschool age children do not meet the National Association for Sport and Physical Education guidelines of 60 minutes of daily physical activity (Cardon & Bourdeaudhuij, 2008; Tucker, 2008). Low levels of physical activity results in many negative consequences for children, including impacts on bone health, motor skills, self-esteem (Timmons et al., 2007), and academic achievement (Sibley & Etnier, 2003). On the contrary, physical activity has been shown to have many physical, mental, and cognitive health benefits (Brown et al., 2016). The connection with physical health is undeniable:

cardio exercise benefits the cardiovascular system and strengthening exercises benefit body composition and bone health (Strong et al., 2005). The impact of physical activity on mental health and cognitive outcomes are more complex, and possibly result from several different pathways, including neurobiological (e.g. neurotrophin gene and protein expression and grey matter volume), psychosocial (e.g. social connectedness and self-esteem), and behavioral (e.g. sleep) mechanisms (Lubans et al., 2016).

Unfortunately, the technology to examine the complete pathway from physical activity to changes in brain structure to changes in cognitive function is just developing (Lubans et al., 2016). For example, tests such as fMRI and EEGs require the participant to remain still, whereas newer technology like fNIRS can be used during movement (Cutini & Brigadoi, 2014). Therefore, much of the existing research on the relationship between physical activity and executive function relies on behavioral EF outcome tasks rather than measures that could reveal the brain-related mechanisms occurring during physical activity. Research using these EF behavioral outcome tasks with adolescents and adults provides support for this connection between physical activity and improvements in EF (Best, 2010; Carson et al., 2015; Esteban-Cornejo et al., 2015; Reinert et al., 2013; Tomporowski et al., 2008; Tomporowski et al., 2011; Tomporowski et al., 2015; Verburgh et al., 2014). Furthermore, there is some evidence that not just physical activity, but cognitively engaging physical activity has a stronger effect on children's executive function (Best, 2010; Diamond, 2015).

However, many questions remain unanswered. What is cognitively engaging physical activity? Does cognitively engaging physical activity have a greater impact on EF than either physical activity alone or cognitively engaging activities alone? Are the different components of EF: working memory, inhibition, and shifting differentially impacted by physical activity? The following discussion will provide a more detailed explanation of EF and its three components, introduce physical activity as an important factor related to EF development for children, review the recently introduced concept of cognitively engaging physical activity, elucidate why this topic is so important in early childhood, and highlight the challenges of existing research in this area. This examination of the literature will then lead to a recommendation for the present study investigating the immediate impact of cognitively engaging physical activity on preschool children's EF ability.

Defining Executive Function

Executive function includes the neurocognitive skills required for the intentional control of thought, action, and emotion to accomplish a goal. These skills can be observed through certain goal-directed behaviors, such as self-control, emotion regulation, persistence, and planning. These behaviors are not equivalent to EF, but rather are the results of EF abilities (Zelazo et al., 2016). Also, these behaviors are often seen in individuals with certain temperaments such as effortful control, openness to experience, self-discipline, and grit. However, these temperaments are relatively stable traits, unlike the developing capability of an individual’s EF skills. Figure 1 below shows some of the related terms that are often incorrectly juxtaposed with EF.

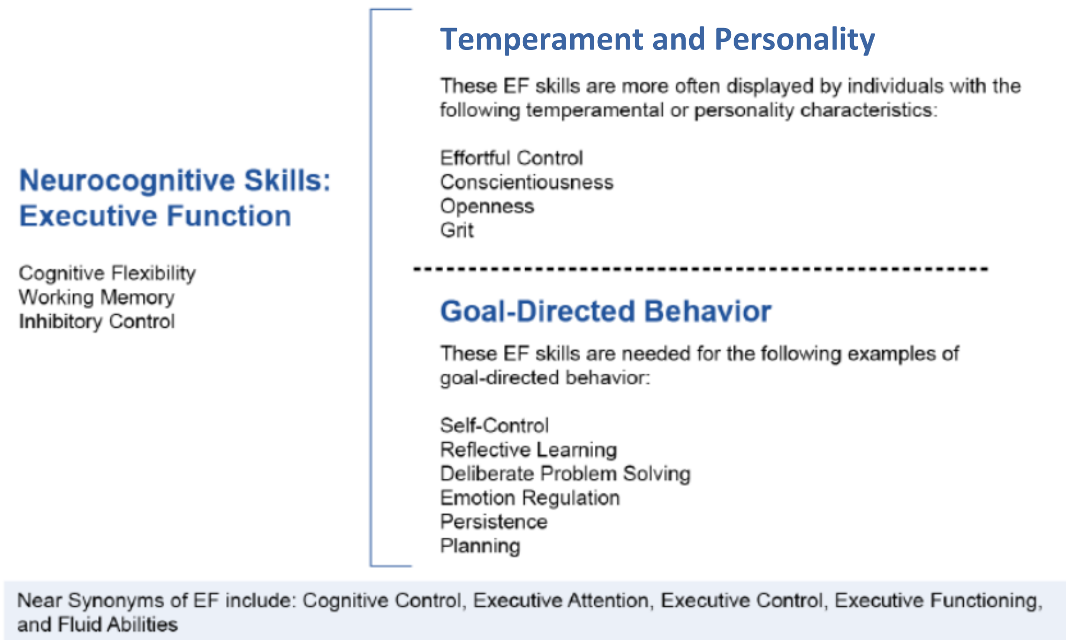

Figure 1 Semantic map of executive function and related terms (Zelazo et al., 2016)

Executive function may also be incorrectly presented as synonymous with social and emotional learning, non-cognitive skills, and self-regulation (Zelazo et al., 2016). Socioemotional learning and non-cognitive skills include EF abilities, plus a wide range of other constructs such as pro-social behaviors, persistence and determination. Self-regulation is also a broad conceptualization of human behavior, referring to all the ways people make conscious and unconscious adjustments in behavior. EF skills are involved when individuals purposefully modify their behavior to achieve a goal (Zelazo et al., 2016). In the psychobiological model of self-regulation (Blair & Raver, 2015), EF is one component that reciprocally influences and is influenced by attention, emotional reactivity, stress response, and genes. Careful interpretation of terms in the literature is advised because sometimes self-regulation (and other terms) are operationalized by the three primary constructs of EF (e.g. Tominey & McClelland, 2011), and therefore may be considered synonymous to EF.

Factor Structure and Development

Most recent research defines and measures EF in terms of three different constructs: working memory, inhibition, and shifting (Lehto et al., 2003; Miyake et al., 2000), yet there is some question of whether these constructs are completely separable and whether that varies across developmental stages. When confirmatory factor analyses were applied to younger preschool children, a one-factor model provided excellent fit to the data (Wiebe et al., 2008; Wiebe et al., 2011). Some studies with preschool children report two-factor models of inhibitory control and working memory (Zelazo et al., 2016); a two-factor model with inhibitory control and shifting as one factor and working memory as another (Lee et al., 2013); and a one-factor model (Nelson et al., 2016).

The developmental changes in EF that occur during these preschool years may be leading to these slightly different models. In fact, longitudinal studies have found stronger correlations among the factors with younger children that become more differentiated as they age (Zelazo et al., 2016). For example, Davidson et al. (2006) administered a battery of EF tasks to children ages 4- to 13-years-old and young adults, finding that even 13-year old children were not at adult levels of shifting ability. Diamond (2013) also suggests that inhibition develops before working memory and that shifting skills develop last. Considering all these models together, the evidence indicates that the structure of these skills may start as a unitary construct in early childhood and then develop into a multi-dimensional three factor construct (working memory, inhibition, and shifting) in middle childhood and beyond (Brydges et al., 2012; Huizinga et al., 2006). More details about how these three EF factors are conceptualized is reviewed below.

Working Memory

Working memory, also referred to as updating, involves selecting and keeping relevant information in mind and mentally manipulating or working with the information (Baddeley & Hitch, 1974; Diamond, 2012; Tominey & McClelland, 2011; Zelazo et al., 2016). Working memory helps make connections between different pieces of information and organize them into a coherent whole.

Baddeley's (2000) model of working memory includes two components that are particularly relevant to this study: the visuospatial sketchpad and the phonological loop (see Figure 2). The phonological loop includes a subvocal rehearsal system that helps hold verbal and acoustic information in a temporary storage system. The visuospatial sketchpad also holds information in a temporary store for subsequent manipulation, and includes separate visual, spatial, and possibly kinesthetic components (Baddeley 2003). The central executive monitors and coordinates the work of the phonological loop and the visuospatial sketchpad by controlling attentional processes. The episodic buffer acts as a backup storage for information and provides a temporary interface from the visuospatial sketchpad and phonological loop to long term memory. Lastly, visual semantics and language are part of long-term memory and include knowledge and facts that have already been acquired.

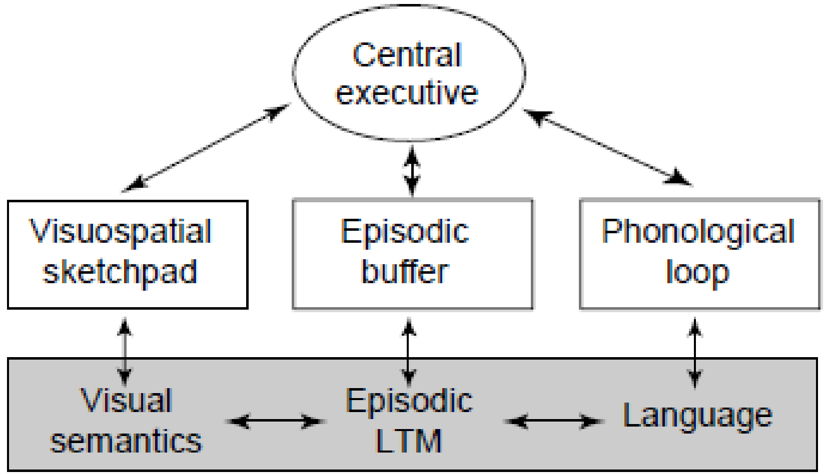

Figure 2 Baddeley's multi-component working memory model (Baddeley, 2000). The episodic buffer is controlled by the central executive and provides a temporary interface between the slave systems (the phonological loop and the visuospatial sketchpad) and long-term memory (LTM).

Assessments of working memory that require utilization of the phonological loop typically require remembering a list of information and then working towards a goal having to do with that information, such as recalling in order, or reverse order, the last items presented (e.g. letter memory task, Miyake et al., 2000; pictorial updating task, Jäger et al., 2014; forward and backward digit span). Tasks that incorporate the visuospatial sketchpad involve visual and spatial relations, such as remembering items that were previously selected to find a hidden object (e.g. Spatial Working Memory; Spin the Pots, Hughes & Ensor, 2005).

Working memory skills are helpful for tasks such as reading comprehension, understanding cause and effect, and mentally calculating math problems. For example, a young child sounding out a word while reading must remember the words read previously while figuring out the new word and combine the information together to comprehend the sentence. Similarly, when mentally working through a two-digit addition problem, children must remember the sum from the ones column while adding the tens column and then combine the numbers together for the final answer.

Inhibition

Inhibition is the ability to exert self-control by considering and eliciting a more adaptive behavior rather than providing a reactionary response (Tominey & McClelland, 2011). Tasks that measure inhibition require identifying the target stimulus while inhibiting attention to a second stimulus (such as congruently or incongruently pointed arrows or fish in the Flanker task), ignoring an audible tone (Stop-Signal test), ignoring word spelling to identify the color of the letters (Stroop task and Color-Word Interference Task), or performing the opposite of an observed skill (Peg Tapping).

Inhibition is helpful for ignoring distractions, avoiding temptations, and responding in a controlled manner to emotional situations. Successful inhibitory behaviors in school settings allow children to focus on a learning task and discern relevant content while ignoring distracting information.

Shifting

Shifting, also referred to as cognitive flexibility, is the ability to change perspectives or think about something in multiple ways (Zelazo et al., 2016), and allows individuals to adjust to changing rules and take advantage of sudden unexpected opportunities (Diamond, 2012). Tasks that measure shifting ability require children to complete a task with one set of rules, and then shift to accommodate a new set of rules (Dimensional Change Card Sorting Task, Zelazo, 2006).

Shifting ability is helpful for figuring out multiple ways to solve a problem, perhaps when an initial method is not working or to discover more efficient or effective solutions. With young children, shifting supports children's ability to transition between activities, use inside and outside voices based on the appropriate context, and adapt to changing rules during games.

Executive Function Development and Training

Research consistently supports the notion that EF skills are malleable (Blair & Raver, 2014). Interventions that have successfully improved EF skills include school curricula, mindfulness, and physical activity (Diamond & Lee, 2011), and specific training on executive function tasks (e.g. computer-based training). These trainings have resulted in improvements on an EF task similar to the construct being trained. For example, computer-based trainings typically train one aspect of EF, such as working memory, resulting in near-transfer improvements to untrained tasks within the working memory construct. However, few of these computerized-training studies have had far-transfer success to a different construct (Diamond, 2012; Thorell et al., 2009).

More comprehensive interventions like school curricula, mindfulness, and physical activity have had greater success at improving more than one EF construct, perhaps because they train multiple constructs simultaneously. Early childhood curriculum programs like Tools of the Mind and Montessori, and curriculum add-on programs like Promoting Alternative Thinking Strategies (PATHS) and the Chicago School Readiness Project (CSRP) have all been shown to improve EF (Diamond & Lee, 2011; Zelazo et al., 2016). These curricula challenge children to develop both academically and in the EF skill domains. For example, in Tools of the Mind, children participate in "Play Planning" where they draw pictures of what they intend to do during the first few minutes of pretend play, thereby helping children to become better self-regulated learners. Curricula interventions also benefit from the continued scaffolding and support from teachers throughout the entire year, providing regular and increasingly more difficult tasks and expectations as children improve in their EF skills.

Some preschool interventions have found that children who start with low levels of EF benefit the most from an intervention. For instance, Bierman et al. (2008) found that children who started the year with low EF showed higher levels of social competence, reduced aggression, and improved print knowledge after participating in a Head Start program enriched with the PATHS curriculum compared to children in typical Head Start classrooms. Also, Tominey and McClelland (2011) found that children who started with low levels of EF experienced significant gains in EF after participating in an intervention that included 16 sessions of circle time games focused on self-regulation over eight weeks, though no effects were found for the overall sample.

Mindfulness and physical activity interventions can also address multiple EF constructs simultaneously. Mindfulness training requires participants to consciously bring awareness and attention to experiences occurring in the present moment, such as focusing on breathing. Tae Kwon Do and yoga interventions that include both mindfulness and physical activity have been particularly encouraging at improving EF with children (Diamond, 2015; Lakes & Hoyt, 2004). Other mindfulness specific trainings have resulted in a consistent benefit to inhibition, but less consistent improvements to shifting and working memory (Gallant, 2016). This selective benefit is similar to the focused results of computerized trainings, perhaps because mindfulness interventions primarily train inhibition through focused control of breathing and attention to the present moment.

Not all physical activity is equally supportive of the development of EF. A consistent theme arising from this research is that practice using higher order thinking skills combined with the neurobiological response due to exercise may impact the development of EF over and above either mechanism alone. For instance, exercise that also includes cognitive demands such as eye-hand coordination or complex coordinated movements required by team sports have all significantly benefitted EF skills (Diamond, 2015). Best (2010) also suggested that simple physical activities like treadmill running and stationary biking may improve some EF skills, but cognitively engaging exercise appears to have a stronger effect on children's EF. This conclusion has been controversial in the literature (Diamond & Ling, 2018; Hillman et al., 2018) but a clear question arising from this debate is that future studies should investigate the difference between cognitively engaging physical activity versus aerobic exercise with minimal cognitive demands.

Physical Activity and Cognitive Engagement

To study cognitively engaging physical activity, the terms *physical activity* and *cognitive engagement* must first be operationalized, especially for young children who do not typically engage in exercise like running on a treadmill or riding on a stationary bike. The following section will examine each of these concepts separately.

Physical Activity

Physical activity is any body movement produced by the skeletal muscles that results in more energy expenditure than a resting state (Tremblay et al., 2007). Physical activity research varies widely in the age, health diagnoses, current obesity status and physical fitness of the sample populations. Many studies focus on the determinants of physical activity such as demographics, the physical environment, and psychological, cognitive, social, and emotional factors (Bauman et al., 2002). Study interventions vary to include walking, running, biking and other programs like yoga, martial arts, sports, physical education classes, and specific activity interventions. Outcome studies investigate either the immediate effects of a single bout of physical activity (acute physical activity interventions) or the impact of multiple sessions of physical activity participation over several weeks, months, or years (chronic physical activity interventions). Note that the term *intervention* is used here to describe one session of activity followed immediately by outcome measures (acute intervention) or several sessions of activity over a longer period of time (chronic intervention), and is more like a training session rather than a detailed program intervention as is typical in education research.

For young children, physical activity often occurs in the context of play, with short bursts of movement and considerable variation in movement type rather than sustained periods of moderate to vigorous physical activity (Bailey et al., 1995). Children's physical activity can be measured in many ways, including self-report and proxy report measures such as questionnaires and diaries, direct observation by a trained researcher, and objective measures such as accelerometry, heart rate, and maximal oxygen consumption (VO_2 max). Objective measures of physical activity are preferred because they minimize bias and can capture small bursts of physical activity typical of preschool children (Oliver et al., 2007).

Cognitive Engagement

The phrase “cognitively engaging physical activity” describes activities that require a combination of both cognitive and physical exercise demands. Inherently difficult actions that require coordination of multiple body parts or require adaptation to changing conditions (Best, 2010) are cognitively engaging. To assess the impact of cognitively engaging physical activity on outcomes such as executive functioning skills, we must discern how much cognitive demand is present in the required activity (Pontifex et al., 2019). Cognitive load theory aids in understanding how to conceptualize the difficulty and complexity of a task.

Consider for instance, how much cognitive demand occurs while participating in a sport such as basketball compared to jogging on a treadmill. Basketball requires an individual to dribble and run at the same time, catch, pass, and shoot a ball, and switch from offense to defense as necessitated by the game. Clearly, basketball is more complex and mentally challenging than jogging on a treadmill. However, complexity cannot be defined solely by the type of activity; the participant's age, previous experience, and familiarity with the task must also be considered. For instance, jumping jacks are relatively easy for teenagers but would be more difficult and require more thought for a preschool child to complete.

Cognitive load is a multidimensional construct that specifically addresses this connection between the characteristics of the task and the variations within individuals. In cognitive load theory, tasks differ based on variables such as complexity, time pressure, and pacing of instruction. Individual differences are based on variables such as expertise and age (Paas et al., 2003). Additionally, cognitive load includes three assessment constructs: mental load, mental effort, and task performance.

Mental load is based solely on the task characteristics (Paas et al., 1994). For instance, in our above examples of cognitively engaging physical activity, the inherently difficult movements requiring coordination of multiple body parts and adaptation to changing conditions are tasks that require more mental load than simple treadmill running. Therefore, mental load can be considered the specific activities. The *mental effort* construct incorporates the human characteristics along with the task demands to reflect the amount of resources an individual utilizes to complete the task, given age, expertise, and prior experience (Paas et al., 1994). This variable can be measured with self-report questionnaires or with physiological measures such as heart rate variability and fMRI (de Jong, 2010). Finally, our conceptualization differs from the standard one in that task *performance* is a product of mental load times mental effort. Individuals may compensate for increases in task complexity (i.e., mental load) by applying more mental effort, therefore resulting in the same performance level.

Existing Research on Physical Activity and Executive Function

The exact mechanism that connects physical activity and executive function remains unknown. However, considering the interdisciplinary nature of this question, we can utilize research from fields such as neuroscience, kinesiology, and developmental psychology to hypothesize that cognitively engaging physical activity (Best, 2010; Diamond, 2015) will result in greater benefits to children's executive function skills when compared to only physical activity, only cognitively engaging activity, or a sedentary control. This hypothesis would rely on a reciprocal interaction of two simultaneous hypotheses: 1) that exercise results in physiological changes in the brain such as releases of brain-derived neurotropic factors (BDNF, Chaddock et al, 2010) or changes in grey matter volume (Lubans et al., 2016); and 2) cognitively engaging activities requiring the use of EF skills may prime these skills for subsequent use (Best, 2012; Pesce et al., 2009), either in near-transfer to tasks within a similar domain or far-transfer to other executive function constructs. Alternatively, the impact of cognitively engaging physical activity on executive function may be solely a result of one of these mechanisms without the other.

Studies are beginning to show that when neurobiological changes occur in the pre-frontal cortex where executive function skills are located, EF improvements are also reflected in behavioral outcome tasks such as the flanker task (Chaddock-Heyman, et al., 2013). Even in studies that do not measure changes in brain structure, evidence of this mechanism can be established by comparing physical activity with a sedentary activity that requires the same level of cognitive demand. For example, Ellemberg and St-Louis-Deschênes (2010) investigated the impact of cycling on a stationary bike with 7-and 10-year-old boys (n=36). Participants in the intervention condition watched a television show and cycled for a 5-minute warm up and then maintained a heart rate of 130 beats per minute for 30 minutes, followed by a cool-down to return their heart rate to 100 beats per minute. Participants in the control condition just sat on the stationary bike and watched the same television show. Children in the physical activity condition significantly improved on a choice task measuring inhibition and shifting compared to the control television watching condition. A limitation of this study is the assumption that watching a television show while biking versus sitting requires the same level of cognitive engagement. If biking while watching television is more cognitively demanding for a child than just watching television, the findings may not be about physical activity, but rather about the differences in cognitive engagement between conditions.

In the latter explanation, this study may be providing evidence that the relationship between physical activity and executive function is due to the cognitive priming that occurs by using higher order thinking skills during an intervention. Claims have been made that many different sedentary cognitive interventions such as computer training programs (Alloway et al., 2013; Ang et al., 2015; Klingberg et al., 2005; Thorell et al., 2009), music instruction (George & Coch, 2011; Sala & Gobett, 2017; Slevc et al., 2016), and chess playing (Bart, 2014) improve executive function skills. However, many of these results are limited by finding only near-transfer performance improvements (Diamond & Lee, 2011), utilizing conceptions of executive function other than the typical three factor model presented in this review, and other study design issues (Boot et al., 2011; Sala & Gobet, 2016).

Although physical activity alone or cognitive engagement alone may result in improvements to executive function, it may be that the combination of these two mechanisms results in even greater improvements (Best, 2010). The only way to discriminate between these two mechanisms, especially in comparison to activities that involve a combination of both, is to utilize a 2 x 2 study design crossing physical activity and cognitive engagement. A few studies have begun to use this design with older children.

Best (2012) found that exergaming (i.e. video games that require vigorous full-body movement) improved executive function skills of 6- to 10-year old children regardless of cognitive engagement. The two exergame conditions included a cognitively engaging version that required adaptation to avoid obstacles combined with increasing difficulty throughout the game compared to a running game that required movements similar to treadmill running. The two low physical activity conditions included watching a video and playing a sedentary video game that increased in difficulty and required adaptation to changing demands.

Jäger et al. (2015) found no main effect for physical activity or cognitive engagement on working memory, shifting, or inhibition for 10- to 12-year-old children. Here, the combination of physical activity and cognitive engagement condition included cooperative and competitive games designed to activate EF skills, the physical activity condition included activities focused on running, the high cognitive engagement condition included card games that required activating EF, and children in the sedentary without cognitive engagement condition sat and listened to a story. Working memory improved significantly more in the physical activity conditions for children with higher fitness levels, and working memory also improved in all three conditions for children with higher academic achievement.

Egger et al. (2018) found that regardless of physical activity, activities with high cognitive engagement resulted in *lower* shifting performance for 7- to 9-year-old children, with no differences by condition in working memory and inhibition. In the cognitively engaging conditions, children listened to a song that had three words dubbed into the music (car, coin, and post office). The two-minute song was played three times, and each time the children were given rules to follow when they heard the words (i.e. car = jump, coin = spin around, and post office = sit down). These rules were shuffled before the song was played a second and third time, so that instead of car prompting them to jump like the first song, the car prompt would mean spin around for the second song. The cognitively engaging but sedentary condition used the same song and rule format, but the motions were seated such as pretending to drive a car after hearing the word car and circling their forefinger and thumb when they heard coin. In the high activity but low cognitive engagement condition, children ran around to the same music, but they imitated the experimenter's motions after each word prompt. The low activity and low cognitive engagement group listened to a 20-minute audio book. Contrary to the study hypothesis, cognitive engagement was detrimental to shifting ability, perhaps because the cognitive engagement requirements of these conditions were too taxing for the children in this study.

Schmidt et al. (2016) also used this 2 x 2 study design to study attentional performance, not specifically EF, finding that acute cognitively engaging activities, but not physical exertion, had an immediate impact on focused attention and processing speed. Conditions lasted 10 minutes and included listening to a story, running at various speeds, doing a paper-and-pencil task that required drawing lines to connect numbers in a sequential order and then doing mental math to add up their score, and doing a physical version of this same task by running from number to number and performing mental math calculations. Changes in positive affect during the intervention also had an important mediating role in their findings.

The conflicting results across these four studies are difficult to interpret due to the many differences in the intervention activities, cognitive tasks and outcomes, and other influencing factors. In particular, the intensity of physical activity has been shown to have an inverted-U relationship with cognitive effects such that too high or too low of physical activity would lead to suboptimal cognitive performance (Jäger et al., 2015). Schmidt et al. (2016) also speculates about a similar inverted-U relationship between the cognitive demands during a physical activity intervention and the cognitive outcomes. Future studies will need to ensure that the physical and cognitive demands of the intervention provide appropriate levels of challenge for the study participants.

Two other studies (Benzing et al., 2016; Schmidt et al., 2015) have varied cognitive engagement and physical activity without the explicit 2x2 design, concluding that physical activity with high cognitive engagement resulted in significantly better shifting ability than two conditions with low cognitive engagement (high and low amounts of physical activity). Because there was not a condition with low amounts of physical activity combined with high cognitive engagement, it may be that the cognitive engagement requirements of the task led to the improvements in shifting rather than the physical activity. Again, a 2x2 study design is crucial to better understand which components of the intervention are the most effective at improving young children's executive function skills immediately following the activity.

Importance of Physical Activity and Executive Function for Early Childhood

In addition to not fully understanding the mechanisms supporting the connection between physical activity and executive function, only a few studies have investigated the impact of physical activity on EF skills in children younger than 6-years-old. Executive function abilities are critical for young children's school readiness and early academic achievement (Cameron et al., 2012; Oberer et al., 2018). Early EF development provides children with a noticeable advantage in school entry (Blair & Razza, 2007), and this advantage continues to accrue, resulting in higher academic achievement (Raver et al., 2011). Finding successful interventions to support young children's EF development, particularly those starting out with lower EF skills, is critical for providing equal opportunities for all children in our education system (Diamond, 2012).

Preschool children are of particular interest because they are not yet participating in formal K-12 school but are old enough to follow directions and participate in games with rules, such as would typically be offered in a preschool environment. Also, EF skills are rapidly developing from about two to six years of age, indicating a potential sensitive period whereby the brain may be particularly susceptible to EF interventions (Zelazo, et al., 2016). Hillman et al. (2008) also suggested that physical activity might result in optimal brain development in early childhood that results in lasting changes in brain structure and function later in life.

To study physical activity with young children, we must consider that they do not engage in traditional moderate-to-vigorous physical activity like adolescents and adults. Instead, physical activity can be thought about in the context of play (Timmons et al., 2007). The impact of play on EF has been studied (Savina, 2014; Whitebread et al., 2009), including both sociodramatic/pretense play (Berk & Myers, 2013; Bodrova & Leong, 2006; Carlson et al., 2014; Elias & Berk, 2002; Thibodeau et al., 2016), and games with rules (Tominey & McClelland, 2011). Exercise play, or vigorous gross-motor movement in the context of play (Pellegrini & Smith, 1998; Telford et al., 2005) is a type of play comparable to physical activity performed by older children and adults. Exercise play occurs in both solitary and social scenarios and includes activities such as walking fast, running, chasing, jumping, pushing, pulling, lifting, climbing, cycling, and participating in sports and games (Pellegrini & Smith, 1998).

Since physical activity is related to improvements in EF for older children and adults, exercise play may provide an opportunity to investigate whether this relationship between physical activity and EF also occurs in young children. Two studies have shown promising results for this relationship with 6 to 8-week long physical activity interventions. Mulvey et al. (2018) found that 3- to 6-year-old children participating in a six-week gross motor skill intervention significantly improved their executive function skills from pre-test to post-test on the Head, Toes, Knees, Shoulders task. Also, Chang et al., (2013) found that kindergarten students participating in an 8-week soccer program improved on their inhibition skills as measured by the Erikson Flanker Task. To better understand the mechanism behind this relationship without considering the multitude of other factors that could be involved in a multi-week intervention, we can start with looking at whether one physical activity session can result in immediate improvements in children's EF skills. Additionally, the immediate effects are of interest, as they may improve classroom readiness behaviors thereby increasing learning immediately following an activity, and ultimately leading to longer term academic achievement. These immediate effects may provide further justification for mandating opportunities for physical activity and exercise play in school curricula through recess and outdoor time, physical education classes, and other similar movement brain breaks. Knowing the best method for impacting immediate improvements in EF skills could lead to future research determining whether engaging in effective activities over a longer term would continue increasing children's overall EF abilities.

Other studies exploring the relationship between physical activity and EF in early childhood have mostly been correlational research designs (Becker et al., 2014; Cameron et al., 2012; Cook et al., 2018; Laufs, 2018; Ludwig & Rauch, 2018; Niederer et al., 2011; Oberer et al., 2018; Stein et al., 2017; Willoughby et al., 2018), used cognitive outcomes and tasks different than the standard three-factor executive function concept presented in this review (Barcelona, 2017; Palmer et al., 2013), or compared intervention groups to different types of control groups such that the contribution of physical activity versus cognitive engagement could not be differentiated (Palmer et al., 2013; Tandon et al., 2018; Zach et al., 2015). Because there are so few studies conducted on this topic during early childhood, more information on each of these studies is provided below.

Correlational Research Designs

Several studies have used correlational research designs to extend the connection between physical activity and EF in older children and adults down to young children. For instance, Becker et al. (2014) found that preschoolers' active play at recess as measured by accelerometers had a significant and direct relationship with self-regulation measured by the HTKS task, and a significant indirect relationship with math and emergent literacy outcomes. Ludwig and Rauch (2018) similarly had 4- to 6-year-old children wear accelerometers for a week. Parents completed a measure of positive affect and self-regulation every evening. Findings showed that moderate-to-vigorous physical activity was indirectly related to self-regulation through parents' daily ratings of their child's positive affect.

Because motor skills and physical fitness are outcome indicators of physical activity, these two constructs have also been studied for their relationship with EF and academic achievement. Preschool children's EF skills have been shown to mediate the relationship between physical fitness (Oberer et al., 2018) or motor skills (Cameron et al., 2012, Laufs, 2018) and academic achievement as measured by standardized tests in reading and math. In another correlational study, Niederer et al. (2011) found that preschool children's aerobic fitness and motor skills related to spatial working memory and attention. In addition, higher baseline fitness and motor skills correlated with improvements in these cognitive skills over the next nine months. Stein et al. (2017) also found a positive correlation between 5- to 6-year old children's motor skills (e.g. manual dexterity, ball skills, and balance) and their executive function skills. However, a subsequent 25-minute intervention focused on coordinative exercises matched to the participant's ability level only impacted motor inhibition via a Simon Says task when tested immediately following the intervention. There were no significant differences between the intervention and control conditions on cognitive inhibition and shifting. Another recent study investigated the correlation between both gross motor skills and a week of physical activity measured by accelerometers with working memory, inhibition and shifting for low-income preschool children in South Africa (Cook et al., 2018). Inhibition and working memory, but not shifting were related to gross motor skills and physical activity was negatively associated with working memory. Here, the majority of children's physical activity throughout the week was during unstructured play, leading the authors to propose that perhaps more cognitively engaging physical activity would yield more beneficial effects on EF.

Willoughby et al. (2018) also found results contrary to the hypothesized relationship between physical activity and EF. They conducted a cross-sectional investigation of one week of accelerometer data and executive function assessed at the beginning of the week using EF Touch, a computerized battery of EF tasks designed for early childhood. Contrary to the study hypotheses, they found an inverse relationship between moderate-to-vigorous physical activity and EF. Because the context of children's physical activity during that time was unknown, other factors may have compounded this relationship, such as varying levels of social interaction and cognitive challenges that occurred throughout the day. Also, the more active children may have hyperactive-impulsive behaviors reflective of lower EF abilities, but leading to more activity across the five-day period. Note that physical activity has been shown to improve EF skills for children with ADHD (Piepmeier et al., 2015; Ziereis & Jansen, 2015), though a review of those studies is beyond the focus of the current study.

Because the conceptualization of physical activity and EF is so different across these studies, that several of them use fitness or motor skills as indicators of higher physical activity, there is variation in other factors considered (social engagement and affect), and the results are inconsistent across studies, these correlational studies provide a great starting point for future research. One particularly interesting area of research is to determine whether physical activity interventions could have an impact not only on fitness and motor skills, but also on children's executive function skills.

Other Cognitive Outcomes and Tasks

Only a few studies have investigated the immediate impact of a physical activity intervention on preschool children's cognitive function. In two of them, the outcomes variables, such as attention and academic achievement, had a slightly different focus than the three-factor executive function model in this review. Barcelona (2017) found that 4- to 6-year-old children who participated in six minutes of a physically active dance activity outperformed peers on attention and math performance tasks immediately following the activity. This dance condition was deemed more cognitively engaging than an aerobic intervention condition and more high intensity than a yoga control, although cognitive engagement was not measured during the study.

Palmer et al. (2013) investigated EF outcomes after preschool children's participation in a 30-minute movement program targeting motor skills through activities like hopping onto targets, throwing, and dribbling, compared to sedentary activities like arts and crafts, cooking, and listening to a story. Children in the movement program performed significantly better on a test of sustained attention compared to children in the sedentary condition. Results for response inhibition trended in the hypothesized direction but were not significant. Attention and inhibition were measured with the same task, the Picture Deletion Task for Preschoolers (PDTP), which requires the child to only circle images of a target animal and inhibit circling all the other animals on the page. The authors suggest the PDTP may not be sensitive to detect changes in inhibition, perhaps because this task does not require children to override a prepotent response like a Flanker or Stroop task. Also, the sedentary activities may have activated children's use of executive function by employing their creativity in the activities. Regardless of the insignificant inhibition results, this study is one of the first to investigate the immediate impact of preschool children's physical activity on cognitive skills like the inhibition component of EF. Future research should utilize more commonly used measures of all three EF factors and make sure the control conditions can differentiate between physical activity and cognitive engagement required during the activities.

Unknown Contribution of Cognitive Engagement and Physical Activity

The three remaining studies investigating the immediate impact of a physical activity intervention on executive function skills in early childhood compared intervention groups to different types of control groups such that the contribution of physical activity versus cognitive engagement could not be differentiated. For example, in Palmer et al.'s (2013) study discussed above, it is unclear whether the arts and crafts, cooking, and listening to a story incorporated similar cognitive demands as the motor skill activities, thereby priming the children's EF skills for subsequent use.

In another recent study, Zach et al. (2015) randomly assigned 123 kindergarten children by classroom to one of three conditions: orienteering, dance, or the recess as usual control condition. All three programs lasted for 9 weeks with the two intervention groups receiving instruction that gradually increased in level of difficulty. Based on pre- and post-test data within and between groups, Zach et al. (2015) confirmed their hypothesis that physical activity programs such as orienteering and dance improve executive function in early childhood. However, there were no objective measures of physical activity, nor any attempts to control for the level of cognitive engagement, so it is unclear whether the findings are a result of physical activity as the authors claim, or the cognitive demands of the intervention.

Tandon et al. (2018) conducted a study investigating the immediate impact of 15 minutes of physical activity on three- to five-year-old preschoolers' inhibition and working memory. A research assistant focused on engaging one child in chasing games, running, and jumping activities during their preschool outdoor play time, although other children were allowed to participate too. After 15 minutes of play time, the focal child was taken to a quiet room to complete the executive function tasks. One to two weeks later, the same child completed a sedentary condition by engaging in 15 minutes of story time, crafts, and coloring, followed by the same EF tasks. The order of conditions was counterbalanced across participants. In both conditions, researchers were trained to minimize the amount of cognitive engagement during the intervention by not asking questions or playing games like Red Light/Green Light. Contrary to the hypothesis, the only significant difference in EF outcomes was that after the *sedentary* condition, 3-year-old children did *better* on a test of inhibitory control. There were no differences by condition for any of the other cognitive tasks, and no differences were found on any of the outcome tasks for the 4- and 5-year old children. There may be many reasons why the physically active condition did not result in greater EF performance for 3-year-olds, including the participants young age, the length of the intervention, or the social interaction in both conditions. Or perhaps the story book reading activity in the control condition was more cognitively engaging than the loosely structured physical activity on the playground, or in other words, the physical activity alone was not as effective for improving EF outcomes as a cognitively engaging control activity.

Present Study

Research with adolescents and adults suggests there is a relationship between executive function and both acute and chronic physical activity, but the mechanisms supporting these connections remain unclear (Best, 2010). In addition, very few studies have explored this relationship with young children. These existing studies have limitations in their study design such that we still do not know which type of activities best impact children's executive function skills immediately following the intervention.

Therefore, the present study utilizes a 2 x 2 study design, crossing cognitive engagement and physical activity, to differentiate which type of activities will lead to the greatest immediate improvements in 4- and 5-year-old children's executive function skills. This study hypothesizes that cognitively engaging physical activity will result in greater performance on children's working memory, inhibition, and shifting ability compared to activities high in physical activity but low in cognitive engagement, activities low in physical activity but high in cognitive engagement, and activities low in both physical activity and cognitive engagement.

Having an understanding of which type of activities result in the best immediate improvements in EF will provide guidance to parents, teachers, and administrators who are interested in maximizing the caregiving environments of young children. For instance, the immediate effects of these activities may provide further justification for increasing physically and cognitively engaging activities immediately prior to important instructional moments and activities. In addition, future research could better design intervention and control conditions for longer-term interventions to ascertain whether engaging in these activities over time would continue increasing children's overall executive function abilities.

Chapter 2

METHOD

Participants

One hundred twenty-six children were recruited from ten childcare facilities in southeastern Pennsylvania and northern Delaware. Many of the childcare facilities offered subsidized programs based on family income such as Migrant Education, Head Start, and Pennsylvania Pre-K Counts. Informed consent letters were distributed by the childcare directors and teachers to all families with a child in their four- and five-year-old classrooms. Fifteen children were dropped from the study because they were absent at post-test (n=13) or did not participate in the intervention (n=2). The final sample included 111 children ages 48- to 71-months (M=58.5, SD=6.5). This sample was 53% female, 91% White and 59% Latino. Primary caregiver's education level was used as a proxy for socioeconomic status. Approximately 34% of the primary caregivers attended or completed primary school or graduated high school, 41% completed some college, attended a certificate program or obtained a college degree, and 25% completed a post-graduate degree.

Procedure

A parent completed a consent form and background questionnaire prior to their child's participation. The study utilized a pre-test, intervention, post-test study design as shown below in Figure 3.

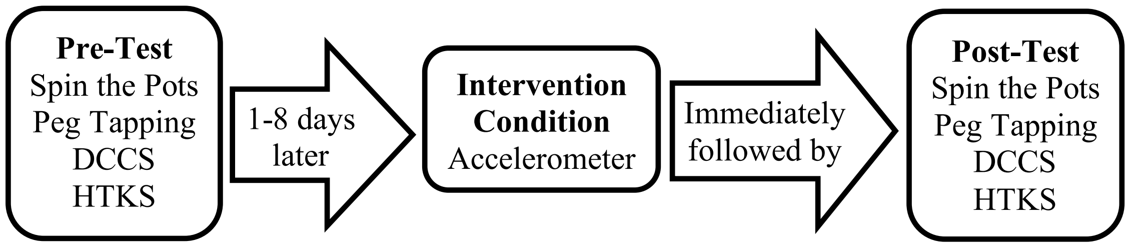

Figure 3 Pre-Test, Intervention, Post-Test Study Design with Measures Used

Each participant was randomly assigned to one of four conditions that varied physical activity and cognitive engagement in a 2x2 grid (see Table 1). The high activity combined with high cognitive activities incorporated rules and goals within the activities that intentionally challenged specific components of executive function and required children to spend a majority of the time in moderate-to-vigorous physical activity. The high activity with low cognitive condition still included movement activities requiring moderate-to-vigorous physical activity yet minimized the use of executive function skills by utilizing simple instructions. Children in the low activity with high cognitive condition sat while they participated in activities that challenged their executive function skills. Children in the low activity and low cognitive condition sat while they participated in a simple coloring activity. The specific activities for each of these conditions are described below under intervention conditions.

Table 1 Description of physical activity and cognitive engagement conditions for a 2x2, between subjects, study design

	High Cognitive Engagement	**Low Cognitive Engagement**
High Physical Activity	High Activity/High Cognitive (PACE) *Freeze Dance* Increasingly difficult rules of activity require use of working memory, inhibition, and shifting Majority of time spent in moderate to vigorous physical activity	High Activity/Low Cognitive (PA) *Dance Party* Rules require following simple instructions Majority of time spent in moderate to vigorous physical activity
Low Physical Activity	Low Activity/High Cognitive (Cognitive) *Freeze Drumming* Increasingly difficult rules of activity require use of working memory, inhibition, and shifting Mostly sedentary and light physical activity	Low Activity/Low Cognitive (Low) *Coloring* Rules require following simple instructions Mostly sedentary and light physical activity

Researcher Training

Twelve research assistants participated in a training workshop on basic elements of research with children (e.g. reliability, validity, staying blind to condition, child development and child-friendly communication) and how to run the pre- and post-test measures of executive function. Researchers were given an orientation to the protocols and then practiced administering each measure until they were comfortable with the scripts. Prior to working with children, each research assistant demonstrated administering the measure while the first author (hereafter referred to as "lead") observed to ensure adherence to the protocols. Throughout the testing period, the lead occasionally observed each research assistant to ensure continued fidelity to the protocol.

Pre-Test Procedures

Children were divided into small groups of three to five participants to ensure that each testing group for the day was similar in size. Group size was also based on the number of research assistants present and the children's availability to participate. The lead brought the small group of children to an area separate from their classroom to complete the pre-test session. Children stood in a circle with the lead who introduced the research team, explained the plan for the day, and asked the children for their assent, indicated by a thumbs up, if they were ready and willing to participate.

Each child was paired with a research assistant who stood next to their assigned child in the circle. The lead led everyone in a welcome song to help the children become comfortable with the researchers. Each research assistant then led their assigned child to a separate area of the room, divided by classroom furniture and other objects, to complete the four pre-test measures of executive function skills: working memory, inhibition, shifting, and overall executive function (see measures section below). The order of the first three tasks was counterbalanced across participants to control for the potential impact the tasks could have on each other. The overall executive function measure was always administered last because the gross motor movement requirements of the task could have impacted subsequent executive function testing. Children were randomly assigned to a specific order for the cognitive tasks, used at both pre- and post-test.

Upon completion of the tasks, the research assistant measured the child's height and weight which was necessary for initializing the accelerometer during the intervention. The researcher and child then read a book or sat quietly until all children in the small group finished with their pre-test measures. The lead then gathered the children together, explained that the researchers would be back in a few days to play more games, and walked the children back to their classrooms.

Intervention and Post-test Procedures

Within one to eight days after the pre-test session (*M* = 2.6 days), participants completed the intervention and post-test procedures. Over 85% of the children participated in the intervention and post-test between two to four days after the pre-test. Children were assigned to small groups of three to five participants based on assigned intervention condition, the number of research assistants present and the children's availability to participate.

The accelerometer devices were prepared and initialized by the lead. The lead then brought the small group of children to an area separate from their classroom to complete the intervention and post-test session. Once all children were present, the lead explained the plan for the day, including that the activities were going to be a little different and asked the children for their assent. Each child was paired with a research assistant (different from the researcher who conducted their pre-test) who fitted their assigned child with the accelerometer to wear for the duration of the intervention, approximately 15 minutes. The pairs then stood next to each other in a circle and the lead led the children and research assistants in the welcome song. A neutral observer sat to the side of the group to record the start and stop time of the intervention activities which were used as start and stop times for the accelerometer data collection.

The research assistants left the room so they could not see or hear which intervention condition was being conducted. The lead then led the children in the intervention activities as explained below. Once the intervention was complete, activity materials were packed up and the research assistants were brought back into the room.

Each research assistant then greeted their assigned child, removed the accelerometer device and led the child to a separate area of the room where they conducted the four post-test measures of executive function: working memory, inhibition, shifting, and overall executive function (see measures section below). The order of the first three tasks was the same as used for that child at pre-test.

Upon completion of the tasks, the child read a book or sat quietly with their research assistant until all the children completed the four tasks. The lead then gathered the children together, thanked them for their participation, and walked the children back to their classrooms.

Intervention Conditions

High Activity/High Cognitive Condition (PACE)

Children participated in a Freeze Dance activity described in McClelland and Tominey (2016) and adapted to be appropriate for one-time participation by a small group of children rather than utilized within a preschool classroom over the school year. Freeze dance requires children to dance when the music plays and freeze when the music stops (McClelland & Tominey, 2016).

The lead explained to the children that they were going to have a dance party, demonstrated a variety of physically active movements that could be used while dancing (e.g. jumping, wiggling, stomping feet, bear crawls, crab walks, floss) and reviewed safety rules for the game. For the first song children were instructed to quickly freeze when the music stopped, and dance when the music played. The song lasted approximately 3 minutes and 22 seconds and included nine pauses for the children to freeze. This rule was designed to challenge inhibition skills. Children were given reminders of the freeze dance rule throughout the song (see Appendix A for a full script of the intervention activities).

After the first song, children were given a 30 second break to catch their breath while the procedures for the second song were introduced. For this song, children were instructed to dance fast when the music sounded fast and dance slow when the music sounded slow. Children were also reminded of the different motions they could use while dancing, such as wiggling and sliding. The second song lasted two minutes and 38 seconds. Children were given reminders of the tempo changing rules throughout the song as shown in the script.

Children were given another thirty second break to catch their breath while the procedures for the third song were introduced. For this song, children were instructed to do the silly version by dancing fast when the music sounded slow and dancing slow when the music sounded fast. Children were also reminded of the different motions they could use while dancing, such as bear crawls, crab walks, and jumping from side to side. The third song lasted three minutes and 11 seconds. Children were given reminders of the silly version rules throughout the song as shown in the script. The additional rules from songs two and three required children to use working memory and shifting skills as they had fun with the freeze dancing game.

High Activity/Low Cognitive Condition (PA)

This condition was similar to the Freeze Dance activity in the use of music and dance movement activities but without the cognitive demand. Thus, the activity was more like a dance party activity.

The lead explained to the children that they were going to have a dance party, demonstrated a variety of physically active movements that could be used while dancing (e.g. jumping, wiggling, stomping feet, bear crawls, crab walks, floss) and reviewed safety rules for the game. For the first song, the pauses were removed from the music, but otherwise the same music from the PACE condition was used and the total song lengths remained the same. Children were instructed to keep moving for the entire song.

After the first song, children were given a thirty second break to catch their breath. Children were reminded of the different motions they could use while dancing, such as wiggling and sliding and again encouraged to dance during the entire song. The music for the second song was the same as used in the PACE condition.

Children were given a final thirty second break to catch their breath and were reminded of the different motions they could use while dancing, such as bear crawls, crab walks, and jumping from side to side. The final song was also the same as used in the previous condition and children were encouraged to keep moving the entire song.

Low Activity/High Cognitive Condition (Cognitive)

This condition, called Freeze Drumming, was similar to the Freeze Dance activity in the use of music but instruments requiring hand movements while seated (hand drums, maracas, and tambourines) replaced the more physically demanding gross motor movements. Throughout this condition, the music was the same as the PACE freeze dance condition.

The lead explained to the children that they were going to have a music party with instruments, demonstrated a variety of motions that could be used while drumming (e.g. drumming with alternating hands, drumming with one hand, tapping drum sticks together), and then handed a drum and two drumsticks to each child. Next, children were instructed to use these different motions during a game of Freeze Drum, so when the music played, they played the drums and when the music stopped, they had to freeze.

After the first song, a 30-second break allowed the lead to collect the drums and drumsticks, give each child two maracas, and review the rules for the second song. In this song, children could shake their maracas in a variety of ways (over their head, down low, one at a time, alternating hands). Additionally, they had to shake fast when the music sounded fast and shake slow when the music sounded slow.

Children were given another 30-second break while the lead collected the maracas, gave each child two tambourines, demonstrated a variety of motions with the tambourines (e.g. shaking up high, drumming, shaking behind their back), and introduced the procedures for the third song. For this song, children were instructed to do the silly version by shaking fast when the music sounded slow and shaking slow when the music sounded fast.

Low Activity/Low Cognitive Condition (Low)

The lead explained to the children that they were going to have a coloring party with music. Children sat in a circle on the floor and coloring pages and crayons were distributed to each child. Physical activity and the use of executive function skills were minimized during the activity. However, the activity was designed to be fun and interesting because boring tasks requiring persistence could potentially call on children to use their executive function skills, which is contrary to the purpose of this control condition. The lead provided additional coloring pages with each new song if the child finished their first page or was ready for a new page.

Measures

Table 2 provides a summary and explanation of the measures used.

Table 2 Measures used for all four conditions and approximate time to complete

	Construct	Measure	Number of Items	Time to Complete
Pre- and Post-test	Working Memory	Spin the Pots	6 to 16	5-7 minutes
	Inhibition	Peg Tapping	16	3-5 minutes
	Shifting	DCCS	50*	10-15 minutes
	Overall EF	HTKS	30	5-8 minutes
Physical Activity Manipulation Check	Physical Activity	Accelerometer		Worn throughout intervention (approximately 15 minutes)

Note: DCCS = Dimensional Change Card Sort Task with Developmental Extension on the NIH Toolbox. HTKS = Head, Toes, Knees, Shoulders task. *Number of items ranged from 10-50 for children who completed the developmental extension.

Physical Activity Manipulation Check

ActiGraph accelerometers are widely used in pediatric research (Trost, 2007) and have been found to be valid and reliable for quantifying physical activity in preschool children (Pate et al., 2010; Sirard et al., 2005). The accelerometer was initialized at 80 Hz to collect 80 samples every second, using information provided by the parents (gender, birthdate, race) or measured at pre-test (height, weight, hand-dominance.) Participants were fitted with an accelerometer attached to an elastic belt and positioned on the hip of their non-dominant hand just prior to starting the welcome song and intervention. The accelerometer was removed immediately following the intervention, prior to the post-tests. Data was downloaded in one second epochs and calibrated using cut-points designed for preschoolers (Pate et al., 2006) to quantify the child's step counts and time spent in sedentary, light, and moderate-to-vigorous physical activity.

Executive Function Measurements

To capture both the potential unity and developing diversity of executive function skills, this study utilized four separate tasks, one for each of the three executive function constructs: working memory, inhibition, and shifting, plus an overall measure of executive function. Each measure is described in more detail below.

Working Memory

The Spin the Pots task (Hughes & Ensor, 2005) was used to measure working memory because it requires children to store information in mind about the location of stickers in certain boxes and use this information to make additional selections. Many working memory tasks (e.g. backward digit span) require participants to use the phonological loop portion of working memory, whereas the Spin the Pots task may also incorporate the visuospatial sketchpad.

Children were shown eight distinctly decorated boxes placed on a Lazy Susan (see Figure 4). The experimenter then placed a sticker under six boxes, with two left empty. The experimenter covered the boxes with a cloth, spun the Lazy Susan, and uncovered the boxes so the child could choose one box to look for a sticker. The experimenter then covered the boxes with the cloth and repeated the same process. The goal of the task was to find all 6 stickers, one at a time, in the fewest number of trials by keeping in mind which two boxes were empty and which boxes had already been tried. The task ended when children found all the hidden stickers or reached the maximum number of spins (16). Scores were calculated as 16 minus the number of errors (e.g. choosing an empty box). Appendix B provides a detailed script for this task.

Figure 4 Spin the Pots Task Materials Showing Decorated Boxes of Different Shapes and Colors on a Lazy Susan

Inhibition

The Peg Tapping Task (Diamond & Taylor, 1996) was used to measure inhibition. Children were given a wooden dowel and instructed to tap once when the experimenter taps twice, and vice versa. The task required children to inhibit their prepotent response to match the experimenter's taps. This task is frequently used with preschool children, including assessments of children in Head Start programs, where inhibitory control measured by the Peg Tapping task at age three was related to literacy and numeracy skills at age five (Blair & Razza, 2007) and in studies of preschool spatial and math skills where early spatial and executive function skills had a greater impact on later math skills than early mathematics skills like number knowledge (Verdine et al., 2017). Scores were calculated as the number of correct trials, ranging from one to 16. Appendix C provides a detailed script for this task.

Shifting

The Dimensional Change Card Sort Test (DCCS) is a reverse categorization task used to measure shifting ability and is available on the NIH Toolbox iPad app. The task (Version 2.1 with an experimental developmental extension) was designed for children ages three to seven-years-old. The DCCS is widely used with young children (Zelazo, 2006), is valid with children ages 3–5 years (Beck et al., 2011), and has established test–retest reliability (Beck et al., 2011; Fuhs et al., 2014). In the DCCS, children sort items first by shape, then by color, and back to shape. Then children sort 30 additional items by color or shape depending on the prompt. Children must shift their sorting decisions to accommodate the increasingly difficult new rules. If a child did not sort at least 4 out of 5 items correctly on the initial sorts (prior to the mixed trials), they switched to the developmental extension version which had more detailed prompts and simpler sorting tasks. For example, in one section of the developmental extension, children are shown a picture of a big kitty or a little kitty to sort into a matching box. After a wrong answer, the sorting rule is repeated and demonstrated (i.e. “If it’s a little kitty, then it goes in the little kitty box. If it’s a big kitty, then it goes in the big kitty box”).

Depending on the point at which a child switches from the standard version to the DEXT, they may receive 0 to 10 points on the standard DCCS plus up to 40 points on the DEXT. Raw scores on the standard DCCS also ranged from 0 to 40. Children who did not fail any phase of the standard DCCS are assumed to receive full credit for accuracy on the DEXT (40 points). Raw scores from the two tests were combined in order to explore results for all children in the same analysis, resulting in a possible score ranging from 0 to 80. Additional analyses may also be conducted on the subsample of children who completed the standard version of the assessment without the developmental extension. For this standard version, normative scores incorporate a measure of reaction time for the 30 items presented in the mixed set providing an age-adjusted score relative to a nationally representative sample, where a score of 100 indicates performance at the national average of children at the same age.

Overall Executive Function

The Head, Toes, Knees Shoulders Task (HTKS, Cameron Ponitz et al., 2009) was used as an overall measure of executive function. This task consisted of three sections, each including a varying number of practice items followed by ten test items. In this game-like task, children were first asked to do the opposite of what the experimenter said by touching their toes when the experimenter said touch your head and vice versa. A child must score at least four points on the test items in one section to advance to the next section. The second group of test items added in additional commands with knees and shoulders and the third group of items added a rule switch (e.g., the child touched their toes after hearing the command for knee, whereas previously head and toes were paired together). This task required children to inhibit their natural tendency to mimic the experimenter, use working memory to remember the rules of the game and shift to accommodate the addition of new rules. The HTKS has established reliability and validity and has been significantly related to other measures of executive function (Cameron Ponitz et al., 2008; Cameron Ponitz et al., 2009; McClelland et al., 2007; McClelland et al., 2014; Schmitt et al., 2014; Wanless et al., 2011). With two possible points on each test item, scores on just the test items ranged from 0 to 60. To obtain more variability the practice items may also be included resulting in scores ranging from 0 to 94.

Chapter 3

RESULTS

This study used a pre-test, short-term intervention, post-test design to examine the immediate impact of physical activity and cognitive engagement on four- and five-year-old children's executive function skills. Dependent variables included (1) Working Memory using the Spin the Pots task, (2) Inhibition using the Peg-Tapping task, (3) Shifting using the Dimensional Change Card Sort Task with Developmental Extension on the NIH Toolbox (DCCS), and (4) Overall Executive Function using the Head, Toes, Knees, Shoulders task (HTKS). The independent variable was the condition group based on the four conditions in the study: High Activity/High Cognitive (PACE), High Activity/Low Cognitive (PA), Low Activity/High Cognitive (Cognitive), and Low Activity/Low Cognitive (Low).

An a priori power analysis was completed for a one-way ANOVA using the GPower 3.0 program (Faul et al., 2007). Two-tailed p values were employed. Four groups were used in the analysis representing each of the four conditions. Power was set to .80, meaning there would be an 80% probability of reaching statistical significance if the obtained sample differences were present in the population. A medium-to-large effect size was estimated for the sample ($f = .33$, as per Cohen, 1988). Results from the power analysis indicated 108 participants would be required. Therefore, approximately 27 participants were recruited for each condition to create equal groups balanced by gender.

Confirming Random Distribution of Participants by Condition

Preliminary analyses were conducted using chi-square, Kruskal-Wallace, and one-way ANOVAs to compare background variables of participants in the four conditions, ensuring that random assignment resulted in equivalent distributions across conditions. Conditions did not differ by demographic factors or cognitive task order as indicated by chi-square analyses for gender (p = .834), race (p = .254), ethnicity (p = .848), or order of cognitive tasks (p = .890). Conditions also did not differ by primary caregiver's level of education (p = .675) as indicated by a Kruskal-Wallace analysis, or by age at pre-test (p = .564 for the overall model) as indicated by a one-way ANOVA. See Table 3 for descriptive information on the sample by condition. Primary caregiver's education level was divided into three groups for future analyses: 1) primary school up to high school graduate, 2) some college, college degree, certificate programs, and 3) post-graduate degree. When grouped into these three categories, a chi-square analysis indicated conditions still did not differ by caregiver education level (p = .693).

Table 3 Descriptive Information About the Study Participants by Condition

Condition	Number of Subjects	Age in months Mean (SD)	Gender % female	Race % White	Ethnicity % Latino	Primary Caregiver Education (% up to high school grad - college - advanced degree)
PACE	29	58.8 (6.7)	59%	93%	54%	33% - 42% - 25%
PA	28	58.9 (5.6)	46%	96%	56%	26% - 48% - 26%
Low	28	59.2 (7.3)	54%	93%	65%	44% - 41% - 15%
Cognitive	26	56.9 (6.3)	54%	79%	59%	33% - 33% - 33%

Note. PACE = High physical activity and high cognitive engagement, PA = High physical activity, Low = Low physical activity and low cognitive engagement, Cognitive = High cognitive engagement.

Physical Activity Manipulation Check

One-way ANOVA analyses were conducted separately on two outputs from the accelerometer data, percent of time during the short-term intervention in moderate to vigorous physical activity (Percent MVPA) and step counts, to ensure the conditions differentiated between high and low levels of physical activity as predicted. Both overall models were significant (Percent MVPA, $F = 121.62$, df [3, 101], $p < .001$; Step Counts, $F = 275.93$, df [3, 101], $p < .001$). Post-hoc analyses confirmed that children in the two high physical activity conditions experienced similar levels of physical activity (Percent MVPA, $p = .372$; Step Counts, $p = .995$). Also, children in the two high physical activity conditions were more physically active than children in the two low physical activity conditions (Percent MVPA $p < .001$; Step Counts, $p < .001$). See Table 4 for descriptive data on physical activity for each condition.

Table 4 Accelerometer Data by Condition with the Two Physical Activity Conditions More Active.

Condition	**Percent of Time in MVPA** Mean (SD)	**Step Counts** Mean (SD)
PACE	47.7 (12.2)	768 (178)
PA	54.7 (17.4)	780 (191)
Low	14.2 (9.4)	66 (31)
Cognitive	3.4 (3.2)	24 (22)

Note. Time of intervention averaged 11.98 minutes. MVPA = Moderate to vigorous physical activity. PACE = High physical activity and high cognitive engagement, PA = High physical activity, Cognitive = High cognitive engagement, Low = Low physical activity and low cognitive engagement.

Pre-Test Executive Function Ability

Pre-test scores on the four measures of executive function did not differ by condition as confirmed by a one-way ANOVA (Spin the Pots, $p = .188$; Peg Tapping,

p = .175; DCCS, p = .103; HTKS, p = .982). Table 5 shows the pre-test raw scores for each task by condition. To control for individual differences at pre-test, pre-test score was included in the regression models and used as a covariate in all further analyses.

Table 5 Pre-Test Raw Scores for Each Task by Condition

Condition	**Spin the Pots** Mean (SD)	**Peg Tapping** Mean (SD)	**DCCS** Mean (SD)	**HTKS** Mean (SD)
PACE	11.2 (3.5)	11.8 (4.8)	54.8 (23.1)	31.1 (25.3)
PA	11.7 (3.3)	10.4 (4.8)	50.9 (25.0)	31.7 (30.3)
Low	11.1 (3.4)	8.6 (6.0)	39.7 (26.2)	30.8 (30.7)
Cognitive	9.6 (4.2)	10.3 (5.3)	42.8 (27.3)	33.9 (31.1)

Note. Spin the Pots measured working memory. Peg-Tapping measured inhibition. Dimensional Change Card Sort Task with Developmental Extension on the NIH Toolbox (DCCS) measured shifting. Head, Toes, Knees, Shoulders task (HTKS) measured overall executive function. PACE = High physical activity and high cognitive engagement, PA = High physical activity, Cognitive = High cognitive engagement, Low = Low physical activity and low cognitive engagement.

Analysis of Post-Test Scores

Correlational analyses were conducted on scores from the four post-tests to see whether they should be interpreted as separable components of executive function or combined into one composite score. Results are shown below in Table 6. Because of the multicollinearity between Peg Tapping, DCCS, and HTKS scores, separate analyses were conducted on each dependent variable.

Table 6 Correlations Between Executive Function Post-Test Scores

	Spin the Pots	Peg Tapping	DCCS	HTKS
Spin the Pots	1			
Peg Tapping	.04	1		
DCCS	.15	.50**	1	
HTKS	.18	.48**	.47**	1

Note: ** $p < .01$. Spin the Pots measures working memory. Peg-Tapping measures inhibition. Dimensional Change Card Sort Task with Developmental Extension on the NIH Toolbox (DCCS) measures shifting. Head, Toes, Knees, Shoulders task (HTKS) measures overall executive function.

For each analysis, a linear regression was conducted to see whether post-test scores on each executive function measure could be predicted based on the pre-test score for the same EF task, age at pre-test, SES category, and gender. These variables were included in the models because executive function skills are rapidly developing during the preschool ages and are known to vary based on gender and the socioeconomic conditions of a child’s environment (Zelazo, et al., 2016). Follow-up analyses using a general linear model were then conducted on each EF outcome measure to elucidate any significant condition differences.

If neither the regression model nor the general linear model revealed significant differences by condition, additional post-hoc analyses were conducted using a subgroup of children who scored in the lowest 50th percentile on that particular measure at pre-test. A similar method of analysis was used by Tominey and McClelland (2011) to explore whether children who started low in self-regulation via the HTKS improved as a result of an eight-week intervention, even though no significant condition differences were found for the overall sample. In addition, because normative scores on the standard version of the DCCS include reaction time, post-hoc analyses were conducted with a subsample of children who scored higher on the DCCS at pre-test and therefore had these reaction time adjusted scores.

Working Memory – Spin the Pots

At pre-test, the average score on Spin the Pots was 10.9 (SD = 3.6, range = 5 – 16), with skewness of -0.46 and kurtosis of -1.05. Although scores of 0 are possible on this measure, they are unlikely because that would require children to guess one of two boxes for all 16 trials. Approximately 18% of children scored a 5 at pre-test, meaning they found 5 of the 6 stickers. Also, almost 30% of children scored a 14 or above, which suggests they may be at or close to ceiling at pre-test. At post-test, the average score was 11.8 (SD = 3.4, range = 5 – 16), with skewness of -0.73 and kurtosis of -0.65. Here, only 7% of children scored a 5 at post-test and 37% scored a 14 or above.

The overall regression model was statistically significant [$F = 4.215$, df [5, 96], $p = .002$]. Condition made a statistically-significant, unique contribution to the estimation of post-test score ($p = .016$). Effect sizes were calculated for the overall model and the significant predictors using Cohen’s (1988) f^2, where values of .02 represent a small effect, values of .15 equal a medium effect, and values of .35 denote a large effect. Results show the overall model had a medium-to-large effect size ($f^2 = .22$) in predicting post-test Spin the Pots scores and both condition and the pre-test score had small effect sizes (respectively, $f^2 = .06, .10$). A summary of the regression analysis is presented in Table 7. This model explains 18% of the variance in the Spin the Pots post-test scores.

Table 7 Regression Analysis Summary for Variables Predicting Post-Test Spin the Pots Scores

Variable	*B*	SE *B*	β	sr^2	f^2
Age at pre-test	-0.039	0.050	-0.076		
Spin the Pots pre-test Score	0.267	0.088	0.298**	.079	.10
SES (3 category)	0.259	0.401	0.060		
Gender	-1.029	0.611	-0.156		
Condition	-0.687	0.281	-0.228*	.051	.06
Constant	13.933	3.097			

Note: $R^2 = .180$ ($N = 102$, $p = .002$), sr^2 = squared semi-partial coefficient, f^2 = Cohen's (1988) effect size statistic for multiple regression analyses. * $p < .05$, ** $p < .01$. Spin the Pots measured working memory.

To better understand how condition impacted post-test scores, a follow-up analysis was conducted using a general linear model, controlling for pretest score on Spin the Pots and age at pretest. Table 8 presents the adjusted post-test means for the four groups. Post hoc comparisons using the Bonferroni adjustment indicated that the PACE condition significantly outperformed physical activity ($p = .008$) and cognitive ($p = .025$) at post-test when controlling for age and pre-test score ($F = 4.459$, *df* [3, 105], $p = .005$).

Table 8 Adjusted Post-Test Mean Scores by Condition on the Spin the Pots Working Memory Task with Standard Error in Parentheses.

Condition	Spin the Pots Adjusted Post-Test Mean (SE)
PACE	13.5 (.57)
PA	10.8 (.58)
Low	11.7 (.58)
Cognitive	11.0 (.61)

Note: Covariates evaluated at following values (pre-test score = 10.9, age at pretest = 58.5). PACE = High physical activity and high cognitive engagement, PA = High physical activity, Cognitive = High cognitive engagement, Low = Low physical activity and low cognitive engagement.

Inhibition – Peg Tapping

At pre-test, the average score on Peg Tapping was 10.3 (SD = 5.3, range = 0 – 16), with skewness of -0.60 and kurtosis of -1.05. Only 5% of children scored a 0 at pre-test, but 41% of children scored a 14 or above, which suggests that many of the children were at or close to ceiling at pre-test. At post-test, the average score was 10.8 (SD = 4.7, range = 0 – 16), with skewness of -0.77 and kurtosis of -0.65. Only 2% of children scored a 0 at post-test and 41% scored a 14 or above.

The overall regression model was statistically significant ($F = 20.842$, df [5, 94], $p < .001$]. However, only pre-test score on Peg Tapping made a statistically-significant, unique contribution to the estimation of post-test score ($p < .001$). Condition was not significant ($p = .333$). Follow up analyses with a general linear model, controlling for pretest score on Peg Tapping and age at pretest yielded similar results. Table 9 presents adjusted post-test means for the four groups. The overall model was not significant ($F = 1.127$, df [3, 101], $p = .342$).

Table 9 Adjusted Post-Test Mean Scores by Condition on the Peg Tapping Inhibition Task with Standard Error in Parentheses.

Condition	Peg Tapping Adjusted Post-Test Mean (SE)
PACE	10.9 (.646)
PA	10.0 (.636)
Low	11.4 (.664)
Cognitive	11.5 (.691)

Note: Covariates evaluated at following values (pre-test score = 10.46, age at pretest = 58.7). Score is calculated as the total number of correct trials with maximum score equal to 16. PACE = High physical activity and high cognitive engagement, PA = High physical activity, Cognitive = High cognitive engagement, Low = Low physical activity and low cognitive engagement.

Previous research has shown that children who start lower at pre-test may benefit from an intervention, even when no significant differences were found for the overall sample (Bierman et al., 2008; Connor et al., 2010; Tominey & McClelland, 2011). Therefore, a new model was run including only the children who scored in the lower 50^{th} percentile on the Peg Tapping measure at pre-test (score at 12 and below). The average pre-test score for this subgroup of children was 6.1 (SD = 3.9) and average score at post-test was 8.3 (SD = 4.6, range = 0 – 16). The overall regression model was statistically significant ($F = 4.031$, df [5, 45], $p = .004$], but again, only pre-test score on the Peg Tapping measure made a statistically-significant contribution to the estimation of post-test score ($p < .001$). Condition was still not significant ($p =$ .533).

NIH Toolbox DCCS – Shifting

At pre-test, the average raw score on the DCCS was 47.3 (SD = 25.8, range = 0 – 79), with skewness of -0.20 and kurtosis of -1.42. Approximately 36% of children had a raw score at 70 or above at pre-test (maximum possible score = 80), so standard scores that incorporate measures of reaction time may be necessary to further differentiate children scoring high at pre-test. At post-test, the average score was 53.9 (SD = 25.8, range = 0 – 80), with skewness of -0.57 and kurtosis of -1.26. Almost 46% of participants had a raw score of 70 or above at post-test.

The overall regression model for the Dimensional Change Card Sort Task with Developmental Extension on the NIH Toolbox (DCCS) task was statistically significant ($F = 16.322$, df [5, 93], $p < .001$]. However, only pre-test score on the DCCS ($p < .001$) and age ($p = .034$) made statistically-significant, unique contributions to the estimation of post-test score. Condition was not significant ($p = .177$). A follow up analyses was conducted using a general linear model, controlling for pretest DCCS score and age at pretest. The overall model was not significant ($F = 2.147$, df [3, 102], $p = .099$).

As was done by Tominey and McClelland (2011), a post-hoc analysis was conducted to see whether children who started in the lower 50th percentile on the DCCS (pre-test score at 47 or below) benefitted from the short-term intervention, even though no significant differences were found for the overall sample. The initial analyses were conducted on raw test scores for all children in the sample, as normative scores were not available for 37 children at pre-test and 29 children at post-test who only received developmental extension scores. Using raw scores allowed all children to be analyzed in a single analysis. However, these raw scores did not include a reaction time computation which can help differentiate children who scored higher on the standard version of the measure. Figure 5 shows the distribution of pre-test scores on the DCCS by condition, with a vertical line indicating the 50th percentile score of

47. Age-corrected normative scores provide additional information on the subset of children who had scores on the standard DCCS version. This subsample included 82 participants at post-test, and all but four of these children were above the 50^{th} percentile on raw scores at pretest. Therefore, a final post-hoc analysis was conducted for these children who started above the 50^{th} percentile at pre-test using the age-corrected normative scores that account for reaction time as appropriate.

Table 10 presents descriptive statistics about these subgroups compared to the full sample. The lower 50^{th} percentile subgroup is similar to the original sample in age, with slight increases in the percentage of Latino children, and slight increases in the percent of primary caregivers whose education level included up to a high school diploma. The subgroup of children who scored in the upper 50^{th} percentile at pre-test were also similar to the original sample in age, but with slight decreases in the percentage of Latino children, and slight decreases in the percent of primary caregivers whose education level included up to a high school diploma. For both subgroups, conditions still did not differ by cognitive task order or demographic factors including age, gender, race, ethnicity, and primary caregiver's level of education.

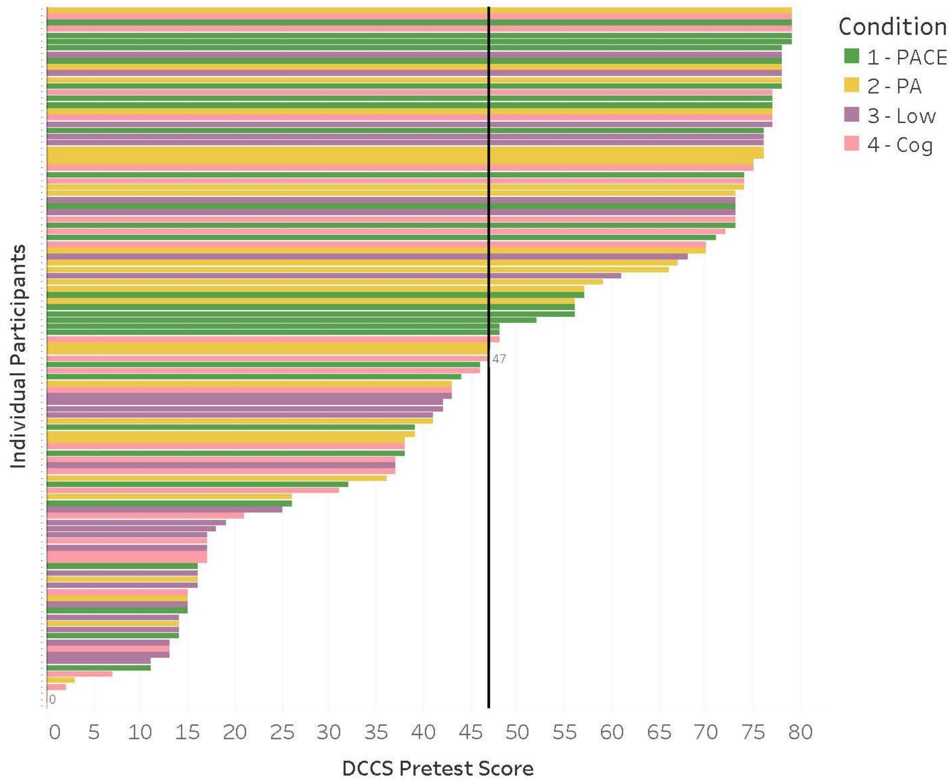

Figure 5 Distribution of Individual Participants' Pretest Scores on the Dimensional Change Card Sort Task with Developmental Extension on the NIH Toolbox (DCCS) Task. Line indicates 50th Percentile Cutoff Score of 47.

Table 10 Descriptive Information: Study Participants by Condition Illustrating Differences Between the Original Sample and Subgroups of Participants Who Scored in the Lower 50th Percentile (Pre-Test Score ≤ 47) and Upper 50th Percentile (Pre-Test Score >47) on the DCCS at Pretest

	Condition	Number of Subjects	Age in months Mean (SD)	Gender % female	Ethnicity % Latino	Primary Caregiver Education (% up to high school grad - college - advanced degree)
Original Sample	PACE	29	58.8 (6.7)	59%	54%	33% - 42% - 25%
	PA	28	58.9 (5.6)	46%	56%	26% - 48% - 26%
	Low	28	59.2 (7.3)	54%	65%	44% - 41% - 15%
	Cognitive	26	56.9 (6.3)	54%	59%	33% - 33% - 33%
Lower 50th Percentile Subgroup	PACE	10	59.1 (7.4)	40%	78%	63% - 13% - 25%
	PA	13	58.8 (5.6)	39%	54%	50% - 17% - 33%
	Low	18	57.4 (7.2)	50%	81%	59% - 29% - 12%
	Cognitive	16	54.1 (4.0)	50%	77%	57% - 14% - 29%
Upper 50th Percentile Subgroup	PACE	19	58.6 (6.5)	68%	41%	19% - 56% - 25%
	PA	15	58.9 (5.8)	53%	58%	7% - 73% - 20%
	Low	9	61.9 (6.8)	56%	33%	22% - 56% - 22%
	Cognitive	10	61.3 (6.9)	60%	33%	0% - 60% - 40%

Note. PACE = High physical activity and high cognitive engagement, PA = High physical activity, Low = Low physical activity and low cognitive engagement, Cognitive = High cognitive engagement. Dimensional Change Card Sort Task with Developmental Extension on the NIH Toolbox (DCCS) measured shifting.

Post-Hoc Analyses for Children in Lower 50th Percentile at Pretest

The overall regression model with the subgroup of participants who scored in the lower 50th percentile at pretest was statistically significant ($F = 9.285$, $df[5, 43]$, $p < .001$). Condition ($p = .002$), gender ($p = .008$), and pre-test DCCS score ($p < .001$) made statistically-significant, unique contributions to the estimation of post-test score.

The overall model had a large effect size (f^2 = 1.1) in predicting post-test HTKS scores. Pre-test score had a large effect size (f^2 = .36), gender had a medium effect size (f^2 = .18), and condition had a medium-to-large effect size (f^2 = .26). A summary of the regression analysis is presented in Table 11. This model explains 51.9% of the variance in DCCS post-test scores.

Table 11 Regression Analysis Summary for Variables Predicting Post-Test DCCS Scores for Children Scoring in the Lower Half of the Sample at Pre-Test (Pre-Test Score ≤ 47)

Variable	*B*	SE *B*	β	sr^2	f^2
Age at pre-test	0.439	0.496	0.108		
DCCS Pre-test Score	0.811	0.206	0.456***	.174	.36
SES (3 category)	-1.750	3.406	-0.055		
Gender	-15.569	5.576	-0.304**	.087	.18
Condition	-9.344	2.811	-0.378**	.124	.26
Constant	46.504	32.257			

Note: R^2 = .519 (N = 49, p < .001), sr^2 = squared semi-partial coefficient, f^2 = Cohen's (1988) effect size statistic for multiple regression analyses. Dimensional Change Card Sort Task with Developmental Extension on the NIH Toolbox (DCCS) measured shifting. * p < .05, ** p < .01, ** p <.001.

To better understand how condition impacted post-test scores for children who started in the lower half of the sample at pre-test, a follow-up analysis was conducted using a general linear model, controlling for pretest DCCS score and age at pretest with gender and condition as independent variables. Gender was included as an independent variable because of the significant relationship with post-test scores in the regression model. Note that a gender by condition interaction was not significant, and was therefore not included in this model. Results revealed main effects for condition (p = .033), pretest DCCS score (p < .001), and gender (p = .009). Table 12 presents the adjusted post-test means for the four conditions. Post hoc comparisons using the

Bonferroni adjustment indicated that the PACE condition significantly outperformed the low condition ($p = .044$) at post-test when controlling for age and pre-test score ($F = 3.153$, *df* [3, 48], $p = .033$). In addition, across conditions, girls scored approximately 14 points higher at post-test when controlling for age and pre-test score (female adjusted post-test mean = 49.8, male = 35.6).

Table 12 Adjusted Post-Test Mean Scores by Condition on the DCCS Task for Children Scoring in the Lower Half of the Sample at Pre-Test (Pre-Test Score ≤ 47) with Standard Error in Parentheses.

Condition	DCCS Adjusted Post-Test Mean (SE)
PACE	54.4 (6.0)
PA	46.6 (5.5)
Low	33.4 (4.5)
Cognitive	36.5 (5.0)

Note: Covariates evaluated at following values (pre-test score = 25.9, age at pretest = 56.98). Possible scores range from 0-80. Dimensional Change Card Sort Task with Developmental Extension on the NIH Toolbox (DCCS) measured shifting. PACE = High physical activity and high cognitive engagement, PA = High physical activity, Cognitive = High cognitive engagement, Low = Low physical activity and low cognitive engagement.

The estimated post-test means in Table 12 suggest that children in the two high physically active conditions combined may significantly outperform children in the two low physical activity conditions, even though only PACE outperformed Low when the four conditions were included in the model. To further investigate this trend, regression and general linear models were run to see whether the participants who scored in the lower half of scores at pre-test significantly improved at post-test after physical activity, while continuing to control for pre-test score on the DCCS, age, and gender. The overall regression model was significant ($F = 9.571$, *df* [5, 43], $p < .001$).

Results reveal main effects for physical activity (p = .001), pretest DCCS score (p = .001), and gender (p = .006). The overall model (f^2 = 1.11) had a large effect size in predicting post-test DCCS scores and physical activity (f^2 = .28), gender (f^2 = .19), and pre-test DCCS score (f^2 = .31) had medium-to-large effect sizes.

A summary of the regression analysis is presented in Table 13. This model explains 52.7% of the variance in DCCS post-test scores.

Table 13 Regression Analysis Summary of Variables Predicting Post-Test DCCS Scores for Children Scoring in the Lower Half of the Sample at Pre-Test (Pre-Test Score ≤ 47) Using High Versus Low Physical Activity

Variable	*B*	SE *B*	β	sr^2	f^2
Age at pre-test	0.614	0.481	0.151		
DCCS Pre-test Score	0.748	0.206	0.420**	.145	.31
SES (3 category)	-2.031	3.385	-0.064		
Gender	-15.900	5.544	-0.311**	.090	.19
Physical Activity	20.124	5.831	0.385**	.131	.28
Constant	5.947	27.491			

Note: R^2 = .527 (N = 49, p < .001), sr^2 = squared semi-partial coefficient, f^2 = Cohen's (1988) effect size statistic for multiple regression analyses. Dimensional Change Card Sort Task with Developmental Extension on the NIH Toolbox (DCCS) measured shifting. * p < .05, ** p < .01, *** p <.001.

A general linear model further elucidates how participation in physical activity improved post-test scores for children who started in the lower half of scores at pre-test when controlling for pre-test score, age, and gender. Gender was still included as an independent variable because of the significant relationship in the regression model. Note that the gender by condition interaction was still not significant, and thus was not included in the model. Table 14 presents the adjusted post-test means for the high versus low physical activity groups. Children who participated in the physical activity conditions outperformed children in low physical activity conditions at post-test when controlling for age and pre-test score ($F = 8.466$, *df* [1, 50], $p = .005$). In addition, across conditions, girls scored approximately 14 points higher at post-test when controlling for age and pre-test score (female adjusted post-test mean = 49.7, male = 35.3; $F = 7.758$, *df* [1, 50], $p = .008$).

Table 14 Adjusted Post-Test Mean Scores on the DCCS Task for Children Scoring in the Lower Half of the Sample at Pre-Test (Pre-Test Score ≤ 47) with Standard Error in Parentheses When Comparing High Versus Low Physical Activity

Condition	DCCS Adjusted Post-Test Mean (SE)
High Physical Activity (PACE and PA)	50.2 (4.1)
Low Physical Activity (Cognitive and Low)	34.8 (3.3)

Note: Covariates evaluated at following values (pre-test score = 25.91, age at pretest = 56.98). Possible scores range from 0-80. Dimensional Change Card Sort Task with Developmental Extension on the NIH Toolbox (DCCS) measured shifting. PACE = High physical activity and high cognitive engagement, PA = High physical activity, Cognitive = High cognitive engagement, Low = Low physical activity and low cognitive engagement.

Post-Hoc Analyses for Children in Upper 50th Percentile at Pretest

Another post-hoc analysis was conducted using age-corrected normative scores for children who scored in the upper 50th percentile of raw scores at pre-test. The overall regression model with this subgroup was statistically significant ($F = 9.387$, *df*[4, 41], $p < .001$), but only pre-test DCCS score made a statistically-significant, unique contribution to the estimation of post-test score ($p < .001$). Condition was not significant ($p = .271$). A follow up analyses was conducted using a general linear model, controlling for pretest DCCS score. The overall model was not significant (F = 2.530, df [3, 44], p = .069). Because the sample size was restricted to 48 participants, the analysis may have been underpowered to detect small effects. The estimated post-test means presented in Table 15 suggest that children in the two high cognitive conditions (PACE and Cognitive) may outperform the children in the two low cognitive conditions (PA and Low), even though the model was not significant with all four conditions. Final regression and general linear models were run to further investigate this trend.

Table 15 Adjusted Post-Test Mean Scores (using Age-Adjusted Standard Scores) by Condition on the DCCS Task for Children Scoring in the Upper Half of the Sample at Pre-Test (Pre-Test Raw Score > 47) with Standard Error in Parentheses.

Condition	DCCS Adjusted Post-Test Mean (SE)
PACE	109.9 (2.3)
PA	105.1 (2.4)
Low	104.3 (3.2)
Cognitive	113.9 (2.9)

Note: Covariate evaluated at following value (pre-test score = 108.8). Score of 100 = national average for participant's age. Dimensional Change Card Sort Task with Developmental Extension on the NIH Toolbox (DCCS) measured shifting. PACE = High physical activity and high cognitive engagement, PA = High physical activity, Cognitive = High cognitive engagement, Low = Low physical activity and low cognitive engagement.

The overall regression model was significant (F = 19.146, df [2, 46], p < .001). Gender and SES were not included in the model because they were not significant. Results revealed main effects for cognitive engagement (p = .015) and pretest DCCS score (p < .001). The overall model (f^2 = .83), and pre-test DCCS score (f^2 = .72) had large effect sizes in predicting post-test DCCS scores and cognitive engagement had a medium effect size (f^2 = .14).

A summary of the regression analysis is presented in Table 16. This model explains 45.4% of the variance in DCCS post-test scores.

Table 16 Regression Analysis Summary of Variables Predicting Post-Test DCCS Scores for Children Scoring in the Upper Half of the Sample at Pre-Test (Pre-Test Raw Score > 47) Using Age-Corrected Standard Scores and Comparing High Versus Low Cognitive Engagement

Variable	*B*	SE *B*	β	sr^2	f^2
DCCS Pre-test Score	1.099	0.191	0.628***	.393	.72
Cognitive Engagement	6.558	2.584	0.277*	.076	.14
Constant	-14.733	20.922			

Note: R^2 = .454 (N = 49, p < .001), sr^2 = squared semi-partial coefficient, f^2 = Cohen's (1988) effect size statistic for multiple regression analyses. Dimensional Change Card Sort Task with Developmental Extension on the NIH Toolbox (DCCS) measured shifting. * p < .05, ** p < .01, *** p <.001.

A general linear model (controlling for pre-test score) further examined how participation in cognitively engaging activities improved post-test scores for children who started in the upper half of raw scores at pre-test. Table 17 presents the adjusted post-test means for the high versus low cognitive engagement groups. Children who participated in the cognitively engaging conditions outperformed the children in low cognitive engagement conditions at post-test when controlling for pre-test score (F = 6.441, df [1, 46], p = .015).

Table 17 Adjusted Post-Test Mean Scores on the DCCS Task for Children Scoring in the Upper Half of the Sample at Pre-Test (Pre-Test Raw Score > 47) with Standard Error in Parentheses Using Age-Corrected Standard Scores and Comparing High Versus Low Cognitive Engagement

Condition	DCCS Adjusted Post-Test Mean (SE)
High Cognitive Engagement (PACE and Cognitive)	111.4 (1.8)
Low Cognitive Engagement (PA and Low)	104.8 (1.9)

Note: Covariate evaluated at following value (pre-test score = 108.8). Score of 100 = national average for participant's age. Dimensional Change Card Sort Task with Developmental Extension on the NIH Toolbox (DCCS) measured shifting. PACE = High physical activity and high cognitive engagement, PA = High physical activity, Cognitive = High cognitive engagement, Low = Low physical activity and low cognitive engagement.

Summary of Findings for DCCS

Regression and general linear model analyses for the overall sample did not reveal significant differences by condition. However, children in the PACE condition who started in the lower 50th percentile at pre-test outperformed children in the Low condition. Due to the small sample size in this subset, an additional model explored children's performance at post-test after high versus low physical activity. For the same subset of children who started low at pretest, participation in high physical activity resulted in higher post-test scores than children in low physical activity conditions. Also, in this lower subgroup, girls outperformed boys by approximately 14 points at post-test. For children who started in the upper 50th percentile at pre-test, age-corrected standard scores that incorporated reaction time measures were available from the standard version of the DCCS. These normative scores helped differentiate the performance of children approaching ceiling in raw score measurements. A model investigating the age-corrected standard scores for this subset of children who scored in the upper 50th percentile in raw scores at pretest revealed that participating in cognitively engaging activities resulted in better shifting performance at post-test than low cognitively engaging activities.

Head, Toes, Knees, Shoulders – Overall EF

At pre-test, the average score on the HTKS with practice points was 31.8 (SD = 29.0, range = 0 – 89), with skewness of .42 and kurtosis of -1.32. Approximately 9% of children scored a 0 at pre-test. Ceiling effects were unlikely as the highest score was 89 out of a possible 94 points. At post-test, the average score was 40.3 (SD = 27.8, range = 0 – 91), with skewness of .17 and kurtosis of -1.13. Only 6% of children scored a 0 at post-test.

For the HTKS task, the overall regression model was statistically significant [F (5, 94) = 52.319, $p < .001$]. However, only pretest score on the HTKS made a statistically-significant, unique contribution to the estimation of post-test score ($p < .001$). Condition was not significant ($p = .439$). A general linear model controlling for pretest score and age at pretest yielded similar results. Table 18 presents adjusted post-test means for the four groups. The overall model was not significant ($F = .516$, df [3, 102], $p = .672$).

Table 18 Adjusted Post-Test Mean Scores by Condition on the HTKS Task with Standard Error in Parentheses.

Condition	HTKS Adjusted Post-Test Mean (SE)
PACE	40.5 (2.8)
PA	40.4 (2.9)
Low	38.4 (2.8)
Cognitive	43.6 (3.0)

Note: Covariates evaluated at following values (pre-test score = 32.23, age at pretest = 58.6). Possible scores range from 0-94. Head, Toes, Knees, Shoulder task (HTKS) measured overall executive function. PACE = High physical activity and high cognitive engagement, PA = High physical activity, Cognitive = High cognitive engagement, Low = Low physical activity and low cognitive engagement.

Because no significant differences were found for the overall model, a new model was run including only the children who scored in the lower 50^{th} percentile on the HTKS measure at pre-test (score at 26 and below). The average pre-test score for this subgroup of children was 6.3 (SD = 6.6) and average score at post-test was 19.8 (SD = 17.4, range = 0 – 68). The overall regression model was statistically significant for this subgroup ($F = 2.600$, df [5, 42], $p = .039$], but again, only pre-test score on the HTKS made a statistically-significant contribution to the estimation of post-test score ($p = .003$). Condition was still not significant ($p = .653$). A follow-up analysis using a general linear model, controlling for pretest score and age at pretest yielded similar insignificant results ($F = .941$, df [3, 48], $p = .428$). Table 19 presents adjusted post-test means for the four groups. Additional models comparing high and low physical activity, and comparing the PACE condition to other three conditions were not significant (respectively, $p = .286$, $p = .148$).

Table 19 Adjusted Post-Test Mean Scores by Condition on the HTKS Task for Children Scoring in the Lower Half of the Sample at Pre-Test (Pre-Test Score ≤ 26) with Standard Error in Parentheses.

Condition	HTKS Adjusted Post-Test Mean (SE)
PACE (n = 13)	25.3 (4.5)
PA (n = 14)	19.1 (4.3)
Low (n = 15)	15.2 (4.1)
Cognitive (n = 12)	20.2 (4.8)

Note: Covariates evaluated at following values (pre-test score = 6.15, age at pretest = 56.2). Possible scores range from 0-94. Head, Toes, Knees, Shoulder task (HTKS) measured overall executive function. PACE = High physical activity and high cognitive engagement, PA = High physical activity, Cognitive = High cognitive engagement, Low = Low physical activity and low cognitive engagement.

Summary of Post-Test Findings

In summary, the PACE and PA conditions resulted in the greatest immediate improvements in executive function. Specific results for each task are summarized in Table 20. For working memory assessed via Spin the Pots, the PACE condition outperformed the Physical Activity and Cognitive conditions. For shifting assessed via the DCCS, no significant differences by condition were found for the overall sample. However, children in the PACE condition who started with low pre-test DCCS scores outperformed the low control condition, and the two physical activity conditions combined significantly outperformed the two low physical activity conditions. Also in this lower subgroup, girls outperformed boys by approximately 14 points at post-test. For children who started high on shifting skills via the DCCS, age-corrected standard scores revealed that participating in cognitively engaging activities resulted in better shifting performance at post-test than activities with low cognitive engagement. There were no significant condition differences on inhibition assessed with the Peg Tapping task or on overall EF assessed with the HTKS.

Table 20 Summary of Post-Test Findings for Each EF Task Based on General Linear Model Analyses

	Spin the Pots Working Memory	**Peg Tapping** Inhibition	**DCCS** Shifting	**HTKS** Overall EF
Full Sample	PACE outperformed PA and Cognitive Conditions	No Significant Condition Differences	No Significant Condition Differences	No Significant Condition Differences
Post-Hoc Analysis: Low at Pre-test	N/A	No Significant Condition Differences	PACE outperformed Low condition. Also, high physical activity (PACE/PA) outperformed low physical activity (Cognitive/Low) Girls outperformed boys across all conditions	No Significant Condition Differences
Post-Hoc Analysis: High at Pre-test	N/A	N/A	High cognitive engagement conditions (PACE/Cognitive) outperformed low cognitive engagement (PA/Low)	N/A

Note. Low at pre-test = significant results only for children who scored in the lower half of the sample at pre-test (Peg Tapping ≤ 12, DCCS ≤ 47, HTKS Pretest ≤ 26). DCCS = Dimensional Change Card Sort Task with Developmental Extension on the NIH Toolbox. HTKS = Head, Toes, Knees, Shoulders task. PACE = High physical activity and high cognitive engagement, PA = High physical activity, Low = Low physical activity and low cognitive engagement.

Chapter 4

DISCUSSION

The goal of the current study was to understand what types of activities have an immediate impact on preschool children's executive function skills (EF). Preschool children are undergoing a period of rapid EF development (Diamond, 2016), and during this time of rapid growth and plasticity the brain may also be particularly susceptible to environmental influences such as EF interventions (Zelazo et al., 2016). Developing strong EF skills early in life is critical, as EF is associated with many school readiness (Nelson et al., 2017) and academic achievement outcomes (Welsh et al., 2010). Furthermore, optimal brain development in early childhood may result in lasting changes in brain structure and function later in life (Hillman et al., 2008).

Previous research with adolescents and adults provides support for a connection between physical activity and improvements in EF (Best, 2010; Carson et al., 2015; Esteban-Cornejo et al., 2015; Reinert et al., 2013; Tomporowski et al., 2008; Tomporowski et al., 2011; Tomporowski et al., 2015; Verburgh et al., 2014). These studies vary widely in the types of activities, the length and intensity of the activity, and the tasks selected to measure EF. Recent reviews suggest that not just any physical activity, but *cognitively engaging* physical activity may have a stronger effect on children's executive function (Best, 2010; Diamond, 2015). Understanding which type of activities result in the best immediate improvements in EF for preschool children will offer guidance to parents, teachers, and administrators who are interested in improving the lives of young children. These immediate effects may also provide further justification for increasing daily opportunities for physical activity and exercise play for preschool children.

Overall Findings

This study hypothesized that physical activity in combination with higher cognitive engagement (PACE) would have the most impact on improving children's working memory, inhibition, and shifting ability compared to activities high in physical activity but low in cognitive engagement (PA), activities low in physical activity but high in cognitive engagement (Cognitive), and activities low in both physical activity and cognitive engagement (Low). This hypothesis was based on Best's (2010) suggestion that during cognitively engaging physical activity, two mechanisms work together to improve children's EF skills: 1) physiological changes in the brain caused by the physical activity, and 2) cognitive engagement requirements of the activity engage higher order cognitive processes, thereby priming EF skills for subsequent use (Best, 2012; Pesce et al., 2009).

Although the current study did not collect any neurological or physiological performance metrics other than the accelerometer movement data, several other studies have shown connections between changes in the brain and EF as a result of physical activity (PA). For example, research has shown that exercise leads to increases in P3 amplitude (Hillman et al., 2003; Kamijo et al., 2009), increases in alpha activity in the precuneus and decreases in beta activity in left temporal areas (Schneider et al., 2009), increases in cerebral blood flow in the prefrontal cortex (Endo et al., 2013), increased release of brain-derived neurotrophic factors (BDNF, Piepmeier & Etnier, 2015), and increased gray matter volume in the frontal and hippocampus regions (Mandolesi et al., 2018).

Also important to the findings from this study is the role of cognitive engagement (CE), namely tasks that increase mental load and require more mental effort (Paas et al., 1994). Mental load was increased by making the task more complex, thereby requiring children to commit more mental resources to achieve successful performance. In the PACE and CE conditions, complex tasks were designed to challenge children's EF by asking them to remember multiple changing rules, inhibit movement by freezing when the music stopped, and shift between fast and slow movements both in coordination with and opposite of the music's tempo. Previous studies have shown that even sedentary CE activities, such as computer training, result in improvements on EF tasks similar to the training (Alloway et al., 2013; Ang et al., 2015; Klingberg et al., 2005; Thorell et al., 2009). Studies with adolescents are also beginning to find that cognitively engaging physical activity is more beneficial to children’s EF than physical activity alone (Benzing et al., 2016; Schmidt et al., 2015).

This study partially confirmed the hypothesis, as findings revealed that the combination of physical activity and cognitive engagement resulted in greater immediate improvements in *working memory* than physical activity or cognitive engagement alone. Also, for children who started with low shifting ability, the PACE condition outperformed the Low condition on shifting skills at post-test, and high physical activity outperformed low physical activity. Interestingly, children who started with higher shifting ability benefited from both cognitively engaging conditions. No effects were found on inhibition as measured by the Peg Tapping task or overall EF as measured by the HTKS. Because the findings differed based on the task and construct being tested, the remaining discussion considers the findings from each EF task separately.

Separate Components of Executive Function

The EF tasks used here were selected to measure different components of executive function. Previous researchers have acknowledged that even though EF tasks are designed to discretely measure one construct, success on the tasks may require other overlapping skills (Espy et al., 2008). Table 21 provides a summary of the tasks used in this study, showing the specific components of each task that correspond with the desired EF component, while also illustrating how multiple overlapping skills are needed for success.

Table 21 Analysis of the Components of Executive Function Each Task Required for Producing Correct Responses.

Task Requirements	Spin the Pots (Working Memory)	Peg Tapping (Inhibition)	DCCS* (Shifting)	HTKS (Overall EF)
Remember items based on color and shape, adapting to changes in spatial location	Yes			
Perform opposite response of prompt		Yes		Yes
Remember additional rules				Starts at Item 11 and Item 21
Shift to accommodate rule change			Sorting rules change after items 5, 15, and 20	Starts at Item 21
Remember multiple rules simultaneously			Items 21-50	Items 11-30
Frequency of rule reminders	Only at beginning	Only at beginning	After items 5, 10, 15, and 20	When rules change after every 10 items

Note. DCCS = Dimensional Change Card Sort Task with Developmental Extension on the NIH Toolbox. HTKS = Head, Toes, Knees, Shoulders task. Number of test items varies by task (Spin the Pots varies from 6 to 16 trials, Peg Tapping has 16 trials, DCCS has 50 trials and HTKS has 30 trials). *The developmental extension portion of the DCCS provided detailed prompts and rule reminders for each item along with simpler sorting tasks.

Not only is it difficult to choose a single behavioral task to pinpoint one EF component, evidence also suggests that EF starts as a unitary construct in early childhood, and then later develops into a multi-dimensional three factor construct (Brydges et al., 2012; Huizinga et al., 2006). In this study, participants fall into this developmental transition period, and the results suggest that the three-factor construct was appropriate, as the findings differed for each task. Also, only Peg Tapping, DCCS, and HTKS, but not Spin the Pots were correlated at post-test as shown in Table 6 with correlation coefficients ranging between .47 to .50, suggesting that while these tasks may be measuring some overlapping skills, each skill also has some unique capacity for improvement based on a short-term physical activity intervention.

Working Memory – Spin the Pots

Spin the Pots is a working memory task that requires children to find stickers hidden in boxes in as few trials as possible. To succeed children must remember which boxes they already selected based on the color and shape of the box, and then select a new box, even when the boxes' spatial location changes. Results on the Spin the Pots task confirmed that engaging young children in cognitively engaging physical activity may help them remember and mentally manipulate relevant information. These skills will be especially helpful in early childhood academic contexts as children learn to read, build reading comprehension skills, and begin to perform mental math calculations.

This finding is in contrast with many previous studies who have not found beneficial effects of cognitively engaging physical activity on working memory (Egger et al., 2018; Jäger et al., 2014; Tandon et al., 2018). Jäger et al. (2015) also found that only children with higher fitness and higher academic achievement experienced working memory benefits from a physical activity intervention. Given these discouraging results, why did the current study find that the combination of physical activity and cognitive engagement improved preschool children's working memory? And why was the PACE condition effective over and above physical activity alone? The answer to this question may lie in individual differences in the study's participants, in the task selected for use, or both.

It is worth noting that the current study worked regardless of children's pre-test working memory ability, suggesting that at this young age, working memory may be more responsive to a short-term physical activity intervention than older children and adults. Some previous studies have shown that short-term physical activity is only beneficial for participants who start low on working memory (Budde et al., 2010; Sibley & Beilock, 2007). However, most of those studies included children at least 6-years-old through adults, whereas the current study utilized 4- and 5-year old children. Because children's working memory performance grows linearly from 4 years to adolescence and the subsystems of working memory (e.g. the central executive, phonological loop, and visuospatial sketchpad) are not in place until around age 6 (Gathercole et al., 2004), the present participants may be experiencing a growth period for working memory that increased their susceptibility to this intervention.

Another possibility for the success of this intervention lies in the task. The Spin the Pots task used here has been shown to be engaging for young children, free from language constraints, and taps into the visuospatial portion of working memory (Zimmermann, 2016). Most previous studies of physical activity and working memory used tasks that required remembering information and then working towards a goal having to do with that information, such as recalling a list of items presented in reverse order (e.g. Backward Digit Span). According to Baddeley's (2000) model of working memory, these tasks measure the phonological loop portion of working memory, whereas the Spin the Pots task may also incorporate the visuospatial sketchpad. It may be that movement inherent to physical activity has a greater impact on visuospatial working memory. For instance, here, the PACE condition may have triggered parts of the brain relating to the visuospatial sketchpad as children had to navigate around the room, avoiding obstacles and each other, while remembering to follow the rules of the game. Utilizing this visuospatial sketchpad during the intervention activities may have subsequently led to improvements on a task where children can use visuospatial working memory, rather than just the phonological loop, to be successful.

Interestingly, children in the PACE condition benefitted the most from the short-term intervention, though physical activity alone and cognitive engagement alone did not have the same effects. For the PA condition, the activities were designed to be low in cognitive engagement, so freely moving and dancing around the room may not have engaged the visuospatial sketchpad as much as the PACE condition. Similarly, the Cognitive condition was designed to have increases in task complexity to match the PACE condition while varying physical activity, so that the rule changes occurred while children were either dancing around the room (PACE) or sitting while playing instruments (Cognitive). Again, the full body motions in the PACE condition may have required slight differences in cognitive engagement demands, through the use of this visuospatial sketchpad.

Although the connection between full-body movement and visuospatial working memory sounds promising, children can also use internal speech to help remember which boxes still had stickers. If so, then something else about cognitively engaging physical activity was responsible for the improvements on this working memory task. Future research should continue to explore the mechanisms by which this type of short intervention impacts working memory for preschool children.

Another task related element worth noting is that the sticker rewards from the Spin the Pots task anecdotally resulted in more positive affect and motivation, as the children were excited to find all the stickers. Positive affect (Yang et al., 2012) and motivation (Taylor et al., 2004) have been shown to improve performance on working memory tasks, and therefore may have increased children's ability to benefit from the PACE condition.

In summary, the PACE condition resulted in the greatest immediate improvements on preschool children's working memory performance. The working memory skills of preschool children may be in a particularly sensitive growth period which increases their susceptibility to an intervention relative to older school-age children and adults. Additionally, children in the PACE condition may have used their visuospatial skills more than children in the other conditions, subsequently leading to improved performance on a task where they can also utilize visuospatial working memory skills. Positive affect and motivation resulting from the sticker rewards during the Spin the Pots task may have also increased children's ability to benefit from the intervention.

Inhibition – Peg Tapping

Peg Tapping is an inhibition task that requires children to inhibit the prepotent response to mimic the number of times the experimenter taps a wooden rod (1 or 2 times), and instead perform the opposite response. Contrary to many previous studies, this short-term intervention did not have an immediate impact on children's inhibition skills.

Interestingly, Jäger et al. (2015) stated that acute physical activity shows relatively consistent positive effects on inhibition for children (i.e. Best, 2012; Ellemberg & St-Louis-Deschênes, 2010, Hillman et al., 2009; Jäger et al., 2014; Pontifex et al., 2013). These studies all differ from the current study because they were conducted with children individually, such as in lab-based treadmill walking, exercise biking, or exergaming. Other studies using more naturalistic small group settings with school-age children have had mixed results. For example, Egger et al. (2018) and Jäger et al. (2015) both used a 2 x 2 study design varying physical activity and cognitive engagement finding that none of the intervention conditions impacted inhibition. On the other hand, Chang et al. (2013) found inhibition improved after an 8-week soccer program and Jäger et al. (2014) found inhibition improved immediately following a 20-minute sequence of playful sports-oriented games. Both soccer and the playful sports games were considered cognitively engaging physical activities. However, neither of these two studies intentionally compared high and low cognitive engagement, so it is unclear whether the physical activity alone, or the inclusion of more cognitively demanding activity was responsible for the improved inhibition.

So why was the short-term intervention in the current study not effective? First, the Peg Tapping task may not be appropriate for detecting improvements in inhibition for this sample of participants. Over 40% of the children scored a 14 or higher at pre-test, and another 11% scored a 12 or 13 at pre-test. Conducting the post-hoc analysis by removing these high scorers left a sample size of 55, which may be underpowered for detecting small effects. Given that the intervention was only 12 minutes long, children may have needed more exposure to the activities to impact their inhibition skills. Also, because so many children scored high on the measure at pre-test, knowing whether the short-term intervention supported gains in inhibition for this higher sub-sample is inconclusive, as there was little room for improvement in their post-test score.

Another important facet to consider is why the intervention, and specifically the PACE condition, supported working memory, but not inhibition. Diamond (2013) suggested that the components of EF develop at different times and that inhibition is the first EF skill to develop. Thus, it may be that all the children in the current study were in the midst of developing their working memory, especially as visuospatial working memory is rapidly developing for 4- to 6-year-old children (Gathercole et al., 2004). On the contrary, some children's inhibition skills may have been beyond the window of rapid growth and susceptibility to this short-term intervention. As mentioned previously, over 40% of children approached ceiling on this measure at pre-test ($N = 44$) by scoring a 14 or higher, which further supports the idea that many children have already made strides in their inhibition development. Drollette et al. (2014) found that 8- to 10-year old children with lower inhibition skills benefitted the most immediately after 20 minutes of moderate intensity treadmill walking. Also, event-related brain potentials revealed that the P3 amplitudes of children with lower inhibition scores became comparable to the children with higher inhibition scores after the treadmill walking. Future research should continue to expand the sample, particularly with children who start low in inhibition, to explore whether this type of short-term intervention can have an immediate impact on inhibition skills. Also measures should be selected that are more sensitive to the variability in inhibition development for 4- and 5-year-old children.

In summary, this short-term intervention did not have a detectable impact on preschool children's inhibition performance, as measured by the Peg Tapping task. This task may not have been sensitive to the variability in inhibition for 4- and 5-year old children, as a large percentage of children in this study approached ceiling at pre-test. Also, because inhibition develops before working memory and shifting (Diamond, 2013), some children’s inhibition skills may have already been beyond a window of rapid growth and susceptibility to this short-term intervention. Future research should continue to try and identify short activities that immediately impact preschool children's inhibition, as inhibition skills help children return to the classroom ready to learn, to ignore distractions, and to respond in controlled manners to emotional situations.

Shifting – NIH Toolbox DCCS

The DCCS task required children to sort pictures on an iPad first by shape, then by color, back to shape, and then concluded with 30 items where children sorted between color and shape depending on the prompt. If a child did not sort at least 4 out of 5 items correctly on the initial sorts (prior to the mixed trials), they switched to the developmental extension version which had more detailed prompts and simpler sorting tasks. For example, in one section of the developmental extension, children are shown a picture of a big kitty or a little kitty to sort into a matching box. After a wrong answer, the sorting rule is repeated and demonstrated (i.e. “If it’s a little kitty, then it goes in the little kitty box. If it’s a big kitty, then it goes in the big kitty box”).

The DCCS task was selected to measure children's ability to shift between changing rules, while understanding that children must also use inhibition to suppress their natural tendency to continue using the same sorting rules. Working memory may also be required as children try to remember the changing rules, although prompts prior to each item should minimize this confound. Like working memory and inhibition, shifting is also an important cognitive performance skill for young children. Improved shifting ability helps support creativity and figuring out multiple ways to solve problems, especially when an initial method is not working, such as when a puzzle piece needs to be rotated to fit into the correct location. In early childhood settings, shifting supports children's ability to transition between activities, use inside and outside voices based on the appropriate context, and adapt to changing rules during games.

Results on the DCCS found no differences by condition for the full sample of children. However, a post-hoc analysis found that children in the PACE condition who started with low pre-test DCCS scores outperformed the low control condition. This analysis had a sample size of 49, and therefore may be underpowered for detecting small and medium effects. Combining the physical activity conditions to compare high versus low physical activity increased power in the model. Thus, in this new model, high physical activity conditions (PACE and PA) outperformed low physical activity (Cognitive and Low) for children who started low on the DCCS at pre-test. Also, for these children who started low at pre-test, girls outperformed boys by about 14 points across all the conditions. Another post-hoc analysis was conducted with children who started in the upper 50^{th} percentile of raw scores at pre-test because age-corrected standard scores that incorporated reaction time measures were available from the standard version of the DCCS. These normative scores helped differentiate the performance of children approaching ceiling in raw score measurements. This post-hoc analysis revealed that for children who scored higher at pretest, participating in cognitively engaging activities resulted in better shifting performance at post-test compared to low cognitively engaging activities.

These findings raise several questions in relation to the working memory results discussed above where the PACE condition was most effective, and inhibition results where no condition differences were found. For working memory, the likely mechanism was a combination of physiological changes in the brain as a result of PA combined with training on cognitive tasks during the intervention. But for shifting, why was physical activity, with and without cognitive engagement, beneficial for children who started with *low* shifting ability? Also, why was cognitive engagement, with and without physical activity beneficial for children who started with *high* shifting ability?

Using the DCCS task on the NIH toolbox provided two helpful features for this sample of preschool participants. First, the developmental extension yielded additional information about children with low shifting skills that would otherwise have scored at floor on the standard measure. Second, having normative scores that included reaction time measurements for children with higher shifting skills allowed for discrimination amongst children who scored high on the DCCS. None of the other measures discussed thus far allowed for this type of analysis with the entire sample. Unfortunately, because normative scores were not available for the developmental extension, the sample had to be divided in half, which reduced power for detecting differences between all four conditions in the study. However, determining that physical activity benefits children who start with low shifting skills and cognitive engagement benefits children who start with high shifting skills is an interesting finding to consider.

Previous research on the relationship between shifting and physical activity is more limited than the research on working memory and inhibition, especially with young preschool children. Some studies have found effects on shifting both from immediate and longer-term cognitively engaging physical activity interventions (Benzing et al., 2016; Ellemberg & St-Louis-Deschênes, 2010; Gao et al., 2019; Schmidt et al., 2015). Other studies found no effects (Jäger et al., 2015; Stein et al., 2017), and even decreases in shifting ability (Egger et al., 2018) with no clear patterns to explain the results.

Therefore, to understand the findings here, it is helpful to reflect on the characteristics of this particular intervention and the mechanisms that may be influencing the shifting results. First, the intervention required children to use shifting skills to remember that fast tempo music no longer meant to dance (or shake tambourines) fast, but rather to do the silly version by moving slow. Succeeding in a shifting task such as this is difficult even for adults. Unfortunately, video recordings are not available to confirm whether the children were successful at shifting during the intervention, though both the lead researcher and neutral observer acknowledged that some children had difficulty with this shifting task. Diamond (2013) proposes that shifting is the last of the three EF components to develop (Diamond, 2013) and thus it may be more difficult to design short-term interventions where preschool children can successfully practice using shifting skills. If children with low shifting skills were not able to benefit from the cognitive training, the results realized for them may be solely a function of the benefits from physical activity. Likewise, children with higher shifting skills perhaps may have been able to practice moving (dancing and shaking tambourines) at the opposite tempo of the music, therefore priming this shifting skill for subsequent use.

But why would physical activity (with and without cognitive engagement) improve shifting ability, especially when this was not the case for working memory and inhibition? Notably, the DCCS had many more items and required the longest time to complete compared to the other EF measures (see Table 2). It may be that another benefit of physical activity, enhanced concentration and attention (Budde et al., 2008), contributed to the benefits of the PA and PACE condition. This increase in attention may have been especially important to realize gains in the long DCCS task, but not necessarily a contributing factor for the short and engaging Spin the Pots task and the quickly administered Peg Tapping task.

Another explanation for the benefits of both physical activity conditions lies in the different types of neural improvements that result from physical activity, including increased gray matter volume in the frontal and hippocampus regions, increased release of brain-derived neurotrophic factors (BDNF), reduced damage in gray matter, and increases in blood flow and circulation (Mandolesi et al., 2018). Many of these changes impact the pre-frontal cortex which is known to house the executive control functions of the brain including the EF skills studied here. However, it is unclear whether each of these types of physiological changes have different effects on the individual EF constructs. For instance, improvements in white matter integrity after physical activity have been shown to support flexible neural processing and complex crosstalk between neural networks in older adults, which supports shifting ability

(Burzynska et al., 2015). On the other hand, working memory performance was connected with increases in serum BDNF levels after exercise (Håkansson et al., 2017), and improved inhibition was correlated with event-related brain potentials showing increases in P3 amplitude (Hillman et al., 2009). These different physiological responses for each of the EF components may begin to explain why shifting results were benefitted by both physical activity conditions, which was not the case with working memory and inhibition.

An additional caveat in the results is that girls who started low on the DCCS at pre-test outperformed boys across all of the conditions. Small differences in EF by gender have been found to favor girls in the past (Isquith et al., 2004; Zelazo et al., 2016). Because this result was only found on the smaller subsample of children who started low at pre-test, future research is necessary.

In summary, no differences by condition were found in the overall sample, though unique features of the DCCS allowed for post-hoc analyses both for children who started with low scores and for children who started with high raw scores at pre-test. For children who started with low pre-test scores, the PACE condition outperformed the Low condition, and high physical activity conditions combined outperformed low physical activity. Because shifting is the last of the three EF components to develop (Diamond, 2013), it may be more difficult to both train and improve with a short-term intervention. Physical activity may also benefit shifting through improvements in white matter integrity (Burzynska et al., 2015), which is a different neurological response to activity than has been shown to correlate with inhibition (Hillman et al., 2009) and working memory (Håkansson et al., 2017). Additionally, physical activity may benefit attention and concentration (Budde et al., 2008), which could subsequently lead to gains in the long DCCS task. In another post-hoc analysis with children who scored higher at pretest, participating in cognitively engaging activities resulted in better shifting performance at post-test than low cognitively engaging activities. Because these children had better initial shifting ability, they may have benefitted from practicing their shifting skills during the intervention by moving at a speed opposite the music's tempo. This practice may have primed their shifting skills for subsequent use on the DCCS at post-test.

Overall Executive Function - HTKS

The HTKS task was designed to be an overall measure of executive function that incorporates working memory, inhibition, and shifting skills. Children were required to perform the opposite response of a prompt (as in Peg Tapping), incorporate an additional rule, remember multiple rules simultaneously, and shift to accommodate a rule change. Given that the HTKS was selected to measure overall EF, it is notable that at pre-test, HTKS scores were correlated with all three of the other EF tasks, indicating that portions of this task are measuring each of the three components. Contrary to the study hypothesis, this short-term intervention did not have an immediate impact on children's overall EF skills measured by the HTKS.

Most of the previous research using the HTKS found positive results from longer-term interventions (e.g. Becker et al., 2014; Mulvey et al., 2018; Tominey & McClelland, 2011), which may be a slightly different mechanism than the short-term intervention studied here, as the current study was only a 12-minute one-time intervention. For instance, in studies where children participated in activities similar to this study, the interventions lasted 30 minutes, twice a week for six weeks (Mulvey et al., 2018) or eight weeks (Tominey & McClelland). Also, in Tominey and McClelland

(2011), the number of sessions attended significantly predicted gains on the HTKS over the school year for children who started with low pre-test scores. Specifically, children who attended the average number of sessions for their intervention (11.3) would be expected to gain 9.5 points on the task from the fall to the spring. Perhaps this measure is not sensitive to small effects we would expect from a short, one-time intervention.

The current study may have been underpowered to detect small effects from the sample of children who started lower at pre-test. For instance, Table 19 shows that post-test scores for children who started low at pre-test in the PACE condition outperformed the PA and Cognitive conditions by about 5 points and the Low condition by about 10 points at post-test. With the large variability in post-test scores (SD = 17.4 compared to SD = 6.6 at pre-test) and a small sample size of 54 participants, this difference was not significant. Future research should continue to investigate factors that may be contributing to this larger variability at post-test, perhaps revealing variables that help children benefit more from the intervention. A larger sample size will also help determine whether these preliminary (but insignificant) differences are still evident using the HTKS as a measure immediately after a short-term intervention.

Because HTKS measured EF as a composite skill, the exact contribution of working memory, inhibition, and shifting as separate skills is unknown. However, recall that the initial part of the HTKS task is similar to the Peg Tapping task by requiring children to inhibit a prepotent response to mimic the experimenter. No significant condition differences were found for either the Peg Tapping task or the HTKS task. Perhaps the current intervention did not have an immediate impact on inhibition, or the tasks selected to measure inhibition (including the portion of the HTKS targeted towards inhibition skills) are not sensitive to the variability in inhibition after a short-term intervention for 4- and 5-year old children. Additionally, investigating the *immediate* impact means that the post-test tasks must immediately follow the intervention. The HTKS was always administered last, which required children to maintain their attention for at least 20-30 minutes after the intervention. Future research should continue to explore how long the benefits of physical activity persist.

In summary, no significant condition differences were found for the HTKS after this short-term intervention. Most of the previous research using the HTKS investigated longer-term interventions that included 12 to 16 sessions. However, trending differences in post-test scores during the post-hoc analysis favoring the PACE condition for children who started low at pre-test provides a promising opportunity for using this measure even for shorter-term physical activity interventions.

Limitations of the Study

This study was one of the first to conduct a pre-test, intervention, post-test design examining the immediate impact of cognitively engaging physical activity on all three components of preschool children's executive function skills. There were several limitations that can be improved upon for future research.

Because this research was fulfilling the requirements of a dissertation study, the lead researcher conducted all the intervention activities, which allowed her to develop a similar rapport and have similar interactions with all the children in the study. However, this also provided an opportunity for bias during the intervention in areas such as prompting and feedback during the rule changes. To minimize this bias, a detailed script with prompts was written and closely followed. A neutral observer also provided feedback after each session to ensure adherence to the script. Unfortunately, the childcare directors did not approve the use of audio or video recording methods, so we were unable to code for fidelity to the intervention script which could have ensured minimal bias throughout the study. One promising aspect of the study design is that the lead did not conduct any of the post-test measures of EF, and those were only conducted by trained researchers who remained blind to condition.

Another limitation of this study was the small sample sizes analyzed for each of the dependent measures of EF. Collecting data over the summer in childcare settings was difficult, as children's attendance and availability to participate in two sessions several days apart was often not possible due to vacations and other commitments. For this study, 13 children participated in a pre-test session but were not available for the post-test, and many others completed consent forms but were not in attendance on pre-test days. In addition, many of the children scored at or close to ceiling on some of the EF measures at pre-test, making it difficult to see improvements on a post-test measure. Post-hoc analyses on children who started in the lower 50th percentile were promising, especially for shifting skills, but may have been underpowered with sample sizes too small to detect effects. Because the study was conducted with children from pre-K classrooms, the age range encompassed children over a 2-year age-range. Executive function skills are rapidly developing over these preschool years, making it difficult to select measures that are appropriate for this full age range (Doebel & Zelazo, 2015). Continuing to develop normed measures like the

DCCS that automatically adapt based on skill level would be helpful for future research, especially if they were developed for the different EF components.

In finding and selecting measures of EF appropriate for a larger age group, new technology may also help develop affordable and easy to implement tasks that capture reaction time data in addition to accuracy on each task. The DCCS scores included a reaction time measure for participants who proceeded to the mixed trials portion beginning with item 20 on the standard version. Several studies have found improvements in response time but not necessarily accuracy for inhibition and shifting (e.g. Benzing et al., 2018). Adding measures that capture reaction time and accuracy may yield additional insights into the effect of this intervention.

Working in the childcare centers also presented challenges in finding appropriate spaces within the centers to work with small groups of children separate from their classroom. Some facilities had large empty classrooms and multi-purpose rooms that were conducive to larger groups and physically active games, whereas other spaces required the children to navigate around bookshelves and tables in order to participate. These different scenarios will be especially important to consider when trying to scale up the intervention for a full classroom of children simultaneously.

These challenges of working in local childcare facilities also provided a fortuitous opportunity to include children from a wide range of socioeconomic (SES) backgrounds and ethnic diversity. When divided into three SES categories (using primary caregiver's education level as a proxy for SES), 34% of children came from low-income families, 41% came from middle-income households, and 25% came from upper-income households. Additionally, parents of over 52% of children in this study identified their child as Hispanic / Latino and most of these children were English language learners. While no language measures were given to assess the children's comprehension and production of English, it may have impacted their EF outcomes since all the tasks were administered in English. However, the teachers assured us that all the children understood English, and none of the children seemed overly confused by the instructions for the intervention or the EF tasks.

Future Research

In addition to the few study design improvements mentioned above, this preliminary study provides a solid starting point for future research on the connection between physical activity and EF for preschool children. These findings are especially promising because the intervention included 12 minutes of activities that are inexpensive and easy to incorporate in classroom settings. If EF skills can be impacted with after a single short bout of activity, these effects would likely multiply after several days or weeks of participating in these activities. Understanding the mechanisms underlying these effects, including putative changes in the brain, can help determine whether these short-term effects can be compounded and result in lasting changes in brain development.

Future research should continue to explore how other measures of executive function respond to physical activity interventions for preschool children. For instance, researchers can continue to explore working memory by selecting activities and tasks that require children to use the phonological loop versus visuospatial sketchpad, both during the intervention, and during the pre- and post-test tasks. Additionally, future research should explore measures that are sensitive to wide variation in skills across this two-year age range, perhaps by including measures of reaction time.

Also important to consider in future research is the role of cognitively engaging physical activities in combination with or instead of other preschool curriculum programs (e.g. Tools of the Mind; Leong & Bedrova, 1996) that have been shown to benefit executive function skills (Barnett et al., 2008). Would long-term cognitively engaging physical activity have equivalent results? Would adding physical activity into an existing curriculum further extend the benefits on EF skills? Continuing to investigate how these types of playful learning curricula overlap with the benefits of physical activity would be an interesting next step for researchers.

The results of this study also provide a starting place for impacting policies on recess and physical education in schools and early childhood education programs. Since No Child Left Behind was passed in 2001, a survey showed that 44% of schools have reduced the amount of time allocated towards physical education and recess, in addition to art, music, science, and social studies (McMurrer, 2007). Nationwide, schools, including preschools, are becoming more focused on academics. For instance, Bassok et al. (2016) found that from 1998-2010, the percentage of kindergarten teachers who thought children should learn to read in kindergarten increased from 31% to 80%, while the percentage of kindergarten classrooms with dramatic play areas dropped from 90% to 58%. Yet over 80% of these teachers believe following directions, sitting still, paying attention, taking turns, and being sensitive to others' feelings are important for school readiness, compared to 35% to 45% who believe knowing letters and counting to 20 are important. The current study provides an important first step in showing how short activities can be used in early childhood settings to impact executive function skills; skills which may then translate into the school readiness behaviors desired by teachers in the Bassok et al. (2016) study.

Continuing to explore whether these gains in EF resulting from cognitively engaging physical activity transfer to classroom behavioral performance and long-term academic achievement will be critical next steps for continuing to justifying increased opportunities for physical activity throughout the school day.

While there are many questions that remain unanswered, this study provides promising results regarding the benefits of physical activity for young children. Understanding the cumulative effect of these types of activities over time is crucial to ensuring the best possible developmental scenarios for young children. If these benefits continue to be affirmed, preschool curricula can be designed to incorporate more cognitively engaging physical activity.

Summary and Conclusions

The present study addressed a topic that has significant implications for early childhood development. Having strong EF skills is crucial for school readiness and later academic achievement. Finding that short interventions combining physical activity with cognitive engagement immediately improve children's EF skills provides hope for teachers working with children who struggle to focus in their preschool classroom. Knowing that children who start low in EF can benefit from these short activities provides a clear call to action for integrating more physical activity in young children's lives.

These findings are especially promising in that children benefitted from the intervention after only 12 minutes of activity. These immediate effects are an important first step in determining the types of interventions that may have a cumulative impact on brain development in the pre-frontal cortex. These exact neurological mechanisms are in the early stages of research as new technology affords the opportunity to study children's brain activity while they move around in physically active interventions. Even if the neurological mechanisms only support an immediate response from physical activity, rather than permanent neurological differences, we can still hypothesize that short term physical activity interventions, especially ones incorporating cognitive engagement, will benefit children as they return to the classroom. Their ability to inhibit negative behaviors, keep more information in mind and mentally manipulate that information, and shift to accommodate new activities, rules, and information will prepare children to be ready to learn, which should then lead to greater academic achievement over time. Future studies should consider both of these possible mechanisms (cumulative neurological effects resulting in permanent changes in brain structure, and short-term effects on readiness to learn) for improving long-term academic achievement as a result of physical activity in early childhood.

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Appendix A

INTERVENTION PROTOCOL SCRIPT

Day 1: Pre-Test Procedures

Prior to arrival at the daycare, each child will be randomly assigned to one of three pre-test condition orders and randomly assigned to work with one of the experimenters.

Order 1: WM (Spin the Pots), IN (Peg Tapping), SH (DCCS), Overall (HTKS)
Order 2: IN (Peg Tapping), SH (DCCS), WM (Spin the Pots), Overall (HTKS)
Order 3: SH (DCCS), WM (Spin the Pots), IN (Peg Tapping), Overall (HTKS)

Groups of 3-5 children will be brought to a classroom or space for testing. Children will start in the middle of the room (or obvious open space) standing in a circle, with children and experimenters alternating every other person. A child's assigned experimenter will stand on their right-hand side in the circle.

The lead experimenter will introduce herself, describe what we are going to do, and ask the children to give a thumbs up if they are willing to participate. Then the whole group will sing a welcome song. Each experimenter will then take their partner child to different corners or spaces in the room to do the EF tasks. The child will be faced towards a wall to minimize distraction from the other children. Upon completion of the task, the experimenter will read a book or talk quietly with their child until all the groups are ready to return to the classroom.

Script for Day 1 Welcome and Introductions:

- Hi, my name is ______ and I'm so glad you are going to play some games with us today! I have some friends here that are going to help me today too! This is _____, this is _____, etc…
- The first thing we are going to do is sing a song so we can get to know each other. Then we will pair up so you each get a chance to play the games.
- Once you finish the games, we will measure your height and weight, and then wait quietly and read until everyone finishes so we can go back to your classroom together. We'll be back in a couple days to play some more games together too! Are you guys ready to play? If so, give me a thumbs up!
- Now, it's time for our song. We'll sing it once so you can learn it, and then we'll sing it together a couple times!

  WELCOME SONG: "Hello Friends"

  Hello friends, how are you? I'm very happy to see you! Greet your neighbor. Boogie on down. Give a jump, and turn around.

  https://www.youtube.com/watch?time_continue=96&v=3ywIu30lqKA
- Wow – that was fun! And you are being such great listeners. Now it's time for some more games. Remember, we are going to pair up and spread out so that you

all get to play the games (experimenters talk to child on their left, taking them to their testing area).

See appropriate scripts for tasks based on randomly assigned order.

Once each experimenter completes the EF tasks with her child, take the child to measure height and weight, and notate their left/right handedness (have them draw a picture or observe during Peg Tapping). Then sit with the child and read together until all the groups are done. Meet back in the middle of the room (or open space).

Script for Day 1 Closing: Thank you for coming today! You all worked so hard on the games and did a great job! I hope you had as much fun as I did. It's time to go back to your classroom now, but we will be back in a few days to play some more games with you. Thanks for playing with us!

Day 2: Intervention / Post-Test Procedures

Prior to arrival, each child will be randomly assigned to one of three conditions. Child's post-test EF task order will match the randomly assigned order from pre-test.

Upon arrival, an experimenter will visit the classroom to find out which children are available for testing and give the children a few minutes warning for the transition. A small group of 3-5 children will be identified. The experimenter will then leave the room for final preparations: 1) each child will be assigned to work with a different experimenter than they worked with at pre-test, 2) accelerometer devices will be setup for each participating child based on data collected at pre-test (see Accelerometer Protocol), and 3) NIH Toolbox Apps will be setup and ready to go for each child. If not enough iPads are available for all the children, it will be sorted out which groups are sharing (preferably someone from Order 3 sharing with Order 1). Each experimenter will hold onto the accelerometer device for their assigned child.

Condition 1: Physical Activity Cognitively Engaging (PACE)
Condition 2: Physical Activity (PA)
Condition 3: Low Physical Activity/Low Cognitive Engagement (Control)
Condition 4: Low Physical Activity/High Cognitive Engagement (Cognitive)
Order 1: WM (Spin the Pots), IN (Peg Tapping), SH (DCCS), Overall (HTKS)
Order 2: IN (Peg Tapping), SH (DCCS), WM (Spin the Pots), Overall (HTKS)
Order 3: SH (DCCS), WM (Spin the Pots), IN (Peg Tapping), Overall (HTKS)

Groups of 3-5 children will be brought to a classroom or space for testing. Children will start in the middle of the room (or obvious open space) standing in a circle, with children and experimenters alternating every other person. A child's assigned experimenter will stand on their right-hand side in the circle.

The lead experimenter will introduce herself, describe what we are going to do, and ask the children to give a thumbs up if they are willing to participate. The experimenters will then place the assigned accelerometer device on their child.

The neutral observer will record the start time of the Welcome Song. The children and experimenters will sing the welcome song together. Then experimenters will leave the room and the lead experimenter will start the intervention. The neutral observer will record the start and stop time for the intervention.

Experimenters will come into the room and greet their partner child, removing their accelerometer devices. The lead experimenter will download the data from the devices while the experimenters are conducting post-tests.

Each experimenter will then take their partner child to different corners or spaces in the room to do the post-test EF tasks. The child will be faced towards a wall to minimize distraction from the other children. Upon completion of the tasks, the experimenter will read a book with their child until all the groups are ready to return to the classroom. Groups will meet back in the center of the room so lead experimenter can say thank you and goodbye.

Script for Day 2 Welcome and Introductions:

- Hi, my name is ______ and I'm so glad you came back to play some games with us today! I have my friends here again too! This is _____, this is _____, etc…
- We are going to do things a little different today. The first thing we are going to do is put these belts on our waist. The belts help me keep track of how much you are moving around while we play. Once we get them on your waist, we will sing our welcome song. Then our partner friends are going to leave the room for a little bit while we do an activity all together. At the end, your partner will come back to play games just with you, like we did the other day!
- Remember, just like last time, when you finish the games at the end, you'll wait quietly and read a book until everyone finishes so we can go back to your classroom together.
- Are you guys ready to play? If so, give me a thumbs up!
- Now, it's time for our welcome song. It's the same one we sang before, so just try to join in when you remember it! *(neutral observer records start time and end time of the song)*

  WELCOME SONG: *"Hello Friends"*

  Hello friends, how are you? I'm very happy to see you! Great your neighbor. Boogie on down. Give a jump, and turn around.

  https://www.youtube.com/watch?time_continue=96&v=3ywIu30lqKA
- Wow – that was fun! And you are being such great listeners. Now we are going to say goodbye to our partner friends so the rest of us can do an activity all together. Give a high five and say goodbye!

Experimenters leave the room.
Neutral observer records start and end time of the intervention.
See appropriate script based on child's assigned intervention condition:

Intervention Condition 1: Physical Activity Cognitively Engaging (PACE)

- Today we are going to have a dance party! We have three songs we are going to dance to so let's see if we can keep moving the whole time! When you dance, you can do whatever you want. You can jump, you can wiggle, you can stomp your feet, you can do bear crawls or crab walks, you can even floss if you want! (*demonstrate each dance move as you say it*). Make sure you watch out for your friends when you are dancing so no one gets hurt.
- For the first song, we are going to play freeze dance. When you hear the music playing, make sure you dance as much as you can. And then when the music stops, I want to see your best freeze!
- Okay, let's try it!

Note: neutral observer records start and stop time of the intervention (i.e. song 1 – song 3).
Play 1st song (9 freeze dance pauses)

  - Leader dances with kids through the 3rd pause and gives exaggerated pause when music stops to demonstrate how to play freeze dance.
    - Pause 1 (:12) – "nice freeze!" OR "don't forget to freeze!"
    - Pause 2 (:30) – "nice freeze!" OR " don't forget when the music stops, do your best freeze!"
    - Pause 3 (:50) – "you guys are doing a great job dancing – I'm going to stop but you keep dancing and don't forget to freeze when the music stops!"
    - Pause 4 (1:15) -
    - Pause 5 (1:38) – "Remember to freeze when the music stops"
    - Pause 6 (1:50) – "Great job using lots of different dance moves!"
    - Pause 7 (2:18) -
    - Pause 8 (2:28) – "Almost done with this song – keep dancing until the end!"
    - Pause 9 (2:57) –

- Great job everyone! Now it's time for our 2nd song. For this song you can still dance around just like before, but when the music sounds fast, I want you to dance fast. Let's all practice moving fast! And when the music sounds slow, I want you to dance slow. Let's all practice moving slow! Great job. Remember all those different dance moves I told you about too. This time, make sure you try a new move like the wiggle or the slide (*demonstrate wiggle & slide*). Let's try it with the music!

Play 2nd song (12 switches between fast and slow music)

- Leader dances with kids through the 3rd switch and demonstrates the difference between fast and slow dancing when the music changes.
    - Start (0) – " Here's our fast music. Remember when the music sounds fast, dance fast!"
    - Switch 1 (:19) – "Here's our slow music. When the music sounds slow, dance slow!
    - Switch 2 (:31) – "Nice switch to fast dancing!" OR "don't forget when the music sounds fast, dance fast!"
    - Switch 3 (:47) – "you guys are doing a great job dancing – I'm going to stop but you keep dancing and don't forget to dance slow when the music sounds slow and dance fast when the music sounds fast!"
    - Switch 4 (1:02) -
    - Switch 5 (1:10) –
    - Switch 6 (1:22) – "Remember to dance fast when the music sounds fast!"
    - Switch 7 (1:30) -
    - Switch 8 (1:41) – "Great job using lots of different dance moves!"
    - Switch 9 (1:56) –
    - Switch 10 (2:00)
    - Switch 11 (2:04) - "Almost done with this song – keep dancing until the end!"
    - Switch 12 (2:19)

- Okay, we have one last song. This time we are going to do the silly version! So when the music sounds fast, you are going to dance slow. And when the music sounds slow, you are going to dance fast. Do you think you can do it! Let's try the silly dance song! And don't forget, we have lots of dance moves we can use. This time try the bear crawl and crab walks, or jump from side to side (*demonstrate each dance move as you say it*)!

Play 3rd song (14 switches between fast and slow music)

- Leader dances with kids through the 3rd switch and demonstrates the difference between fast and slow dancing when the music changes.
    - Start (0) – " Here's our fast music. Remember when the music sounds fast, dance slow because we are doing the silly version!"
    - Switch 1 (:30) – "Here's our slow music. When the music sounds slow, dance fast!"
    - Switch 2 (:43) – "Nice switch to slow dancing!" OR "don't forget when the music sounds fast, dance slow!"

- Switch 3 (:58) – "you guys are doing a great job dancing – I'm going to stop but you keep dancing and don't forget when the music sounds slow, dance fast and when the music sounds fast, dance slow!"
- Switch 4 (1:11) -
- Switch 5 (1:25) –
- Switch 6 (1:37) – "Remember to dance slow when the music sounds fast!"
- Switch 7 (1:58) -
- Switch 8 (2:05) –
- Switch 9 (2:14) – "Great job using lots of different dance moves!"
- Switch 10 (2:45)
- Switch 11 (2:59) -
- Switch 12 (3:12) - "Almost done with this song – keep dancing until the end!"
- Switch 13 (3:27)
- Switch 14 (3:51)

- Wow! You all did a great job dancing!
- Let's take a quick minute to rest while our partner friends come back. They will take off your belts and then we are going to spread out so that you all get to play the games just like we did last time. Remember, when you finish your 4 games, you will read quietly until everyone is done!

Note: Neutral observer records stop time of the intervention and goes to get the experimenters from the hallway. Experimenters come into the room and greet their partner child, removing their accelerometer devices. The lead experimenter will download the data from the devices while the experimenters are conducting post-tests.

See appropriate scripts for tasks based on randomly assigned order. Once EF tasks are complete, sit with the child and read together until all the groups are done. Meet back in the middle of the room (or open space).

Script for Day 2 Closing: Thank you for coming today! You all worked so hard on the games and did a great job! I hope you had as much fun as I did. It's time to go back to your classroom now. Thanks for playing with us!

Intervention Condition 2: Physical Activity (PA)

- Today we are going to have a dance party! We have three songs we are going to dance to so let's see if we can keep moving the whole time! When you dance, you can do whatever you want. You can jump, you can wiggle, you can stomp your feet, you can do bear crawls or crab walks, you can even floss if you want! (*Demonstrate each dance move as you say it*). Make sure you watch out for your friends when you are dancing so no one gets hurt.
- When you hear the music playing, make sure you dance as much as you can. I want to see your best dance moves!
- Okay, let's try it!

Note: neutral observer records start time of the intervention.
Play 1st song

- Leader dances with kids through the first 50 seconds demonstrating several different dance moves. At the following time points, give feedback as follows!
    - (:12) – "nice dance moves!"
    - (:30) – "keep trying some of those different dance moves"
    - (:50) – "you guys are doing a great job dancing – I'm going to stop but you keep dancing and don't forget to show me your best moves!"
    - (1:38) – "Remember to keep doing your best dancing"
    - (1:50) – "Great job using lots of different dance moves!"
    - (2:28) – "Almost done with this song – keep dancing until the end!"

- Great job everyone! Now it's time for our 2nd song. For this song you can still dance around just like before, but remember all those different dance moves I told you about too. This time, make sure you try a new move like the wiggle or the slide (*demonstrate wiggle & slide*). Let's try it with the music!

Play 2nd song

- Leader dances with kids through the 3rd switch and demonstrates the wiggle and slide while dancing
    - Start (0) – "Let's get dancing! Let me see some good dance moves"
    - Switch 1 (:19) – "Great job dancing!"
    - Switch 2 (:31) – "Keep up the good work"
    - Switch 3 (:47) – "you guys are doing a great job dancing – I'm going to stop but you keep dancing and don't forget to show me your best dance moves"
    - Switch 4 (1:02) -
    - Switch 5 (1:10) –

    - Switch 6 (1:22) – "Remember to try some new dance moves like the wiggle and slide!" (quick demonstration of moves as you say it)
    - Switch 7 (1:30) -
    - Switch 8 (1:41) – "Great job using lots of different dance moves!"
    - Switch 9 (1:56) –
    - Switch 10 (2:00)
    - Switch 11 (2:04) - "Almost done with this song – keep dancing until the end!"
    - Switch 12 (2:19)

- Okay, we have one last song. And don't forget, we have lots of dance moves we can use. This time try the bear crawl and crab walks, or jump from side to side (*demonstrate each dance move as you say it*)!

Play 3rd song (14 switches between fast and slow music)

- Leader dances with kids through the 3rd switch and demonstrates the bear crawls, crab walks, and side to side jumps.
    - Start (0) – "Let's get dancing! Let me see some good dance moves!"
    - Switch 1 (:30) – "Great job using new dance moves!"
    - Switch 2 (:43) – "Great job dancing!"
    - Switch 3 (:58) – "you guys are doing a great job dancing – I'm going to stop but you keep dancing and don't forget to show me your best dance moves!"
    - Switch 4 (1:11) -
    - Switch 5 (1:25) –
    - Switch 6 (1:37) – "Remember to try some new dance moves like bear crawls, crab walks, and side to side jumps!" (quick demonstration of moves as you say it)
    - Switch 7 (1:58) -
    - Switch 8 (2:05) –
    - Switch 9 (2:14) – "Great job using lots of different dance moves!"
    - Switch 10 (2:45)
    - Switch 11 (2:59) -
    - Switch 12 (3:12) - "Almost done with this song – keep dancing until the end!"
    - Switch 13 (3:27)
    - Switch 14 (3:51)

- Wow! You all did a great job dancing!

- Let's take a quick minute to rest while our partner friends come back. They will take off your belts and then we are going to spread out so that you all get to play the games just like we did last time. Remember, when you finish your 4 games, you will read quietly until everyone is done!

Note: Neutral observer records stop time of the intervention and goes to get the experimenters from the hallway. Experimenters come into the room and greet their partner child, removing their accelerometer devices. The lead experimenter will download the data from the devices while the experimenters are conducting post-tests.

See appropriate scripts for tasks based on randomly assigned order. Once EF tasks are complete, sit with the child and read together until all the groups are done. Meet back in the middle of the room (or open space).

Script for Day 2 Closing: Thank you for coming today! You all worked so hard on the games and did a great job! I hope you had as much fun as I did. It's time to go back to your classroom now. Thanks for playing with us!

Intervention Condition 3: Low Physical Activity / Low Cognitive Engagement (Low/Low)

- Today we are going to have a craft party! We are going to sit down here and listen to music while we color some pictures. If you need help at any time, just let us know. ____ and I will be here to help!

Note: neutral observer records start time of the intervention.

Play 1st song

- Leader colors with kids through the first 50 seconds. At the following time points, give feedback as follows!
    - (:12) – "nice job coloring!"
    - (:30) – "great job using different colors on your pictures"
    - (:50) – "you guys are doing a great job coloring – I'm going to stop but you keep coloring while we listen to music!"
    - (1:38) – "Remember to keep coloring"
    - (1:50) – "Great job using lots of different colors!"
    - (2:28) – "Almost done with this song – keep coloring until the end!"
- Great job everyone! Your pictures are looking great. We have another song to listen to, so I'm going to give you a new coloring sheet if you need it.

Play 2nd song

- Leader colors with kids through the 3rd switch
    - Start (0) – "Let's get coloring! Let me see some pretty pictures"
    - Switch 1 (:19) – "Great job coloring!"
    - Switch 2 (:31) – "Keep up the good work"
    - Switch 3 (:47) – "you guys are doing a great job coloring – I'm going to stop but you keep coloring until the end of the song"
    - Switch 4 (1:02) -
    - Switch 5 (1:10) –
    - Switch 6 (1:22) – "Try a new color if you want"
    - Switch 7 (1:30) -
    - Switch 8 (1:41) – "Great job using lots of different colors!"
    - Switch 9 (1:56) –
    - Switch 10 (2:00)
    - Switch 11 (2:04) - "Almost done with this song – keep coloring until the end!"
    - Switch 12 (2:19)
- Keep up the good work. It's time for our last song, so here is one more picture for you to color!

Play 3rd song

- Leader colors with kids through the 3rd switch
    - Start (0) – "Let's get coloring! Let me see some pretty pictures!"
    - Switch 1 (:30) – "Great job coloring!"
    - Switch 2 (:43) – "Keep up the good work!"
    - Switch 3 (:58) – "you guys are doing a great job coloring – I'm going to stop but you keep coloring until the end of the song!"
    - Switch 4 (1:11) -
    - Switch 5 (1:25) –
    - Switch 6 (1:37) – "We have lots of colors you can use"
    - Switch 7 (1:58) -
    - Switch 8 (2:05) –
    - Switch 9 (2:14) – "Great job using lots of different colors!"
    - Switch 10 (2:45)
    - Switch 11 (2:59) -
    - Switch 12 (3:12) - "Almost done with this song – keep coloring until the end!"
    - Switch 13 (3:27)
    - Switch 14 (3:51)

- Wow! You all did a great job with your pictures!
- Let's take a quick minute to clean up, and then our partner friends will come back. They will take off your belts and then we are going to spread out so that you all get to play the games just like we did last time. Remember, when you finish your 4 games, you will read quietly until everyone is done! I'll make sure you get your pictures when we head back to the classroom.

Note: Neutral observer records stop time of the intervention, collects pictures from children, then goes to get the experimenters from the hallway (once all coloring materials are cleaned up). Experimenters come into the room and greet their partner child, removing their accelerometer devices. The lead experimenter will download the data from the devices while the experimenters are conducting post-tests.

See appropriate scripts for tasks based on randomly assigned order. Once EF tasks are complete, sit with the child and read together until all the groups are done. Meet back in the middle of the room (or open space).

Script for Day 2 Closing: Thank you for coming today! You all worked so hard on the games and did a great job! I hope you had as much fun as I did. It's time to go back to your classroom now. Thanks for playing with us!

Intervention Condition 4: Cognitive Engagement (Cognitive)

- Today we are going to have a music party! We have three songs we are going to play instruments to so let's see if we can keep the beat whole time! When you play, you can do whatever you want. You can use your right hand, you can use your left hand, you can go back and forth or do both hands at the same time! (*demonstrate each dance move as you say it*). Make sure you sit still so I can hear some good music!
- For the first song, we are going to play freeze drumming. When you hear the music playing, make sure you drum as much as you can. And then when the music stops, I want to see your best freeze!
- Okay, let's try it!

Note: neutral observer records start and stop time of the intervention (i.e. song 1 – song 3).
Play 1st song (9 freeze drumming pauses)

- Leader drums with kids through the 3rd pause and gives exaggerated pause when music stops to demonstrate how to play freeze drumming.
    - Pause 1 (:12) – "nice freeze!" OR "don't forget to freeze!"
    - Pause 2 (:30) – "nice freeze!" OR " don't forget when the music stops, do your best freeze!"
    - Pause 3 (:50) – "you guys are doing a great job drumming – I'm going to stop but you keep drumming and don't forget to freeze when the music stops!"
    - Pause 4 (1:15) -
    - Pause 5 (1:38) – "Remember to freeze when the music stops"
    - Pause 6 (1:50) – "Great job using lots of different drum moves!"
    - Pause 7 (2:18) -
    - Pause 8 (2:28) – "Almost done with this song – keep drumming until the end!"
    - Pause 9 (2:57) –

- Great job everyone! Now it's time for our 2nd song. For this song you can still play music just like before, but this time we are going to use maracas. Also, when the music sounds fast, I want you to shake them fast. Let's all practice shaking fast! And when the music sounds slow, I want you to shake slow. Let's all practice shaking slow! Great job. Remember all those different moves I told you about too. This time, make sure you try a new move like up in the air or crisscross (*demonstrate*). Let's try it with the music!

Play 2nd song (12 switches between fast and slow music)

- Leader shakes maracas with kids through the 3rd switch and demonstrates the difference between fast and slow shaking when the music changes.
    - Start (0) – " Here's our fast music. Remember when the music sounds fast, shake fast!"
    - Switch 1 (:19) – "Here's our slow music. When the music sounds slow, shake slow!
    - Switch 2 (:31) – "Nice switch to fast shaking!" OR "don't forget when the music sounds fast, dance fast!"
    - Switch 3 (:47) – "you guys are doing a great job making music – I'm going to stop but you keep shaking and don't forget to shake slow when the music sounds slow and shake fast when the music sounds fast!"
    - Switch 4 (1:02) -
    - Switch 5 (1:10) –
    - Switch 6 (1:22) – "Remember to shake fast when the music sounds fast!"
    - Switch 7 (1:30) -
    - Switch 8 (1:41) – "Great job using lots of different moves!"
    - Switch 9 (1:56) –
    - Switch 10 (2:00)
    - Switch 11 (2:04) - "Almost done with this song – keep shaking until the end!"
    - Switch 12 (2:19)

- Okay, we have one last song. This time we are going to do the silly version using tambourines! So when the music sounds fast, you are going to shake slow. And when the music sounds slow, you are going to shake fast. Do you think you can do it! Let's try the silly song! And don't forget, we have lots of moves we can use. This time try behind your back, or out wide (*demonstrate each dance move as you say it*)!

Play 3rd song (14 switches between fast and slow music)

- Leader shakes with kids through the 3rd switch and demonstrates the difference between fast and slow shaking when the music changes.
    - Start (0) – " Here's our fast music. Remember when the music sounds fast, shake slow because we are doing the silly version!"
    - Switch 1 (:30) – "Here's our slow music. When the music sounds slow, shake fast!"
    - Switch 2 (:43) – "Nice switch to slow shaking!" OR "don't forget when the music sounds fast, shake slow!"

- Switch 3 (:58) – "you guys are doing a great job – I'm going to stop but you keep shaking and don't forget when the music sounds slow, shake fast and when the music sounds fast, shake slow!"
- Switch 4 (1:11) -
- Switch 5 (1:25) –
- Switch 6 (1:37) – "Remember to shake slow when the music sounds fast!"
- Switch 7 (1:58) -
- Switch 8 (2:05) –
- Switch 9 (2:14) – "Great job using lots of different moves!"
- Switch 10 (2:45)
- Switch 11 (2:59) -
- Switch 12 (3:12) - "Almost done with this song – keep shaking until the end!"
- Switch 13 (3:27)
- Switch 14 (3:51)

- Wow! You all did a great job making music!
- Let's sit here for a minute while our partner friends come back. They will take off your belts and then we are going to spread out so that you all get to play the games just like we did last time. Remember, when you finish your 4 games, you will read quietly until everyone is done!

Note: Neutral observer records stop time of the intervention and goes to get the experimenters from the hallway. Experimenters come into the room and greet their partner child, removing their accelerometer devices. The lead experimenter will download the data from the devices while the experimenters are conducting post-tests.

See appropriate scripts for tasks based on randomly assigned order. Once EF tasks are complete, sit with the child and read together until all the groups are done. Meet back in the middle of the room (or open space).

Script for Day 2 Closing: Thank you for coming today! You all worked so hard on the games and did a great job! I hope you had as much fun as I did. It's time to go back to your classroom now. Thanks for playing with us!

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Appendix B

SPIN THE POTS EXPERIMENTER SCRIPT

Training:

Experimenter Script	Instructions
"We're going to play a game that's lots of fun, and you can win lots of stickers. Let's try it! "Now I'm going to hide sticker in a pot and you can try to find it." "Let's try that again!"	Start with all boxes in a circle around the edge of the tray (no boxes in the center) Hide a sticker in a pot, and ask the child to find the sticker where it was hidden. Repeat the training procedure 1 more times.

Testing:

Experimenter Script	Instructions
"Let's open each of these boxes" "Now we'll put a sticker in six of them, like this. I'm going to hide one in here, and one in here" *repeat for each sticker* We don't have enough stickers for all the boxes, so this box is empty and this box is empty." "Now I'll cover it up like this. I'm going to spin the tray." "Can you find a sticker?" If correct say: "Good job. Let's try again." OR If incorrect say: "Oh, it is not there. Let's try again."	Show the child the empty boxes. Place sticker in boxes one at a time and close up that box. Make sure to show to cover of the box as you say "this box is empty" so they can see which ones are the empty ones. RULES for empty boxes: Two empty boxes should NOT be the same shape, NOT be the same color, and NOT be next to each other on the tray. Cover the tray with the silk scarf and spin the tray twice, about 180°. Remove the scarf and ask the child to choose one box to find a sticker. If a sticker was found, the child keeps it as a prize. Congratulate him/her and say that you're going to play again. If the sticker is not found, try again. Each time the child tries to find a sticker, cover all the pots with the silk scarf and rotate again.

	Record the child's searches on the sheet. Repeat the procedure until all 6 stickers are found or the child reaches the maximum number of trials (16)

Notes for experimenter:

- If the child tries to open/pick multiple boxes, stop them by covering the boxes with your hands and say, "wait a minute, we are going to cover them up before you try again."
- If child shakes a box instead of opening, and then tries to pick a different one, say, "oops, you need to open the one that you touched first, and then we can try again." Make them open the first one they shook.

Appendix C

PEG TAPPING EXPERIMENTER SCRIPT

Introduce the activity as follows:

Hold the peg in one hand and tell child **We are going to play a new game**. Tap the peg one time on the table. Hand the peg to the child and tell him/her, **Now you tap one time on the table**. Continue practicing until the child only taps one time

Once the child has successfully tapped one time, take back the peg and tap two times on the table. Hand the peg back to the child and tell him/her, **Now you tap two times on the table**. Continue practicing until the child only taps two times.

PRACTICE:

RULE 1: **Great, now we are ready to play the game. When I tap one time** (tap one time and hand the child the peg) **I want you to tap two times**. Practice until the child is successful on two consecutive trials. Take the peg back and say,

RULE 2: **When I tap two times** (tap the peg two times on the table and hand it to the child) **I want you to tap one time**. Continue practicing until the child is successful on two consecutive trials. **Ready to play my game**?

PRETEST:

TRIAL 1: Tap one time and hand the peg over to the child to respond.

- If the child responds correctly, praise the child and proceed to Trial 2.
- If the child responds incorrectly or not at all, follow rules for Extended Practice.

TRIAL 2: Tap two times and hand the peg to the child to respond.

- If the child responds correctly again, praise the child and count these first two practice trials as trials 1 and 2 of testing. GO TO TRIAL 3.
- If child responds incorrectly or does not respond at all, follow rules below for Extended Practice.

Extended Practice: If the child responded incorrectly or not at all on either of the above trials, these trials are counted as practice. Remind the child of both rules, beginning with the first rule the child identified incorrectly. Then begin the pretest again. If the child is wrong on either of these two pretest trials, the instruction and pretest procedure can be repeated once more.

NOTE: THE PRETEST TRIALS ARE TRIALS 1 AND 2 ON THE SCORE SHEET. Record the child's answers for the pretest trials 1 and 2 on the score sheet. If the child gets both trials 1 and 2 correct, proceed to testing and BEGIN WITH TRIAL 3. If the child does not get both trials 1 and 2 correct after the third attempt of the pretest, proceed to Trial 3, but do NOT remind child of rules again.

TESTING: Administer the tapping in the order listed on the score sheet and record responses in the table. If the child taps other than 1 or 2 times, record the number of taps on the "other" line.

Do NOT give feedback to the child during or between trials.

Appendix D

IRB HUMAN SUBJECTS APPROVALS

UNIVERSITY OF DELAWARE

RESEARCH OFFICE

210 Hullihen Hall
University of Delaware
Newark, Delaware 19716-1551
Ph: 302/831-2136
Fax: 302/831-2828

DATE:	December 3, 2018
TO:	Marcia Shirilla
FROM:	University of Delaware IRB
STUDY TITLE:	[1352778-1] The immediate impact of cognitively engaging physical activity on preschool children's executive function.
SUBMISSION TYPE:	New Project
ACTION:	APPROVED
APPROVAL DATE:	December 3, 2018
EXPIRATION DATE:	December 2, 2019
REVIEW TYPE:	Expedited Review
REVIEW CATEGORY:	Expedited review category # *(6,7)*

Thank you for your submission of New Project materials for this research study. The University of Delaware IRB has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a study design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

This submission has received Expedited Review based on the applicable federal regulation.

Please remember that informed consent is a process beginning with a description of the study and insurance of participant understanding followed by a signed consent form. Informed consent must continue throughout the study via a dialogue between the researcher and research participant. Federal regulations require each participant receive a copy of the signed consent document.

Please note that any revision to previously approved materials must be approved by this office prior to initiation. Please use the appropriate revision forms for this procedure.

All SERIOUS and UNEXPECTED adverse events must be reported to this office. Please use the appropriate adverse event forms for this procedure. All sponsor reporting requirements should also be followed.

Please report all NON-COMPLIANCE issues or COMPLAINTS regarding this study to this office.

Please note that all research records must be retained for a minimum of three years.

Institutional Review Board
210H Hullihen Hall
Newark, DE 19716
Phone: 302-831-2137
Fax: 302-831-2828

DATE:	May 21, 2019
TO:	Marcia Shirilla
FROM:	University of Delaware IRB
STUDY TITLE:	[1352778-2] The immediate impact of cognitively engaging physical activity on preschool children's executive function.
SUBMISSION TYPE:	Amendment/Modification
ACTION:	APPROVED
APPROVAL DATE:	May 21, 2019
EXPIRATION DATE:	December 2, 2019
REVIEW TYPE:	Expedited Review
REVIEW CATEGORY:	Expedited review category # *(4,7)*

Thank you for your Amendment/Modification submission to the University of Delaware Institutional Review Board (UD IRB). The UD IRB has reviewed and APPROVED the proposed research and submitted documents via Expedited Review in compliance with the pertinent federal regulations.

As the Principal Investigator for this study, you are responsible for and agree that:

- All research must be conducted in accordance with the protocol and all other study forms as approved in this submission. Any revisions to the approved study procedures or documents must be reviewed and approved by the IRB prior to their implementation. Please use the UD amendment form to request the review of any changes to approved study procedures or documents.
- Informed consent is a process that must allow prospective participants sufficient opportunity to discuss and consider whether to participate. IRB-approved and stamped consent documents must be used when enrolling participants and a written copy shall be given to the person signing the informed consent form.
- Unanticipated problems, serious adverse events involving risk to participants, and all non-compliance issues must be reported to this office in a timely fashion according with the UD requirements for reportable events. All sponsor reporting requirements must also be followed.

Oversight of this study by the UD IRB REQUIRES the submission of a CONTINUING REVIEW seeking the renewal of this IRB approval, which will expire on December 2, 2019. A continuing review/progress report form and up-to-date copies of the protocol form and all other approved study materials must be submitted to the UD IRB at least 45 days prior to the expiration date to allow for the required IRB review of that report.

If you have any questions, please contact the UD IRB Office at (302) 831-2137 or via email at hsrb-research@udel.edu. Please include the study title and reference number in all correspondence with this office.

Institutional Review Board
210H Hullihen Hall
Newark, DE 19716
Phone: 302-831-2137
Fax: 302-831-2828

DATE:	December 6, 2019
TO:	Marcia Shirilla
FROM:	University of Delaware IRB
STUDY TITLE:	[1352778-3] The immediate impact of cognitively engaging physical activity on preschool children's executive function.
SUBMISSION TYPE:	Continuing Review/Progress Report
ACTION:	APPROVED
APPROVAL DATE:	December 6, 2019
EXPIRATION DATE:	December 2, 2020
REVIEW TYPE:	Expedited Review
REVIEW CATEGORY:	Expedited review category # *(4,7)*

Thank you for your Continuing Review/Progress Report submission to the University of Delaware Institutional Review Board (UD IRB). The UD IRB has reviewed and APPROVED the proposed research and submitted documents via Expedited Review in compliance with the pertinent federal regulations.

As the Principal Investigator for this study, you are responsible for and agree that:

- All research must be conducted in accordance with the protocol and all other study forms as approved in this submission. Any revisions to the approved study procedures or documents must be reviewed and approved by the IRB prior to their implementation. Please use the UD amendment form to request the review of any changes to approved study procedures or documents.
- Informed consent is a process that must allow prospective participants sufficient opportunity to discuss and consider whether to participate. IRB-approved and stamped consent documents must be used when enrolling participants and a written copy shall be given to the person signing the informed consent form.
- Unanticipated problems, serious adverse events involving risk to participants, and all non-compliance issues must be reported to this office in a timely fashion according with the UD requirements for reportable events. All sponsor reporting requirements must also be followed.

Oversight of this study by the UD IRB REQUIRES the submission of a CONTINUING REVIEW seeking the renewal of this IRB approval, which will expire on December 2, 2020. A continuing review/progress report form and up-to-date copies of the protocol form and all other approved study materials must be submitted to the UD IRB at least 45 days prior to the expiration date to allow for the required IRB review of that report.

If you have any questions, please contact the UD IRB Office at (302) 831-2137 or via email at hsrb-research@udel.edu. Please include the study title and reference number in all correspondence with this office.