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Examining the Effects of a Multi-Component Neurocognitive Intervention for School-Aged Children with Co-Occurring ADHD and Reading Difficulties

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EXAMINING THE EFFECTS OF A MULTI-COMPONENT NEUROCOGNITIVE INTERVENTION FOR SCHOOL-AGED CHILDREN WITH CO-OCCURRING ADHD AND READING DIFFICULTIES

by

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ABSTRACT

Examining the Effects of a Multi-Component Neurocognitive Intervention for School-Aged Children with Co-Occurring ADHD and Reading Difficulties

by

Alyssa L. Chimiklis

Advisor: Anil Chacko

Objective: Children with attention deficit hyperactivity disorder (ADHD) frequently exhibit impairments in neurocognitive pathways (i.e., deficits in sustained attention, response inhibition, processing speed, working memory, and cognitive flexibility). There is also extensive support indicating that youth with co-occurring ADHD and reading difficulties share pathological pathways and exhibit deficits in executive functions. Neither behavioral nor pharmacological interventions have been able to fully address executive dysfunction and/or reading deficits in this population. Computerized neurocognitive training interventions have been explored as a treatment alternative for youth with pure ADHD and have demonstrated some merit. Conceptually, computerized neurocognitive training programs that target overlapping pathways may improve executive functioning, which may directly impact ADHD symptoms and reading. **Methods:** A preliminary open clinical trial was conducted over the course of 3-4 months in a sample of 20 7-11 year-olds with all subtypes of ADHD with varying levels of reading difficulties to determine the following primary aims: 1.) To determine if a multicomponent neurocognitive intervention, ACTIVATE, improved executive functions (i.e., sustained attention, working memory, inhibition); 2.) To determine if ACTIVATE improved ADHD symptoms; 3.) To determine if ACTIVATE improved reading outcomes; and 4.) To determine if there were differential rates of improvement in outcome variables (i.e., reading progress,

executive functions and ADHD symptoms) for children with reading difficulties compared to those without reading difficulties.

Results: Positive significant bivariate correlations between decoding, sight word reading, and reading comprehension were identified; however, a relationship between ADHD deficits and reading severity was not found. Findings from 2 (group: reading impaired; reading non-impaired) x 2 (pre-ACTIVATE, post-ACTIVATE) mixed ANOVAs demonstrated a reduction of ADHD symptoms, improvements in some areas of executive functioning (planning, organizing, problem-solving and cognitive flexibility), and reading comprehension and sight word reading gains as a function of the ACTIVATE intervention.

Conclusions: Taken together, the preliminary findings for this study are encouraging. However, definitive conclusions cannot be drawn because this study consisted of an open uncontrolled evaluation with a small sample size. Extensive research is required to further evaluate potency, as well as appropriate target specification. Based on the results of this study, computerized neurocognitive training cannot be viewed as a substitute or supplement for gold standard treatments (i.e., pharmacological and/or behavioral interventions) for youth with ADHD.

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"It is takes a village to raise a child" is a famous proverb, which recognizes that raising a child in a supportive and nurturing environment requires not only the child's parents, but also the commitment of multiple members of the community. In my case, it likewise has "taken a village" to help me achieve my long-term goal of becoming a clinical psychologist. This has been a decade long journey and I am humbled and grateful to everyone who helped make my dream a reality. First and foremost, I would like to thank my immediate family, Theodore, Lynne, and Brian Chimiklis without their unconditional love, as well as emotional and financial support none of this would have been possible. Even when I was overwhelmed, sleep deprived, and very cranky you continued to encourage me to push forward. Thank you for teaching me to always believe in myself and to never stop dreaming! I love you!

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Introduction

The purpose of this research study was to examine whether a computerized program (ACTIVATE) for school-aged children with co-occurring ADHD and varying levels of reading difficulties that targeted multiple executive functions (EF) led to improvements in ADHD, executive functions, and reading difficulties. The introduction was structured to provide the reader with a broad overview of the etiology and maintenance of ADHD, given that the experimental intervention evaluated herein is addressing one specific etiological pathway. At best ADHD is considered multi-determined with EF being one potential pathway. As such, the introduction to this dissertation begins with an overview of ADHD etiology, then a discussion of neurocognitive pathways, followed by ADHD and reading treatments and finally, executive function training.

Introduction to Attention-Deficit/Hyperactivity Disorder

Attention-Deficit/Hyperactivity Disorder (ADHD) is a chronic, heritable, neurodevelopmental disorder affecting 3-7% of school-aged children and is characterized by developmentally inappropriate levels of inattention, hyperactivity, and impulsivity (APA, 2013). The three now-recognized subtypes are: a predominately inattentive presentation, a predominately hyperactive/impulsive presentation, and a combined presentation (a combination of the first 2 subtypes).

Inattention often manifests as distractibility, difficulty remaining focused on tasks for extended periods of time (e.g., lectures or conversations), and daydreaming, while hyperactivity/impulsivity is expressed as excessive talking, fidgeting, and frequently interrupting others. Symptoms of hyperactivity/impulsivity reportedly wane in

adolescence/early adulthood (Evans et al., 2013), whereas symptoms of inattention are not conclusive. For instance, some studies reported a reduction in inattention over time (Evans et al., 2013), whereas others reported that symptoms of inattention persisted into adulthood (Biederman et al., 1996).

Comorbidity is a key clinical feature that is frequently seen in individuals with ADHD that occurs throughout the life cycle. In both clinical and epidemiologic samples, co-occurring ADHD and oppositional defiant disorder (ODD) have been identified in 60% of cases (APA, 2013; Maughan, Rowe, Messer, Goodman, & Meltzer, 2004), whereas ADHD and conduct disorder (CD) have an estimated comorbidity rate of 16-20% (Biederman et al., 2002). ODD is defined as a pattern of hostile and defiant behaviors, whereas CD, a more severe disorder, is characterized by patterns of lying stealing, aggression and destruction and is more common in boys than girls (Biederman et al., 2002). Psychiatric disorders comorbid with ADHD also include depressive disorders, anxiety disorders, and learning disorders (LD) (Bordern et al., 2016; DuPaul, Gormley, & Laracy, 2013; Overgaard et al., 2016). Additionally, there is extensive support that children and adults with ADHD exhibit EF deficits (Huang-Pollock et al., 2012; Sonuga-Barke, Sergeant, Nigg, & Willcutt, 2008). EFs are defined as a set of higher order cognitive processes (attentional control, working memory (WM), cognitive flexibility, and inhibitory control) controlled by the pre-frontal cortex (PFC).

ADHD has also been linked with reduced psychosocial functioning. Children with ADHD often experience parental conflict, rejection by peers, low self-esteem, and poor peer relationships (Barkley, 2003; de Boo & Prins, 2007; Nijmeijer et al., 2008). Furthermore, children who have suffered from ADHD perform poorly on standardized

examinations, have lower grades, and lower rates of graduation (Loe & Feldman, 2007). Impulsive behavior and slower rates of processing information are also shown to negatively hinder the child's academic progress (Cortese, 2012).

Overall, ADHD is not a disorder that is resolved following adolescence; 60%-80% of symptoms associated with childhood ADHD persist into adulthood (Childress & Berry, 2012). For instance, Sharma and Couture (2014) report that impairments such as impulsivity place adults with ADHD at greater risk for motor vehicle accidents, substance abuse and engagement in risky sexual behavior (Childress & Berry, 2012; Dopheide, 2005). Furthermore, EF deficits persist into adulthood and affect both long-term employment and relationships (Barkley et al., 2008). Adults with ADHD have higher death rates (e.g., accidental death) in comparison to their peers (Dalsgaard et al., 2015). Adult ADHD is also associated with significant functional impairments across occupational, family and social domains, which negatively impact quality of life (Antshel et al., 2009). Studies demonstrate that adults with ADHD experience more psychological distress, change jobs more often, are fired twice as often, and report more marital problems (Barkley, 2002; Murphy & Barkley, 1996). The link between ADHD and ongoing functional impairment across the lifespan, as well as the comorbidity of psychiatric disorders, necessitates the identification and utilization of effective treatment interventions.

ADHD Etiology

While exact etiology of ADHD is currently unknown, extensive research supports the notion that there are multiple etiologies contributing to the development of ADHD (Arnsten, 2009; Blokland et al., 2014; Nakao, Radua, Rubia & Matataix-Cols, 2011;

Thakur et al., 2012 Tripp & Wickens, 2008). According to a recently completed review, the cause and maintenance of ADHD is more closely associated with genetic factors than environmental factors (Azeredo, Moreira, & Barbosa, 2018). Functional and structural neuroimaging techniques such as functional magnetic resonance imaging (fMRI), positron emission tomography (PET), and magnetic resonance imaging (MRI) provide a comprehensive portrayal of the brain's microstructure and neural networks, thereby extending the knowledge of the neurological pathways and networks involved in cognition and behavior in children with ADHD.

Neurotransmitter Deficiencies

Studies show that individuals with ADHD have greater deficits in the PFC, caudate and cerebellum (Ellison-Wright, Ellison-Wright & Bullmore, 2008; Mahone et al., 2011; Noordermeer et al., 2017; Valera, Faraone, Murry, & Saidman, 2007). More specifically, research identifies a reduction in activity within these regions (Arnsten & Pliszka, 2011). Importantly, these regions are connected by a network of neurons, which oversee regulation of attention, action, behavior and emotions (Arnsten & Pliszka, 2011; Kesner & Churchwell, 2011).

The network activity between these regions is maintained by two catecholamine neurotransmitters, dopamine (DA) and norepinephrine (NE). These neurotransmitters oversee the maintenance of network activity within these regions and operate concurrently via multiple receptors (Arnsten, 2007; Arnsten et al., 2010; Pliszka, 2005; Robbins, 2003). Notably, several studies demonstrate that individuals with ADHD have lower DA receptor density in multiple brain regions (Cortese, 2012; Fusar-Poli, Rubia, Rossi, Sartori & Balottin, 2012; Tripp & Wickens, 2009), suggesting the possibility of a

neurotransmitter imbalance or dysfunction within the catecholamine system (Arnsten, 2009; Tripp & Wickens, 2008).

The possibility of a neurotransmitter imbalance is supported by the responses of children with ADHD to stimulant medication. For instance, methylphenidate, amphetamines, and atomoxetine demonstrate an increase in DA and NE in the PFC (Arnsten & Pliszka, 2011). Furthermore, neuroimaging studies report that both methylphenidate and amphetamine increase the availability of DA (Riccardi et al., 2008; Swanson, Baler, & Volkow, 2011; Volkow et al., 2012). Collectively, the mechanisms of action for medications used to treat ADHD support the hypothesis of underactive DA and/or NE function.

However, other studies imply a more complex etiology than just an underactive DA and/or NE system. For example, when amantadine or a combination of levodopa/carbidopa (all DA agonists) are administered, this does not result in improvements of ADHD symptoms (Langer et al., 1982; Overtoom et al., 2003; Pliszka, 2005). Thus, if only a neurotransmitter deficit existed, ADHD symptoms would be lessened by the stimulation of postsynaptic receptor, thereby suggesting a more complex etiology than an overactive or underactive DA/NE system.

Even though there is a possibility of a more complete etiology, a U-shaped dose-response curve observed in vitamin consumption may also be applicable to hyperactive and hypoactive catecholamine hypotheses. Importantly, if two separate pools of DA and NE exist in the brain, then extremes of DA or NE will lead to (hyperactivity or hypoactivity) (Arnsten & Pliszka, 2011; Howells, Stein, & Russell, 2012; Pliszka, 2005). Maintenance of a suitable level of DA and NE is therefore required to maintain optimal

functioning in the PFC, as disruptions in these levels may lead to the development of ADHD (Sharma & Couture, 2014).

While specific neurotransmitter deficits have yet to be determined, current research supports that DA and NE contribute to ADHD. For instance, individuals with ADHD generally respond well to stimulant medication, as these medications increase the availability of DA. Furthermore, DA and NE networks are distributed in regions that are associated with ADHD.

Brain Abnormalities in ADHD

In the 1990's, research incorporated the use of MRI to identify whether individuals with ADHD have structural brain abnormalities. When selected brain regions of a control group are compared to individuals with ADHD, there are noticeable differences in brain size (Tannock, 1998). Moreover, when compared to typically developing peers, children with ADHD have abnormal volume in several areas of the brain, including PFC regions, corpus callosum, globus pallidus, caudate nucleus, basal ganglia, and temporal cortices (Ellison-Wright et al., 2008; Hill et al., 2003; Mahone et al., 2011; Shaw et al., 2007; Sowell et al., 2003; Valera et al., 2007). Structural studies also report gray-matter deficits (cell bodies and dendrites) in both children and adults in multiple brain structures including the basal ganglia, cingulate cortex, and cerebellum, as well as frontal and temporal lobes (Almeida et al., 2010; Amico, Stauber, Koutsouleris & Frodl, 2011; Batty et al., 2010 Carmona et al., 2005; Shaw et al., 2014; Noordermeer et al., 2017).

Given the large number of structural imaging studies, multiple meta-analyses reveal sizable differences between ADHD participants and controls. The most significant

differences are evident in the cerebellum, globus pallidus and caudate (Ellison-Wright et al., 2008; Valera et al., 2007). In addition to significantly smaller brain structures, Nakao and colleagues (2011) report a reduction in global grey matter volumes in ADHD cases.

There is substantial evidence from early studies that children with ADHD exhibit decreased cerebellar volume (Castellanos et al., 2001, 2002; Durston et al., 2004). This finding further supports the viewpoint that the cerebellum plays a key role in EFs. Moreover, several earlier studies showed that the cerebellum is involved in motor aspects of sensory perceptions that originate from EF actions such as planning, and that children with ADHD often exhibited impairment in these domains (Diamond, 2000; Houk & Wise, 1995). Consistent with earlier evidence, anomalies are apparent in subcortical structures (Frodl and Skokauskas, 2012; Hoogman et al., 2017; Norman et al., 2016

Neurological involvement in ADHD is also supported by longitudinal developmental neuroimaging studies. Shaw and colleagues (2006; 2007) were able to scan a large sample of typically developing children and those with ADHD over a ten year period. As reported by Barkley (2015), these scans provide researchers with the ability to calculate the degree of delay in cortical maturation across several brain structures.

Shaw and colleagues (2006; 2007) define "cortical maturity" as the age when peak cortical thickness is achieved and suggest that delayed cortical maturation is associated with ADHD. Findings from their study show that the median age for achieving half of cortical thickness varies significantly between children with ADHD and the controls (10.5 vs. 7.5 years), with the largest magnitude of delay in the PFC. These

results are consistent with earlier MRI studies and strengthens the viewpoint that ADHD may be an EF disorder.

Diffusion tensor imaging (DTI) is another neuroimaging technique allowing researchers to further explore the association between ADHD and brain structure. Given that DTI allows for the detection of axonal membrane circumference, axonal density, and thickness of myelin sheaths (brain white-matter), this neuroimaging technique facilitated the technological means to focus specifically on the white-matter tracts connect PFC and subcortical (basal ganglia) structures. A recent meta-analysis (van Ewijk et al., 2012) reports a significant reduction in white-matter integrity in children, adolescents, and adults with ADHD, which appears to be irrespective of age. The review also reveals that specific white-matter regions and tracts are associated with ADHD. These areas include the corpus callosum, caudate nucleus, cerebellum, corticospinal tract, and cingulum, as well as areas within the basal ganglia. While white-matter regions and tracts in the frontal, parietal, temporal and occipital lobes are also implicated in ADHD, there are extensive differences in these regions. Van Ewijk and colleagues (2012) propose that these differences may be indicative of delayed myelination in children and continued to remain mal-developed in adults with ADHD.

Taken together, these studies demonstrate that individuals with ADHD possess a smaller total brain size with the largest reductions in brain volume in the anterior frontal lobes, basal ganglia, cerebellar vermis (cerebellum), and corpus callosum. However, variability of findings exists within the neuroimaging literature. For instance, while volumetric reductions and reduced cortical thickness of the frontal and temporal lobes are reported, inconsistencies are also identified in reviews (Faraone et al., 2015; Rubia,

Algeria, & Brinson, 2014). Furthermore, differences in scanning and analyses procedures make it difficult to draw absolute conclusions about the structural irregularities identified.

Findings from early fMRI research demonstrate that children with ADHD perform more poorly on attention and inhibition tasks in comparison to typically developing peers (Rubia et al., 1999; Yeo et al., 2003). Children with ADHD exhibit more abnormal patterns of activation during these tasks in the right PFC, basal ganglia, and cerebellum. These studies link brain structure and function with psychological measures of ADHD symptoms and EF deficits, thus allowing for correlational inferences to be made regarding the role of these brain abnormalities in the cognitive and behavioral deficits that comprise ADHD.

Meta-analyses of fMRI studies reveal findings consistent with structural MRI studies (Dickstein, Bannon, Castellanos & Milham, 2006; Norman et al., 2016). Specifically, individuals with ADHD have reduced activity in the basal ganglia, parietal and frontal regions. Importantly, there are multiple methods for investigating brain functioning. For instance, some studies utilize functional interregional interconnectivity, a more complex method for analyzing fMRI data. Studies opting to use this methodology report a reduction in functional connectivity within the frontostriatal, frontoparietal, and frontocerebellar regions (Cubillo & Rubia, 2010; Tian et al., 2006; Zang et al., 2007). Results from current literature, as well as results from earlier research, indicate that abnormalities in the development and functioning of frontal, striatum, and cerebellum regions may play a role in the development of ADHD (Arnsten, Steere, & Hunt, 1996; Benton, 1991; Fassbender & Schweitzer, 2006; Shaw et al., 2014).

Overall, fMRI research supports that there are significant differences in brain activity between individuals with ADHD and peers, specifically in the frontal, basal ganglia and cerebellar regions. However, differences in measures across studies, variability in findings, and moderate effect sizes indicate that deficits in brain structure and activity do not fully explain the cause of ADHD. Finally, to make a persuasive case that the results of brain structure studies are correlated with problematic brain functioning and lead to the emergence of ADHD symptoms, researchers must utilize both structural and functional neuroimaging. Structural research needs to show group differences in brain structure, as well as development. Moreover, research must demonstrate that functional difficulties within these brain regions are directly related to the severity of ADHD symptomology.

Genetic Factors

ADHD is a highly heritable disorder. Therefore, research seeks to identify specific gene variants to distinguish who is at risk for development of the disorder, as well as provide an explanation for the variation of symptoms expressed in the general population. Originally, the primary focus of genetic research consists of dopamine regulating genes (DAT1, DBH, DRD4) because of dopamine's significant role in the PFC and striatum, the latter region believed to contribute to the development of ADHD. Now the current focus involves the use of genome-wide scans. This focus results in the identification of several genetic sites within the genome that seem to be implicated in ADHD trait variation. Interestingly, some of the potential genetic variants are related to DA and NE function, supportive of earlier work (Barkley, 2015).

During the last decade, extensive studies reliably support the notion that the following gene variants are related to ADHD (Faraone & Mick, 2010; Franke et al., 2011; Gizer, Ficks & Waldman, 2009): (1) serotonin transporter gene (5HTT); (2) the dopamine transporter gene (DAT1); (3) the D4 dopamine receptor gene (DRD4); (4) the D5 dopamine receptor gene (DRD5); (6) the serotonin 1B receptor gene (HTR1B); and (7) a synaptic vesicle regulating protein (SNAP25) used for gene coding. Importantly, having one of these genetic variants increases the risk for the disorder by less than 50%, because the contribution of each gene is relatively small.

Quantitative genetic analyses using large sample sizes, including the study conducted by Faraone et al. (1992) are not able to isolate a single gene that addresses the manifestation of the disorder. As such, ADHD is now considered polygenetic (inheritance is the result of multiple factors and/or genes). Several genes show promise that they contribute to genetic trait variation in ADHD. However, these genes must interact collectively with each other and likely only explain 20-30% of the disorder (Smoller et al., 2013; Yang et al., 2013). Researchers identify several potential genes such as SLC6A4, DBH, ARRB1, DRD2, MOAA, and COMT (Brookes et al., 2006). In order to identify and better understand genes of significance, studies combine genome-wide scans. Unfortunately, the required threshold for gene identification is not yet met. However, initial results are promising and suggest that with adequately large samples it may be possible to identify which genes are contributing to ADHD (Lasky-Su et al., 2008; Nigg & Barkley, 2014).

Given that ADHD is likely polygenic, multiple gene variants are also examined, including single-nucleotide polymorphisms (SNPs) and copy number variants (CNVs).

As reported by Barkley (2015), SNPs are "single base pair changes in the DNA sequence; whereas CNVs are larger deletions/duplications that remove or add segments of genes." Generally, SNPs are not important functionally. However, if studies do identify SNPs, this may signify that functional gene variants contribute to the development of ADHD and will be located nearby on the chromosome (Barkley, 2015).

While the CNVs are rare, they do have etiological importance since CNVs change gene function. Importantly, research demonstrates that CNVs are found more often in ADHD samples versus the general population and appear to increase risk for development of ADHD (Elia et al., 2009; Lionel et al., 2011; Yang et al., 2013). This viewpoint implies that the genetic cause of ADHD is the result of rare deletions and duplications occurring in the genome.

Since ADHD is considered polygenic, gene-pathway approaches (identifying sets of genes that contribute to functional pathways in the brain) are now being utilized to identify alternative explanations of the pathophysiology of ADHD. For instance, Stergiakouli et al. (2012) reports that metabolic systems linked to central nervous system (CNS) development and cholesterol metabolism (required for neural development) are linked to ADHD. Given these initial efforts are encouraging, identification of other genetic pathways may be possible in the future.

Environmental Toxins

In addition to genetics, environmental adversities also appear to contribute to variance of ADHD expression. These environmental difficulties are not only limited to social or family influences, but also often include biological events. Therefore, environmental sources can encompass pre, peri-, and post-natal

complications/malnutrition, diseases, trauma, as well as any neurologically compromising event (toxins) occurring during nervous system development (either before or after birth; Barkley, 2015).

The literature supports that when exposed to certain environmental toxins, individuals are at risk for inattention and hyperactivity. Studies report a link between prenatal exposure to alcohol and tobacco smoke with inattention and hyperactivity (Mick et al., 2002; Milberger et al., 1996; Nichols & Chen, 1981; Streissguth et al., 1995). Notably, even after controlling for parental ADHD symptoms there is still an association between maternal smoking during pregnancy and ADHD (Mick et al., 2002; Milberger et al., 1996). Furthermore, a review of the literature reveals that exposure to maternal smoking frequently results in a more severe form of ADHD (Thakur et al., 2012). There is also some evidence to support that exposure to secondhand smoke increases the risk of developing ADHD (Max, Sung & Shi, 2013). One possible explanation is a gene by environment (G X E) effect. In other words, during fetal development, individuals that possess risk genes for ADHD are more vulnerable to the harmful effects of maternal smoking (Neuman et al., 2007).

While maternal alcohol consumption may increase the risk for ADHD, the evidence is less conclusive in comparison to the well-established association between maternal tobacco smoking and ADHD. For instance, Rodriquez and colleagues (2009) show that the relationship between ADHD and maternal alcohol consumption appears to be the result of its relationship to maternal tobacco smoking, as women who smoke often consume greater amounts of alcohol while pregnant. Alternatively, there is some evidence that when other factors are controlled, there is a direct link between maternal

alcohol consumption and risk of ADHD development (Fryer, McGee, Matt, Riley, & Mattson, 2007; O'Malley & Nanson, 2002).

Lastly, neuroimaging studies report a link between prenatal exposure to tobacco and alcohol and reduction in brain volume in children with ADHD (de Zeeuw et al., 2012; Ekblad et al., 2010). The studies reveal that children with ADHD exposed to tobacco and alcohol exhibit smaller brain volumes (a smaller cerebellum) in comparison to unexposed children with ADHD.

Complications at Pregnancy and Birth

Many cases of ADHD appear to result from genetic factors leading to structural and functional brain mal-development (Blokland et al., 2014; Kochunov et al., 2015; McKay et al., 2014; Peper et al., 2007). However, approximately 35% of cases may have developed ADHD as a result of an environmental adversity (Nigg, 2006) such as a birth complication (fetal distress) or maternal characteristics that may alter early fetal brain development during pregnancy.

Research over the past five decades explores whether pregnancy or birth complications lead to a higher incidence of ADHD in comparison to typically developing peers. Some evidence supports the idea that pregnancy and/or birth complications increase incidence of ADHD (Claycomb et al., 2004; Sprich-Buckminster et al., 1993). Specifically, Claycomb and colleagues (2004) reveal that factors including lower maternal education and age, time interval between birth and delivery, and delivery complications account for 42% of the variance of ADHD, with age at delivery and maternal education level being the strongest predictors. Earlier and recent studies find that events such as unusually long or short labors, fetal distress, respiratory distress, and

preeclampsia are linked to ADHD (Getahun et al., 2012; Hartsough & Lambert, 1985; Minde, Webb & Sykes, 1968).

In contrast, other studies do not identify a higher prevalence of pregnancy or birth complications in children with ADHD versus their peers with the exception of low birth weight (LBW) (Barkley, 1990; Wagner et al., 2009). While results for pregnancy or birth complications are mixed, there is evidence that LBW is a risk factor for ADHD, more specifically inattention, hyperactivity, disruptive behavior and poor school adjustment (Nichols & Chen, 1981).

Importantly, these findings were replicated across several studies (Schothorst & Engeland, 1996; Sykes et al., 1997; Szatmari et al., 1993). Moreover, Mick and colleagues (2002) demonstrate that LBW is three times more frequent in children with ADHD than their peers, after controlling for factors such as social class, ADHD, perinatal adversities (maternal tobacco and alcohol use).

While a few studies explore whether stress during pregnancy increases incidence of ADHD, results are inclusive. Even though stress and anxiety appear to moderately contribute to ADHD, these results should be viewed with caution, as several methodological difficulties are present (Linnet et al., 2003). Motlagh and colleagues (2011) report that chronic psychosocial stress in mothers increases the risk for having ADHD independent of other factors that correlate with stress, such as higher levels of smoking during pregnancy.

Another study reports a relationship between chronic anxiety in mothers during pregnancy and attentional problems in their children (5-14 years old), most without a diagnosis of ADHD (Clavarino et al., 2010). However, prenatal anxiety may alter the

programming of the fetal brain as the result of stress hormones being released into the maternal blood stream, thereby exposing the fetus to high levels of stress hormones (Barkley, 2015).

Models of ADHD

In an effort to create systematic guidelines for clinical research, several researchers propose models for the pathophysiology of ADHD based on findings from neuroimaging, neuropsychological studies, neurochemical pathways, and ADHD medication treatment effects. Many of these models link ADHD symptoms to neurocognitive deficits/EFs. In order to best explain the behavioral deficits of inattention, hyperactivity, and impulsivity, studies are seeking to identify the EF or EFs that play a causal role. However, there is significant disagreement as to which EFs (e.g., inhibition vs. WM) directly contribute to the disorder.

Research throughout much of the 20th century has struggled to identify a central feature of ADHD. Some theories suggest that ADHD stems from hyperactivity (Chess, 1960; Laufer & Denhoff, 1957), whereas others assert that ADHD arises from difficulty with sustained attention and impulse control (Douglas, 1972; Douglas & Peters, 1979). However, in the 1990's, behavioral inhibition is identified as the central impairment of the disorder (Barkley, 1990, 1994; Quay, 1988; Schachar, Tannock, & Logan, 1993; Schachar, Tannock, Marriott, & Logan, 1995).

Notably, the majority of early research on ADHD is exploratory and descriptive versus theory-based. According to the Behavioral Inhibition Model (Barkley, 1997), there is an association between behavioral inhibition and 4 EFs: (1) WM (e.g., holding information in mind); (2) self-regulation (e.g., emotional self-control); (3) internalization

of speech (e.g., rule governed behavior, problem-solving/self-questioning); and (4) reconstitution (e.g., analyses and synthesis of behavior). More specifically, these four neuropsychological functions appear to be dependent on inhibition for their own effective execution (Barkley, 1997). In the context of this model, poor behavioral inhibition is identified as the central deficit in ADHD. However, secondary EF deficits account for the appearance of inattention, fluctuation in symptoms across settings and tasks, as well as distractibility, the lattermost likely arising from poor interference control.

Instead of focusing on one pathway, some researchers posit that multiple pathways lead to ADHD symptoms and that EFs may play a causative role in only some cases (Pennington, 2005; Sonuga-Barke, 2002, 2003, 2005; Willcutt, Doyle, Nigg, Faraone & Pennington 2005a). For instance, Sonuga-Barke and colleagues (2002; 2003; 2005) hypothesize that two distinct pathways contribute significantly to ADHD deficits, raising the possibility of different neuropsychological subtypes of ADHD. The first pathway involves the mesocortical branch of the DA system that projects to the PFC. This pathway is distinguished by cool and hot EFs. Cool EFs are responsible for planning, WM (ability to keep information in mind and manipulate that information in mind), whereas hot EFs (emotion regulation) oversee regulation of top-down motivational, as well as goal directed behaviors, including the effects of bottom-up motivational/emotions states on EFs (Castellanos, Sonuga-Barke, Milham, & Tannock, 2006; Nigg & Casey, 2005). Deficits in these networks result in poor inhibitory control, which ultimately leads to dysregulation of thought and action.

The second pathway is mediated by the mesolimbic DA branch, which is linked to the nucleus accumbens. A specific feature of ADHD is delay tolerance. According to this

view, children with ADHD frequently avoid situations or contexts where waiting is required. Therefore, when given a choice between a small immediate reward and a larger delayed reward, children with ADHD exhibit a stronger preference for a small immediate reward.

Importantly, not all models ascribe causal roles to EF, as Castellanos and colleagues (2005) propose that deficits in EFs are instead correlates of ADHD. More specifically, this model hypothesizes a catecholaminergic deficiency as one of the causes for repeated lapses in attention, which result in the exhibition of behavioral symptoms including difficulty sustaining attention, careless mistakes, and disorganization (Castellanos et al., 2005).

Notably, most models of ADHD focus on the PFC and its association with the striatum and subcortical structures (basal ganglia and cerebellum). However, research does not fully support these models as several inconsistencies are evident regarding the developmental trajectory of the PCF and EFs. For instance, as articulated by Halperin and Schulz (2006), if the principal cause of ADHD is dysfunction of the PFC, then behavioral difficulties will not emerge until later in development because of late maturation of the PFC and other EF-related regions (Barkovich, 2005; Barnea-Goraly et al., 2005). Interestingly, symptoms of ADHD often first manifest during preschool (Barkley, Fischer, Edelbrock, & Smallish, 1990; Campbell, 1995). Furthermore, research also demonstrates a significant decrease in ADHD symptomology with age (Hill & Schoener, 1996).

Given that neural development of the PFC appears to parallel recovery from ADHD based on the remission of ADHD symptoms (Biederman, Mick & Faraone,

2000), Halperin and Schulz (2006) posit that ADHD is the result of non-cortical dysfunction emerging in early ontogeny and remaining constant throughout the lifespan. For instance, early brain insults such as anoxia produce long-term changes in DA activity (Chen et al., 1997; Zhang, Davids, Tarazi, & Baldessarini, 2002). Until recently, nearly all neuroimaging studies are comprised of school-aged children (ages 6 and older), which prevents further exploration of whether subcortical brain regions contribute to the etiology of ADHD. To better understand the brain structure and functions implicated in ADHD, researchers (Rosch et al., 2018) compare subcortical structures (caudate, putamen, globus pallidus, and thalamus) of preschoolers with ADHD to typically developing children. Results reveal that children with ADHD possess larger reductions in volume in the caudate, globus pallidus, and thalamus compared to typically developing children. Taken together, these neuroanatomical findings parallel the trajectory of symptom onset, and ultimately support Halperin and Shultz's (2006) hypothesis that the principal cause of ADHD is not PFC impairment.

Lastly, some models hypothesize that the disorder is the result of an energetic insufficiency in neurons. Russell and colleagues (2006) hypothesize that ADHD may result from an inadequate supply of lactate in the brain. The primary source of brain lactate comes from astrocytes, small star-shaped cells located in the brain and spinal cord. NE works in conjunction with astrocytes by activating glial adrenoceptors, which increases the release of lactate from astrocytes to fuel depleted neurons.

As discussed earlier, there is significant evidence that supports NE dysfunction in individuals with ADHD, as stimulant medication increases NE levels, thereby improving symptoms. Given NE's role in the facilitation of the release of lactate, Russell and

colleagues (2006) propose that NE is an effective therapeutic agent in lessening ADHD symptoms and encourage the use of any treatment approach stimulating astrocytes to take up glucose and convert it to lactate.

ADHD and Reading Difficulties

A diagnosis of ADHD significantly places the child at greater risk for other co-existing disorders. As cited in Barkley (2015), 67-80% of clinic-referred children with ADHD have one disorder and at least 50% have two disorders (Barkley, Murphy, & Fischer, 2008). Approximately 25-40% of school-aged children with ADHD experience reading difficulties (Willcutt & Pennington, 2000).

Importantly, the severity of ADHD symptoms plays a considerable role in the prediction of academic underachievement in reading, writing, and mathematics (Barry et al., 2002; Polderman et al., 2010). As such, symptoms of inattention often lead to off-task behavior in the classroom, as well as the failure to listen and/or follow classroom instructions (Mash and Barkley, 2003). One recent study reveals that inattentive behaviors are strongly associated with reading fluency and comprehension (Pham, 2016).

Reading is viewed as a complex process that involves two components: word recognition (decoding and sight word reading) and comprehension (Aaron, Joshi & Williams, 1999). When learning to read, children go through a series of pre-reading processes, which include letter-sound identification, building phonemes, and increasing their understanding of phonetics (Lewandowski & Lovett, 2014). Once mastery is achieved, the child is able to successfully identify and decode individual words. Skills are further developed by the ability to understand the meaning of the decoded words (reading comprehension; Aaron et al., 2002). Word recognition and comprehension are considered

two separate processes that develop independently. Therefore, reading difficulties can result from either weak decoding skills or comprehension skills.

Children with ADHD frequently exhibit difficulties with decoding and struggle to identify written words (McGrath et al., 2011; Willcutt et al., 2010). Importantly, EF skills contribute significantly to one's development of reading skills. For instance, organization is required to identify the flow of a reading passage; moreover, planning and problem-solving are needed for the analysis of passages and decoding unfamiliar words (Semsa et al., 2009). Furthermore, recalling previous text and decoding all text requires WM skills (i.e., holding and manipulating information, as well as planning/sequencing multi-steps) (Semsa et al., 2009). Children with reading difficulties frequently have a weakened WM capacity, which prevents the utilization of cognitive resources to engage in multiple reading processes, such as decoding unfamiliar words, retrieving sematic knowledge of familiar words, and/or anticipating where the passage is going next.

The literature also supports the idea that children with ADHD may exhibit deficits in reading comprehension (Fienup et al., 2015; Miller et al., 2013). The results from studies examining reading comprehension abilities in children with ADHD are been mixed. For example, some studies identify reading comprehension deficits in children with ADHD (Brock and Knapp, 1996; Cherkes-Julkowski et al., 1995; Miller et al., 2013); whereas others do not (Ghelani, Sidhu, Jain & Tannock, 2004). Children who experience difficulty with reading comprehension often have lower reading comprehension scores, as well as trouble reporting the central idea from the passage. Such difficulties may be due to attentional demands needed for reading longer passages, which require more effortful processing (Brock & Knapp, 1996).

Importantly, individuals with co-occurring ADHD and reading difficulties are more likely to experience a higher level of impairment in comparison to children with pure ADHD or reading difficulties. More specifically, they are at greater risk of interpersonal difficulties, poor grades, and low rates of secondary education, all of which are present irrespective of socioeconomic status (Sexton, Gelhorn, Bell & Classi, 2012). These negative outcomes are costly and frequently persist into adulthood (Nyden, Myren, & Gillberg, 2008). Given the high levels of impairment, there is a critical need for further identification of the pathophysiology of this comorbidity in order to develop effective interventions for these youth.

Overlap of Neurocognitive Pathways

There are several different types of neuropsychological deficits specific to ADHD. These include deficits in response inhibition (Barkley, 1997), sustained attention (Hanisch, Konrad, Gunther & Herpertz-Dahlmann, 2004; Konrad, Gunther, Hanisch & Herpertz-Dahlmann, 2004), as well as visual spatial WM and verbal WM (de Jong et al., 2009; Rucklidge & Tannock, 2002; Shanahan et al., 2006; Swanson, Mink, & Bocian, 1999). Impairments in processing speed have also been identified (Willcutt, Pennington, Olson, Chhabildas & Hulslander, 2005b; WISC-IV manual, 2003).

Individuals with reading difficulties also exhibit impairments in neurocognitive pathways. Neuropsychological studies reveal deficits in processing speed (McGrath et al., 2011; Shanahan et al., 2006), sustained attention (Kupietz, 1990), verbal WM (Bental & Tirosh, 2007; Rucklidge & Tannock, 2002) and phonological processing (Ghelani et al., 2004). In fact, processing speed is shown to play a fundamental role in the development of reading fluency, the reading of text accurately and quickly (Mahone, 2011).

However, the literature also indicates that impairment in visual spatial WM appear to be specific to only individuals with pure ADHD and not those with pure reading difficulties (de Jong, et al., 2009). Generally only individuals with reading difficulties experience phonological processing deficits. Researchers (Banaschewski et al., 2005) believe this distinction to be the result of an auditory temporal processing deficit (Tallal, 1980), deficits in rapid sequential processing (Wagner & Torgesen, 1987), or a deficit in automatization skills (Nicolson & Fawcett, 1999).

Collectively, neuropsychological studies support the idea that ADHD and reading difficulties share pathological pathways and exhibit impairment in EFs such as processing speed, verbal and visual spatial WM, sustained attention, and response inhibition (Kupietz, 1990; Rucklidge & Tannock, 2002; Willcutt et al., 2001). It is not surprising that reading can be difficult for children with ADHD (Brock & Knapp, 1996), as it is an effortful and complex task that requires sustained attention. Youth with ADHD frequently display decoding difficulties and struggle to identify written words (Willcutt et al., 2010; McGrath et al., 2011). Furthermore, EF skills contribute significantly to the development of reading skills. For instance, as cited by Gray & Climie (2016), decoding unfamiliar words, recalling previous text, and anticipating the storyline all require WM skills (Sesma, 2009). There is also evidence that processing speed plays a vital role in reading fluency development (Mahone, 2011). Given the high prevalence of co-occurring ADHD and reading difficulties, as well as the overlap of neurological pathways and academic challenges, there is a need for further exploration/identification of an intervention to better treat these co-occurring disorders.

ADHD Treatments

Overall, the literature supports the notion that behavioral interventions can be highly effective in improving ADHD symptoms, as well as associated disruptive/oppositional behavior and family functioning (Fabiano et al., 2009). Many behavioral approaches are based on operant conditioning procedures and utilize antecedents (e.g., commands) and consequences (e.g., time-out) to alter the child's behaviors. These interventions involve working with both parent(s) and/or teachers to implement operant conditioning procedures at home and/or school environments. The goal of techniques such as time-out is to increase compliance (increase the desired behavior) and decrease noncompliance (decrease undesirable behaviors) (Fabiano et al., 2009).

Operant conditioning procedures were initially used to treat externalizing behavioral problems including hyperactivity (O'Leary, Becker, Evans, & Saudargas, 1969; O'Leary & Pelham, 1978; O'Leary, Pelham, Rosenbaum & Price, 1976; Patterson, 1974; Pelham, 1977). ADHD was formally added to the DSM-III in 1980 and behavioral interventions were one of the primary treatments for this disorder throughout the 1980's (Abikoff & Gittelman, 1984; Dubey, O'Leary, & Kaufman, 1983; Firestone, Kelly, Goodman, & Davey, 1981). However, in the 1990's there was a shift toward evidence-based treatment interventions (Lonigan, Elbert, & Johnson, 1998) with behavioral interventions identified as an evidenced-based treatment for ADHD (DuPaul & Eckert, 1997; Pelham, Wheeler, & Chronis, 1998).

DuPaul and Eckert (1997) explore behavioral interventions for children with ADHD in classroom settings by computing separate effect sizes for single-subject,

within-subject, and between-group design studies. Effect sizes of between-group (.45), within-subject (.64), and single-subject (1.16) designs reveal that behavioral interventions for ADHD implemented in a classroom setting are effective. Furthermore, later studies of school-based behavioral interventions for children with ADHD demonstrate increases of on-task behaviors (e.g., completing assignments) and decreases of disruptive behaviors (e.g., interrupting) (DuPaul, Eckert, & Vilardo, 2012).

Studies on behavioral parent training (BPT) support the use of BPT within the context of the home. For instance, Van der Oord and colleagues (2008) report pre-post effect sizes, which ranged from .19 (academic outcomes) to .87 (parent ADHD ratings). Overall, the behavioral treatment literature on ADHD is supportive of the idea that approaches such as BPT and classroom contingency management implemented at school meet gold-standard criteria (Evans, Owens, Wymbs, & Ray, 2017; Evans, Owens, Bunford, 2014: Fabiano et al., 2009; Pelham et al., 1998; Pelham & Fabiano, 2008).

However, behavioral interventions are not without limitations. These interventions require a significant amount of time and effort to implement, are costly, and appear to be less effective than stimulant medication for the treatment of ADHD core symptoms (MTA Cooperative Group 1999; Sonuga-Barke et al., 2013). Behavioral interventions also do not seem to generalize to non-targeted behaviors or settings (Rajwan, Chacko & Moeller, 2012). Another notable limitation is that behavioral interventions do not translate to clinically significant gains in academic achievement (Langberg et al., 2012; Raggi & Chronis; 2006; van der Oord 2008). More specifically, the implementation of behavioral interventions does not appear to result in improvements in reading performance.

The primary objective of utilizing behavioral interventions in a school setting is to modify behaviors (e.g., on-task and disruptive behaviors). Therefore many of the earlier studies do not include academic outcome measures. While more recent studies employ academic outcome measures such as grade point average (GPA) (Langberg et al., 2012; Raggi & Chronis; 2006; van der Oord 2008), to our knowledge measures such as reading comprehension or fluency are not included. Thus, without the inclusion of these measures, it is difficult to discern whether behavioral interventions are truly beneficial for individuals with reading difficulties.

Stimulant medication is frequently utilized to treat symptoms of ADHD such as attention or focus (Barkley, 2015). While this evidence-based treatment does provide therapeutic benefit, 10-30% of youth with ADHD do not respond (Goldman et al., 1998) or experience side effects that prohibited further use (Graham & Coghill, 2008). Another limitation is that stimulant medication effects are only present when medication is consistently taken.

Notably, stimulant medication is also studied as a potential intervention for reading problems. Initially, the identification of increased improvements in word and non-word decoding during the evaluation of methylphenidate dosage in the late 1980's (Richardson, Kupietz, Winsberg, Maitinsky & Mendell, 1988) was the impetus for several evaluations investigating methylphenidate's efficacy for children with co-occurring ADHD and reading difficulties (Carison & Bunner, 1993; Forness, Cantwell, Swanson, Hanna & Youpa, 1991; Forness, Swanson, Cantwell, Youpa & Hanna, 1992).

Several early studies comprised of boys with ADHD and with/without a LD find that stimulant medications do not lead to improvements in reading abilities (Forness et

al., 1991; 1992). Additionally a meta-analysis of stimulant medication studies from the 1980's to mid-1990's reports larger effect sizes for only behavioral measures, implying that stimulant medications do not lead to improvements in academic achievement (Forness et al., 1999).

However, more recent studies indicate that medication may improve reading outcomes in children with co-occurring ADHD and reading difficulties (Tannock, Martinussen & Frijters, 2000; Keulers et al., 2007; Bental & Tirosh, 2007; Sumner et al., 2009; Shaywitz et al., 2014). For instance, Bental and Tirosh (2007) report that methylphenidate treatment results in significant treatment effects in the domains of cognitive attention, as well as reading (rapid naming and non-word/word accuracy). It is unclear why earlier studies do not report significant findings. Perhaps the children in these studies have greater deficits, which may impact the results. Taken together, present findings indicate that methylphenidate may lead to improvements in cognitive attention, which appears to be related to reading skills.

In an unblinded clinical trial evaluating the effect of methylphenidate across 3 treatment groups (pure ADHD, pure reading difficulty, and co-occurring ADHD and reading difficulties), Keulers and colleagues (2007) identify an improvement of lexical and phonological decoding skills with small effect sizes of .29 and .32 for the co-occurring ADHD and reading difficulties group. Despite the reported improvement in reading performance and number of correctly read words, overall the children's scores on Een-Minuut-Test. Drie-Minuten-Tests and Klepel (Dutch reading tests) remained below average.

Lastly, Tannock and colleagues (2000) investigate the treatment effects of stimulant medication for children with ADHD and those with ADHD and co-occurring reading difficulties using reading tasks, such as color naming speed, letter naming speed, arithmetic computation and phonological decoding. Small effect sizes are reported for color naming speed in both groups. However, no effects are found for naming speed or digits, which are thought to contribute significantly to one's ability to engage in word identification.

The results for pharmacological treatment are mixed, as some studies show that medication improves reading outcomes, whereas others demonstrate that pharmacological treatment alone cannot improve reading difficulties and associated academic underachievement in youth with co-occurring ADHD and reading difficulties. In summary, the data support that behavioral and pharmacological interventions are unable to provide maximal benefits, as neither approach demonstrates clinically significant gains in reading outcomes.

Reading Interventions

To our knowledge only two educational interventions, phonics tutoring (a phonics-based mastery-oriented approach teaching the development of initial reading skills; Rabiner & Malone, 2004) and computerized-assisted instruction (CAI) (synchronized visual and auditory presentation of text, which incorporates study skills tools for highlighting and note taking; Hecker et al., 2002) evaluate the treatment effects of co-occurring ADHD and reading difficulties. Both programs demonstrate limited benefits. Specifically, children who are both inattentive and poor readers do not exhibit improvements in reading achievement (Rabiner & Malone, 2004). Furthermore, neither

participants in CAI nor phonics tutoring demonstrate normalization in overall functioning (when compared to their peers CAI and phonics tutoring participants' reading scores did not improve; Hecker et al., 2002).

As discussed, there are two evidenced-based interventions used to treat ADHD. Additionally, systematic instruction in phonic and word identification, as well as practicing reading connected text are two frequently used interventions to treat children with dyslexia and less severe reading difficulties (National Reading Panel, 2000). However, given the high prevalence of co-occurring ADHD and reading difficulties perhaps a treatment that simultaneously targets both disorders is needed (Tamm et al., 2017).

A recently completed randomized controlled trial (RCT) compares ADHD treatment alone (behavior management and ADHD medication), a reading intervention alone (targeted phonic, word identification, spelling, reading fluency or comprehension) or combined ADHD treatment + reading treatment for school-aged children with ADHD and word reading difficulties and disabilities (Tamm et al., 2017). The findings reveal that children with co-occurring ADHD and reading difficulties/disabilities benefit best from specific treatment for each disorder. In other words, ADHD treatment is linked to a greater improvement in ADHD symptoms than reading treatment. Finally, while the value of combining treatment is not significant, the combination allows for the treatment of both disorders concurrently (Tamm, et al., 2017). Taken together, these findings imply novel interventions that simultaneously target ADHD and reading difficulties may be best suited for this population.

EF Training

While the exact etiological mechanisms underlying ADHD remain unclear, there is substantial evidence supporting the idea that ADHD is highly heritable and involves alterations to neuroanatomical and neurochemical systems. As a result, researchers focus on the underdeveloped neurocognitive functions associated with ADHD when developing new treatment interventions. As a function of the conceptual models, several recently developed computerized treatment interventions hope to target specific neurocognitive functions to improve ADHD symptomology, as well as functional impairments associated with the disorder (Johnstone, Roodenrys, Phillips, Watt & Mantz, 2010; Kerns et al., 1999; Klingberg et al., 2002: Lange et al. 2012; Rabiner, Murray, Skinner & Malone, 2010; Shalev, Tsal, & Mevorach, 2007).

Early neurocognitive interventions targeting only one or two neurocognitions such as attention, inhibition, or WM, report promising outcomes (Klingberg et al., 2002; 2005, Shalev, et al., 2007). For instance, Klingberg and colleagues (2002) conducted a RCT, double-blind clinical trial to examine whether the computerized program Cogmed leads to improvements in WM and ADHD symptomology. Parental rating scales reveal a significant reduction in symptoms of attention and hyperactivity/impulsivity at post-intervention and follow-up. Additionally, a task measuring visual spatial WM demonstrates a significant treatment effect at post-treatment, as well as follow-up. Shalev and colleagues (2007) tested the efficacy of the computerized progressive attentional training (CPAT) program. Results demonstrate that parents report a reduction of inattentiveness and children improve significantly on non-trained measures of reading

comprehension, as well as passage copying. Notably, significant improvements are not exhibited in the control group.

To further evaluate the treatment efficacy of computerized neurocognitive training programs for children with ADHD, three meta-analyses (Cortese et al., 2014; Rapport, Orban, Kofler, & Friedman, 2013; Sonuga-Barke, Bradeis, Holtman & Cortese, 2014) demonstrate that the reduction of ADHD symptoms following neurocognitive training is minimal and likely due to expectancy effects. More specifically, Rapport and colleagues (2013) report that unblinded raters report larger improvements in ADHD symptoms. Similarly, neither Cortese et al., (2014) nor Sonuga-Barke et al. (2014) find clinically significant improvements of ADHD symptoms when rated by blind observers. However, Cortese and colleagues (2014) identify clinically significant effects of WM (verbal: SMD=0.52, 95% CI=0.24-0.80; visual: SMD=0.47, 95% CI=0.23-0.70) and parent ratings of EF (SMD=0.35, 95% CI=0.08-0.61).

Two of the meta-analyses report that targeting attention or multiple neurocognitive functions does not lead to significant improvements within these targeted domains (Rapport et al., 2013; Sonuga-Barke et al., 2014). Alternatively, short-term memory training results in a moderate improvement in short-term memory (Cohen's *d* = .63, 95% CI 0.46-0.80). Additionally, neurocognitive training irrespective training target (e.g., attention) does not lead to beneficial improvements on blinded behavioral ratings of ADHD symptoms or objective measures of academic achievement (Rapport et al., 2013).

Another surprising finding is the lack of consistency between literature and neurocognitive training targets. Current training protocols generally do not target the neurocognitive factors (sustained attention/vigilance, central executive WM abilities) that

are most closely associated with ADHD behaviors. For instance, 68% of the studies claim to target WM, although none of them do (Rapport et al., 2013). Furthermore, many studies that target sustained attention also target additional attentional processes (Shalev et al., 2007). Thus, it is hypothesized that the limited effects on ADHD symptoms may be the result target misspecification.

Furthermore, poor potency may reflect the number of neurocognitive deficits targeted during training (Cortese et al., 2014; Rapport et al., 2013; Sonuga-Barke et al., 2014). As stated earlier, many of the initial neurocognitive programs only target one or two neurocognitions. Methodological inadequacies also include poor attention given to training time for placebo conditions (placebo treatment condition does not match the training time of the active treatment condition). Lastly, the literature supports the notion that novel interventions targeting multiple EFs and possessing a longer duration would likely be the most beneficial (Cortese et al., 2014; Rapport et al., 2013; Sonuga-Barke et al., 2014). To date, the majority of neurocognitive training programs are 5 to 8 weeks long.

To our knowledge, only one study, CogniFit Personal Coach (CPC), has explored the treatment effects of a multicomponent EF training program (visual memory, split attention, memory, and spatial perception tasks) in adolescents with pure ADHD and those with co-occurring ADHD and reading difficulties (Horowitz-Kraus, 2013). Data reveal that the comorbid group demonstrated greater improvement in both EFs and reading ability, suggesting co-occurring ADHD and reading difficulties contain a unique set of features requiring the targeting of EFs.

In summary, there is a growing interest in utilizing neurocognitive interventions as a treatment approach for ADHD and reading difficulties. Conceptually, interventions that target these overlapping neurocognitive pathways may improve EFs, which may directly impact ADHD symptoms and reading achievement. However, existing neurocognitive training programs do not appear to improve ADHD symptoms or related functional impairments. Results for these interventions, often delivered via computerized "brain training" games, are mixed. There are many methodological inadequacies ranging from poor attention to training time for placebo conditions to study blinding. Therefore, next-generation neurocognitive programs that intensely target core underdeveloped neurocognitions closely related to ADHD and reading difficulties hold the most promise for improving these core deficits as well as associated functional impairments.

Taken together, neither behavioral or pharmacological interventions nor educational interventions are able to fully address academic underachievement associated with ADHD and reading difficulties. Given that underdeveloped neurocognitive functions are associated with ADHD, researchers seek to develop computerized neurocognitive interventions to target one or two neurocognitions (attention or WM; Klingberg et al., 2002; 2005; Shalev et al., 2007). Findings from these early interventions have been mixed. Researchers hypothesized that the limited effect on ADHD symptoms may be the results of target misspecification or number of neurocognitive deficits targeted (Cortese et al., 2014; Rapport et al., 2013; Sonuga-Barke et al., 2014). Importantly, a more recent intervention targeting multiple EFs reported clinically significant gains for both EFs and reading ability for youth co-occurring ADHD and reading difficulties. These findings are encouraging and support targeting multiple neurocognitions.

Additionally, since there is an overlap of neurocognitive pathways between ADHD and co-occurring reading difficulties, targeting these shared EFs may lead to improvements across these domains. The literature supports that the severity of ADHD symptoms plays a considerable role in the prediction of academic underachievement in reading (Polderman et al., 2010) and that inattentive behaviors are strongly associated with reading fluency and comprehension (Pham, 2016). These negative outcomes are costly and frequently persist into adulthood (Nyden, Myren, & Gillberg, 2008). Moreover, youth with co-occurring ADHD and reading difficulties are more likely to experience a higher level of impairment in comparison to children with pure ADHD. Importantly, these children are at greater risk of interpersonal difficulties, poor grades, and low rates of secondary education, all of which are irrespective of socioeconomic status (Sexton, et al., 2012). Given the high levels of impairment, there is a critical need to identify and develop effective interventions for these youth. Ultimately, the overarching aim of this study is to explore whether a multi-component computerized neurocognitive intervention that targets neurocognitions associated with ADHD as well as reading difficulties will translate to improvements in EFs, ADHD symptoms and reading outcomes.

The Current Study

A preliminary open clinical trial was conducted over the course of 3-4 months to evaluate the immediate and longer-term effects of ACTIVATE, a promising computerized EF training program (www.c8sciences.com), which simultaneously targets 8 core EFs (sustained attention, WM, response inhibition, processing speed, cognitive flexibility, multiple simultaneous attention, category formation, and pattern

recognition and inductive thinking) in a sample of 20 (7-11 year-old) youth with all subtypes of ADHD and varying levels of reading difficulties, to determine the following primary aims: 1.) To determine if ACTIVATE improves executive functions; 2.) To determine if ACTIVATE improves ADHD symptoms; 3.) To determine if ACTIVATE improves reading outcomes and; 4.) To determine if there are differential rates of improvement in outcome variables (i.e., EFs and ADHD symptoms) for children with reading difficulties compared to those without reading difficulties.

We hypothesize the following in relation to the specific aims: 1.) After participation in ACTIVATE EF will have improved. The literature has demonstrated that early computerized neurocognitive programs that target EFs can result in clinically significant gains in the domains of WM, inhibition, and attention (Klingberg et al., 2002; 2005; Horowitz-Kraus, 2013; Shalev et al., 2007). Furthermore, current research suggests that neurocognitive programs that target multiple domains will show the greatest improvement (Cortese et al., 2014 Rapport et al., 2013; Sonuga-Barke et al., 2014). Therefore we anticipate improvement in the domains of cognitive flexibility, processing speed, WM, sustained attention, and inhibition following intensive neurocognitive training; 2.) After participation in the ACTIVATE training program, which targets sustained attention participant's ADHD symptoms (i.e., inattention) will have improved; 3.) After participation in the ACTIVATE training program participant's reading outcomes, which include reading progress, sight word reading, and decoding will have improved; and 4.) After participation in ACTIVATE children with co-occurring ADHD and reading difficulties will show greater improvements on outcome variables than children with pure ADHD alone (i.e., reading progress, EFs and ADHD symptoms).

Methods

Experimental Intervention ACTIVATE

The overarching aim of this dissertation was to conduct an initial evaluation of ACTIVATE, C^8 Sciences, New Haven, CT a novel computerized EF training program, which targeted 8 core EFs. The program defined the 8 core EFs as follows: Sustained attention is the ability to maintain attention over time (e.g., to look at, listen to and think about classroom tasks over a period of time); Response inhibition is the ability to resist from acting impulsively (e.g., inhibit response to distractions); Speed of information processing refers to how quickly a learner can process information; Cognitive flexibility and control is the ability to act quickly and flexibly when circumstances change (e.g., change what you are thinking about, how you are thinking about it and even what you think about it; Multiple simultaneous attention is the ability to move attention and effort back and forth between two or more activities when engaged in them at the same time; WM temporarily stores, maintains, manipulates information (e.g., the ability to remember instructions or keep information in the mind long enough to perform tasks); Category formation is the ability to organize information, concepts and skills into categories, and forms the cognitive basis for higher-level abilities like applying, analyzing, and evaluating those concepts and skills; and Pattern recognition and inductive thinking is a special ability of the human brain to not only find patterns, but figure out in a logical way what those patterns suggest about what will happen next .

Children participated in the ACTIVATE intervention at home with their parent for 30 minutes per day, 3-5 times a week for 11-16 weeks for a total of 1600 minutes.

The total amount of weeks required to complete ACTIVATE depended upon how frequently the child participated in the ACTIVATE intervention. ACTIVATE is delivered via an online web system for youth 4-11 who can read letters and numbers. As the child's performance improved, the games became increasingly more challenging. If the child had difficulties with the game, the program reduced the challenge of the game. The child's performance (i.e., response time and accuracy) was evaluated each time the child clicked the mouse. This "adaptive training" allowed the child to train at his/her own pace. Built-in motivational aspects of the training program included a display of the child's score, as well as verbal and visual motivational cues throughout the training session. For example, when the child reached a certain level he/she was awarded coins or stars that went in his/her treasure trunk.

The EF tasks were presented as six games (Pirate Pete's Packing Panic, Treasure Trunk, Magic Lens, Ducks, Monkey Trouble, and Grub Ahoy) that engaged the child and provided feedback to the child based on the child's performance. Each of the games initially focused on one of the 8 EFs, as the child advanced in level the games increased the number of EFs that were targeted. However, none of the six games focus exclusively on all 8 EFs. Magic Lens and Treasure Trunk initially targeted sustained attention as the objective of these games was to track the target object around the screen. As the child progressed the target moved quicker and eventually up to three targets were introduced. Additionally, once the child advanced to higher levels, other core EFs (i.e., response inhibition, cognitive flexibility, multiple simultaneous attention, and WM) were also targeted. Pirate Pete's Packing Panic focused on category formation. The objective of this game was Pirate Pete was late for a trip and was frantically trying to pack his

trunk. Objects were tossed in the air and the participant must click on the object that matches the clue on upper corner of the screen. Once the child achieved multiple correct responses the speed increased and other core EFs including sustained attention, response inhibition, speed of information processing, cognitive flexibility, and multiple simultaneous attention were added. For the Ducks game the child was trained in pattern recognition and inductive thinking. The goal of this game was to find the missing duck so the flock can fly off in the correct formation. This required that the child use different colors and shapes to best complete the pattern or rule. As the child advanced six core capacities were added (e.g., sustained attention, speed of information processing, response inhibition, multiple simultaneous attention, cognitive flexibility, and category formation). Only visual spatial WM was targeted for Monkey Trouble and Grub Ahoy.

Participants were further supported individually on a daily basis by his/her parent, whom in turn received support (telephone and email-based) from a 'coach' practitioner (graduate students and research assistants). The coach monitored each participant's treatment progress online (e.g., minutes played, date last signed in and overall performance percentile) and would speak with each child and with his/her parent during a 30-minute weekly coaching call to enhance motivation, ensure compliance, address challenges, and make necessary modifications.

Participants

An open, uncontrolled evaluation of ACTIVATE was conducted in a sample of 20 school-aged youth ages 7-11 diagnosed with ADHD and varying levels of reading difficulties to determine the effects of ACTIVATE on EFs, ADHD symptoms, and reading outcomes. Based on previous analysis we anticipated 25-40% of the sample to

have co-occurring ADHD and reading difficulties. Participants' range of reading difficulties was determined by conducting subgroup analyses. Recruitment took place by means of flyers, brochures, Internet, print ads and various outreach efforts to the local community (e.g., community centers, physicians' offices, etc.). Recruitment occurred over a period of 2 years. Participants were recruited from October – December for years 1 and 2. A total of 10 participants were recruited per year during the months of October, November and December for a total of 20 participants. This recruitment and enrollment strategy was successfully employed in a previous computerized neurocognitive intervention study (Chacko et al., 2013). A total of 20 participants were recruited by using the aforementioned methods (Title: ACTIVATE: A Computerized Training Program for Children With ADHD; https://clinicaltrials.gov/show/NCT02562469).

Children were included in this study if 1.) The child was between the ages of 7-11 with a diagnosis of ADHD through consensus diagnosis based on parent and teacher ratings on the Disruptive Behavior Disorder Rating Scales (DBD; Pelham, Gnagy, Greenslade, & Milich, 1992) and impairment using the Impairment Rating Scale (IRS; Fabiano et al., 2006); and a semi-structured interview with the parent(s) using the Kiddie-SADS (Kaufman et al., 2013); 2.) Parent and child were fluent English speakers; and 3.) Family had access to desktop/laptop computer at home with Internet access (in order to implement the ACTIVATE intervention component, which was an online-based computer program). Individuals were excluded from the study if 1.) There was evidence of significant developmental delay or psychosis that impacted the child's ability to function and to fully engage in the computerized intervention; 2.) If the youth or parent presented with emergency psychiatric needs that required services beyond that which can

be managed within a preventive intervention format (e.g., hospitalization, specialized placement outside the home), active intervention by research staff to secure what was needed would be made; and 3.) If the child had an estimated Full Scale IQ below 80, based on completing two subtests Vocabulary and Matrix Reasoning of the Wechsler Abbreviated Scale of Intelligence – Second Edition (Wechsler, 2011). Table 1 includes more detailed demographic information regarding participants.

Measures

Outcome Assessment Instruments. All outcome assessments were conducted at baseline and post-treatment to assess key EFs, ADHD symptoms, and reading outcomes for pure ADHD and co-occurring ADHD and reading difficulties.

Cognitive Flexibility. The Delis-Kaplan Executive Function System (D-KEFS; Delis, Kaplan, & Kramer, 2001) is standardized assessment battery that includes a set of tests to evaluate higher-level cognitive functions in children. Specifically, we utilized the Trail making test of the D-KEFS. The trail making test evaluated cognitive flexibility by a visual cancellation tasks and a series of connect-the-circle tasks. Psychometrics of the D-KEFS for this sample indicated good internal consistency (Cronbach's alpha = .88).

Parent Report of Executive Function. The Behavior Rating Inventory of Executive Function (BRIEF; Gioia, Isquith, Guy, & Kenworthy, 2000) rating form is used by parents to rate a child's EFs within the context of his/her everyday environment at home and school, respectively. Parents rated their child for how true each item was using the following scale: N = Never a problem (as far as you know); S = Sometimes a problem; O = Often a problem. The BRIEF is an ecologically valid and efficient tool for screening, assessing, and monitoring a child's EF and development. The BRIEF parent

questionnaire contains 86 items in eight non-overlapping clinical scales and two validity scales. These theoretically and statistically derived scales form two broader Indexes: Behavioral Regulation (three scales) and Metacognition (five scales), as well as a Global Executive Composite score. Normative data is based on child ratings from 1,419 parents from rural, suburban, and urban areas, reflecting 1999 U.S. Census estimates for SES, ethnicity, and gender distribution. Separate normative tables for the parent form provide *T* scores, percentiles, and 90% confidence intervals for four developmental age groups (5-18 years) by gender of the child. Psychometrics of the BRIEF for this sample had strong internal consistency (Cronbach's alpha = .93).

Processing Speed and Working Memory. Wechsler Intelligence Scale for Children-Fourth Edition (WISC-IV; Wechsler, et al., 2003): The WISC-IV is an assessment battery that generates a Full Scale IQ (FSIQ), which represents overall cognitive ability; the four other composite scores are Verbal Comprehension Index (VCI), Perceptual Reasoning Index (PRI), Processing Speed Index (PSI) and Working Memory Index (WMI). Processing Speed is measured using the Coding and Symbol Search subtests. WM is measured using Digit Span and Letter-Number Sequencing subtests. Normative data is based on 2,200 children between the ages of 6:00 and 16:11 years. A total of 200 children were selected for each of the 11 age groups. The sample is stratified on age, sex, parent education level, region, and race/ethnicity. The WISC-IV shows high internal consistency, test-retest reliability, and correlational data. Psychometrics of the WISC-IV for this sample demonstrated adequate internal consistency for Process Speed (Cronbach's alpha = .75) and WM (Cronbach's alpha = .77).

Sustained Attention and Impulsivity. Tasks of Executive Control (TEC; Isquith, Roth, & Gioia, 2010) is a standardized computer-administered assessment battery that measures two fundamental aspects of executive control processes: sustained attention and impulsivity. Each task consists of on-screen instructions, a set of practice trials with feedback, and 100 timed-interval stimuli that require responses. Convergent evidence for validity of the TEC is based on correlations with other well-validated assessment of EF. Validity also is investigated within several clinical samples, including children and adolescents with ADHD, mild traumatic brain injury, learning disabilities, and fragile X syndrome. Psychometrics of the TEC for this sample indicated good internal consistency for Sustained Attention (Cronbach's alpha = .87) and Impulsivity (Cronbach's alpha = .80).

Parent Report of ADHD Symptoms. ADHD symptoms were measured using the well-validated Disruptive Behavior Rating Scale (DBD; Pelham et al., 1992). The DBD is a 45-item measure that asks parents to rate symptoms of ADHD, ODD, and CD on a four-point scale (i.e., Not at all, Just a little, Pretty Much, or Very Much), with higher scores indicating a greater frequency of problems. The sum of individual items for the inattentive symptoms and for the hyperactive-impulsive symptoms was calculated separately and used as outcome measures. For this study, the average scores for DSM-5 ADHD inattentive symptoms, DSM-5 ADHD hyperactive-impulsive symptoms, DSM-5 ODD, and DSM-5 CD symptoms was used. Psychometrics of the DBD for this sample reported good internal consistency of inattentive symptoms (Cronbach's alpha = .82) and hyperactive-impulsive symptoms (Cronbach's alpha = .85).

Reading Progress. The well-validated Kaufman Test of Educational Achievement, Third Edition (KTEA-3; Kaufman & Kaufman, 2014) was used to measure Reading Comprehension (items involved reading passages and answering comprehension questions), Letter and Word Recognition (identification of letters and pronunciation of words), Word Recognition Fluency (reading list of words aloud as quickly as possible), and Decoding Fluency (reading list of nonsense words aloud as quickly as possible) subtests. The overall reliability coefficient is reported at 0.87 to 0.95. Additionally, this measure correlates well with the Wide Range Achievement, the Peabody Individual Achievement Test, the Metropolitan Achievement Test, the Stanford Achievement Test, and the ABC with correlation ratings from 0.75 – 0.86. Psychometrics of the KTEA-3 for this sample demonstrated excellent internal consistency for Reading Comprehension (Cronbach's alpha = .96), Letter Word Recognition (Cronbach's alpha = .91), Word Recognition Fluency (Cronbach's alpha = .98), and Decoding Fluency (Cronbach's alpha = .96).

Reading Difficulties Grouping. Reading impairment (yes/no) was determined if a participant obtained a standard score of 84 or lower on either one or both timed reading achievement tests (Word Recognition Fluency and/or Decoding Fluency).

Procedures

Both parents and children were informed at diagnostic intake that the study was an open clinical trial. Therefore, all participants received the ACTIVATE intervention. Upon completion of the parental consent and child assent a clinician conducted a semi-structured interview with the participant's parent(s) to determine a diagnosis of ADHD and psychiatric co-morbidities, during which parent and teacher rating scales were

completed, as well as the child's diagnostic evaluation. Baseline assessments and rating scales were completed prior to ACTIVATE training. Two weeks after the final training day post-treatment assessments and rating scales were also completed. The assessments lasted for approximately 2.5 hours. Breaks were provided as needed. Parental and teacher reports used ID coding for confidentiality. Study procedures were approved by New York University's Institutional Review Board and conducted by research staff (graduate and undergraduate students).

All participants received the treatment intervention. All research staff members were certified by C^8 Sciences as ACTIVATE training coaches and assigned an equal number of cases. All families participated in a start-up session and were introduced to the ACTIVATE program. A schedule for implementing the intervention and weekly coaching calls was also decided. Families and coaches also developed an individualized incentive system, which rewards on-task behavior during training. The standard ACTIVATE rewards system was augmented by the incentive system and included conditional daily, as well as weekly rewards. The rewards were selected by the child and required parental agreement (e.g., extra iPad time, picking dinner, movie night, etc.). The purpose of the individualized incentive system was to maximize compliance as the treatment was lengthy (3-4 months of training) and the expected rates of oppositional problems within this sample were considered to be high. Computerized training was conducted at home and was completed over a 3-4 month period based upon the family's schedule. Senior staff (AC and ALC) supervised the treatment intervention to monitor coaching calls and verify data.

Statistical Analyses

Preliminary analyses were performed to ensure no violation of the assumptions of normality, linearity multicollinearity, and homoscedasticity. The relationships between inattention, hyperactivity, and reading were investigated initially using Pearson correlation coefficients. Specifically, we wanted to explore if ADHD symptoms (inattention and hyperactivity-impulsivity) were negatively related to reading outcomes and/or time. We also were seeking to ascertain whether change in ADHD symptoms was related to change in reading.

We conducted a mixed 2 (between-subjects: reading impaired ADHD group versus non-impaired ADHD group) x 2 (within-subjects: pre-treatment versus post-treatment) analysis of variance (ANOVA) design to determine the following primary aims: 1.) To determine if ACTIVATE improves EFs; 2.) To determine if ACTIVATE improves ADHD symptoms; 3.) To determine if ACTIVATE improves reading outcomes; and 4.) To determine if there are differential rates of improvement in outcome variables (i.e., reading progress, EFs and ADHD symptoms) for children with reading difficulties compared to those without reading difficulties. Ultimately, we sought to determine whether participants improved across time (baseline to post-treatment) and according to group (impaired readers vs. non-impaired readers). Moreover, did impairment in reading influence the outcome variables (i.e., reading progress, EFs, and ADHD symptoms) irrespective of time.

In order to determine Aim 1 we used the following measures to assess EFs: the D-KEFS (cognitive flexibility), BRIEF (a parental report of EFs), WISC-IV (WM and Processing Speed), and TEC (sustained attention and inhibition). To evaluate Aim 2

whether ACTIVATE improved ADHD symptoms the DBD (a parental measure of symptoms of inattention and hyperactivity/impulsivity) was utilized. For Aim 3 the KTEA-3 (Reading Comprehension, Letter and Word Recognition, Word Recognition Fluency, and Decoding Fluency) was used to assess reading progress. We included Aim 4 to determine if there were differential rates of improvement in outcome variables (i.e., EFs and ADHD symptoms) for children with reading difficulties compared to those without reading difficulties. Participants were considered reading impaired if they earned a standard score of 84 or lower on either one or both timed reading achievement tests (Word Recognition Fluency and/or Decoding Fluency)

Results

Bivariate Correlations

Bivariate correlations for parent rated baseline ADHD inattentive symptoms and reading outcomes (Reading Comprehension, Letter and Word Recognition, Word Recognition Fluency, and Decoding Fluency) are presented on Table 2. Baseline data for bivariate correlations of parent rated ADHD hyperactivity-impulsivity symptoms and reading outcomes (Reading Comprehension, Letter and Word Recognition, Word Recognition Fluency, and Decoding Fluency) are detailed in Table 3. Statistically significant positive correlations were identified in both tables between pre-treatment Letter Word Recognition (sight word reading) and pre-treatment Reading Comprehension ($r = .75$, $p < .001$), as well as baseline Reading Comprehension and baseline Word Recognition Fluency ($r = .71$, $p < .001$). A significant positive correlation between baseline Word Recognition Fluency (decoding words) and baseline Decoding Fluency (decoding non-words) was also found ($r = .85$, $p < .001$). Correlations between pre-

treatment inattention and reading outcomes, as well as pre-treatment hyperactivity-impulsivity and reading outcomes were not found.

Post-treatment data for bivariate correlations of ADHD inattentive symptoms and reading outcomes, as well as ADHD hyperactivity-impulsivity symptoms and reading outcomes are presented in Tables 4 and 5. A significant positive correlation between post-treatment Letter Word Recognition (sight word reading) and post-treatment Reading Comprehension ($r = .78$, $p < .001$) were found in both tables. Data also revealed that post-treatment Reading Comprehension and post-treatment Word Recognition Fluency ($r = .80$, $p < .001$), as well as post-treatment Word Recognition and post-treatment Decoding Fluency were positively correlated. Additionally, a correlation was not identified between post-treatment inattention and reading outcomes, or post-treatment hyperactivity-impulsivity and reading outcomes.

Bivariate correlations presented on Tables 6 and 7 were used to determine whether a change in ADHD symptoms of inattention and/or hyperactivity-impulsivity was related to change in reading outcomes. The data demonstrated no statistically significant bivariate correlation effects.

Bivariate correlations for parent rated baseline ADHD inattentive and hyperactive-impulsive symptoms and EFs (WM, processing speed, and impulsivity) are presented on Tables 8 and 9. Statistically significant negative correlations were identified between pre-treatment parent rated inattention symptoms and pre-treatment inhibition scores (impulsivity; $r = .60$, $p < .01$). The data also demonstrated significant correlations between baseline parent hyperactivity-impulsivity scores and lower level inhibition scores ($r = .54$, $p < .05$). We did not identify correlations between pre-treatment parent

rated inattention and EF measures of WM, processing speed, and higher levels of impulsivity. Similarly, statistically significant associations were not demonstrated between pre-treatment parent rated hyperactivity-impulsivity and EF outcomes (WM, processing speed, and higher levels of impulsivity).

Post-treatment data for bivariate correlations of parent rated ADHD inattentive and hyperactive-impulsive symptoms and WM, processing speed and impulsivity are detailed on Tables 10 and 11. Correlations were not identified between post-treatment parent rated inattention symptoms and EFs, or post-treatment parent rated hyperactivity-impulsivity and EF outcomes. Parent rated EFs (BRIEF) and objective measures of EFs (WM, processing speed, and impulsivity) did not reveal statistically significant correlation effects.

Finally, data presented on Tables 10, 11, 12, 13, and 14 revealed statistically significant positive correlations between post-treatment WM and post-treatment processing speed scores ($r = .62$, $p < .05$), as well as post-treatment lower level impulsivity scores (assessing lower levels of inhibition) and post-treatment moderate level impulsivity scores ($r = .61$, $p < .05$). The data revealed correlations between post-treatment lower level impulsivity scores and post-treatment higher level impulsivity scores ($r = .62$, $p < .05$). A statistically significant correlation was also found between post-treatment moderate level impulsivity scores and post-treatment higher level impulsivity scores ($r = .74$, $p < .01$).

Mixed Model ANOVAs

2 x 2 mixed ANOVAs were used to determine main effect of time (if participants improved from pre-treatment (time 1) to post-treatment (time 2); these results are

presented on Table 8) and main effect of group (does reading impairment influence EFs, ADHD symptoms, and reading progress, regardless of time), as well as their interaction.

Executive Functions

Cognitive Flexibility.

Visual Scanning (Trail 1). A significant main effect of group, $F(1, 9) = 6.72$, $p = .03$, partial $\eta^2 = .43$, indicated that across time points, non-impaired readers ($M = 10.75$, $SE = 1.18$) had higher Visual Scanning scores than impaired readers ($M = 6.20$, $SE = 1.297$). A significant main effect of time, $F(1, 9) = 9.79$, $p = .01$, partial $\eta^2 = .52$, showed that across participants, scores increased from time 1 ($M = 7.52$, $SE = 0.96$) to time 2 ($M = 9.43$, $SE = .90$). However, no group x time interaction emerged $F(1, 9) = .10$, $p = .90$, partial $\eta^2 = .00$.

Number Sequencing (Trail 2). A significant main effect of group, $F(1, 9) = 8.62$, $p = .02$, partial $\eta^2 = .49$, demonstrated that across time points, non-impaired readers ($M = 11.83$, $SE = .95$) had higher Number Sequencing scores than impaired readers ($M = 7.70$, $SE = 1.04$). However, no main effect of time $F(1, 9) = .30$, $p = .60$, partial $\eta^2 = .03$, or group x time interaction emerged $F(1, 9) = .08$, $p = .89$, partial $\eta^2 = .01$.

Letter Sequencing (Trail 3). No significant effects emerged for group $F(1, 9) = 2.51$, $p = .15$, partial $\eta^2 = .22$, time $F(1, 9) = 1.51$, $p = .25$, partial $\eta^2 = .14$, or their interaction $F(1, 9) = 4.69$, $p = .06$, partial $\eta^2 = .34$.

Letter Number/Sequencing (Trail 4). No significant effects emerged for group $F(1, 8) = 2.42$, $p = .16$, partial $\eta^2 = .23$, time $F(1, 8) = .80$, $p = .79$, partial $\eta^2 = .01$, or their interaction $F(1, 8) = .00$, $p = .97$, partial $\eta^2 = .00$.

Motor Speed (Trail 5). No significant effects emerged for group $F(1, 9) = 3.79$, $p = .08$, partial $\eta^2 = .30$, time $F(1, 9) = .34$, $p = .58$, partial $\eta^2 = .04$, or their interaction $F(1, 9) = 2.69$, $p = .14$, partial $\eta^2 = .23$.

Parental Report of Executive Functions.

Behavioral Regulation Index. No significant effects emerged for group $F(1, 14) = .17$, $p = .69$, partial $\eta^2 = .01$, time $F(1, 14) = 1.79$, $p = .20$, partial $\eta^2 = .11$, or their interaction $F(1, 14) = 1.11$, $p = .31$, partial $\eta^2 = .07$.

Metacognition Index. There was a significant main effect of time, $F(1, 14) = 6.68$, $p = .02$, partial $\eta = .32$, showing that across participants, Metacognition scores decreased from time 1 ($M = 70.17$, $SE = 3.18$) to time 2 ($M = 64.42$, $SE = 3.29$). No significant effects emerged for group $F(1, 14) = .07$, $p = .80$, partial $\eta^2 = .01$ or the group x time interaction $F(1, 14) = .62$, $p = .45$, partial $\eta^2 = .04$.

Global Executive Composite. There was a main effect of time, $F(1, 14) = 5.50$, $p = .03$, partial $\eta^2 = .28$, such that across all participants scores decreased from time 1 ($M = 65.98$, $SE = 3.16$) to time 2 ($M = 60.42$, $SE = 3.17$). No significant effects emerged for group $F(1, 14) = .00$, $p = .99$, partial $\eta^2 = .00$ or the group x time interaction $F(1, 14) = .91$, $p = .36$, partial $\eta^2 = .06$.

WM and Processing Speed.

WM Index. No significant effects emerged for group $F(1, 14) = 1.44$, $p = .25$, partial $\eta^2 = .09$, time $F(1, 14) = 1.86$, $p = .19$, partial $\eta^2 = .12$, , or their interaction $F(1, 14) = 3.21$, $p = .10$, partial $\eta^2 = .19$.

Processing Speed Index. No significant effects emerged for group $F(1, 14) = 2.21$, $p = .16$, partial $\eta^2 = .14$, time $F(1, 14) = .13$, $p = .73$, partial $\eta^2 = .01$,, or their interaction $F(1, 14) = .63$, $p = .44$, partial $\eta^2 = .04$.

Impulsivity.

Commissions 0BI. No significant effects emerged for group $F(1, 14) = .02$, $p = .89$, partial $\eta^2 = .00$, time $F(1, 14) = 2.11$, $p = .17$, partial $\eta^2 = .13$, or their interaction $F(1, 14) = .02$, $p = .91$, partial $\eta^2 = .00$.

Commissions 1BI. No significant effects emerged for group $F(1, 14) = .17$, $p = .69$, partial $\eta^2 = .01$, time $F(1, 14) = 3.53$, $p = .08$, partial $\eta^2 = .20$, or their interaction $F(1, 14) = 1.93$, $p = .19$, partial $\eta^2 = .12$.

Commissions 2BI. No significant effects emerged for group $F(1, 7) = 1.32$, $p = .29$, partial $\eta^2 = .16$, time $F(1, 7) = .19$, $p = .67$, partial $\eta^2 = .03$, or their interaction $F(1, 7) = .38$, $p = .56$, partial $\eta^2 = .05$.

Sustained Attention.

Standard correct 0B. There was a significant main effect of time, $F(1, 14) = 5.48$, $p = .04$, partial $\eta = .28$, showing that across participants, scores decreased from time 1 ($M = 62.38$, $SE = 5.11$) to time 2 ($M = 51.08$, $SE = 4.06$). No significant effects emerged for group $F(1, 14) = 3.82$, $p = .07$, partial $\eta^2 = .21$ or the group x time interaction $F(1, 14) = 021$, $p = .66$, partial $\eta^2 = .02$.

Standard correct 1B. No significant effects emerged for group $F(1, 14) = .82$, $p = .38$, partial $\eta^2 = .05$, time $F(1, 14) = .20$, $p = .66$, partial $\eta^2 = .01$, or their interaction $F(1, 14) = .89$, $p = .36$, partial $\eta^2 = .06$.

Standard correct 2B. No significant effects emerged for group $F(1, 8) = .46$, $p = .52$, partial $\eta^2 = .06$ ($p = .52$), time $F(1, 8) = 2.67$, $p = .14$, partial $\eta^2 = .25$, or their interaction $F(1, 8) = 3.31$, $p = .11$, partial $\eta^2 = .29$.

Standard correct 0BI. No significant effects emerged for group $F(1, 14) = 1.04$, $p = .33$, partial $\eta^2 = .07$, time $F(1, 14) = 1.01$, $p = .33$, partial $\eta^2 = .07$, or their interaction $F(1, 14) = .27$, $p = .62$, partial $\eta^2 = .02$.

Standard correct 1BI. No significant effects emerged for group $F(1, 14) = .32$, $p = .58$, partial $\eta^2 = .02$, time $F(1, 14) = 2.00$, $p = .18$, partial $\eta^2 = .13$, or their interaction $F(1, 14) = .63$, $p = .44$, partial $\eta^2 = .04$.

Standard correct 2BI. There was a group x time interaction, $F(1, 7) = 6.34$, $p = .04$, partial $\eta^2 = .46$. Follow-up pairwise comparisons indicated that although groups did not differ from each other at time 1 ($p = .49$) or time 2 ($p = .66$), non-impaired readers decreased from time 1 (M = 58.00, SE = 9.11) to time 2 (M = 45.20, SE = 8.67) ($p = .02$, $\eta^2 = .56$). However, impaired readers did not change from time 1 (M = 48.00, SE = 10.19) to time 2 (M = 51.25, SE = 9.70) ($p = .52$, $\eta^2 = .06$) No significant effects emerged for group $F(1, 7) = .02$, $p = .88$, partial $\eta^2 = .00$ or time $F(1, 7) = 2.24$, $p = .18$, partial $\eta^2 = .24$.

ADHD Symptoms

Inattention symptoms. A significant main effect of time, $F(1, 14) = 11.81$, $p = .01$, partial $\eta^2 = .46$, was further qualified by a group x time interaction, $F(1, 14) = 5.15$, $p = .04$, partial $\eta^2 = .27$. Follow-up pairwise comparisons indicated that: 1.) Groups did not differ in scores at time 1 ($p = .50$) or time 2 ($p = .40$); 2.) Scores in the reading impaired group significantly decreased from time 1 ($M = 20.00$, $SE = 2.63$) to time 2 (M = 13.17,

SE = 2.87) (p = .01, partial η^2 = .48), whereas scores in the non-impaired group did not change from time 1 (M = 17.70, SE = 2.04) to time 2 (M = 16.30, SE = 2.23) (p = .36, partial η^2 = .06). No significant effects emerged for group $F(1, 14) = .01$, p = .90, partial η^2 = .00.

Hyperactivity-impulsivity symptoms. There was a main effect of time, $F(1, 14) = 10.75$, p = .01, partial η^2 = .43, showing that across participants, scores decreased from time 1 (M = 13.72, SE = 1.94) to time 2 (M = 9.63, SE = 1.66). No significant effects emerged for group $F(1, 14) = .16$, p = .70, partial η^2 = .01 or the group x time interaction $F(1, 14) = 1.62$, p = .22, partial η^2 = .10.

Reading Progress

Reading Comprehension. There was a main effect of group, $F(1, 14) = 28.09$, p = .01, partial η^2 = .67, such that across time, non-impaired readers *(*M = 114.15, SE = 3.26*)* had higher Reading Comprehension scores than impaired readers *(*M = 85.92, SE = 4.21*)*. No significant effects emerged for time $F(1, 14) = .21$, p = .66, partial η^2 = .01 or the group x time interaction $F(1, 14) = .26$, p = .62, partial η^2 = .02.

Letter Word Recognition. There was a main effect of group, $F(1, 14) = 16.54$, p = .01, partial η^2 = .54, such that across time, non-impaired readers *(*M = 112.35, SE = 4.21*)* had higher Letter Word Recognition scores than impaired readers *(*M = 84.42, SE = 5.43*)*. No significant effects emerged for time $F(1, 14) = .49$, p = .50, partial η^2 = .03 or the group x time interaction $F(1, 14) = 2.02$, p = .18, partial η^2 = .413.

Discussion

The purpose of this study was to evaluate the efficacy of ACTIVATE, a multi-targeted neurocognitive intervention, on ADHD, EFs, and reading outcomes in a sample

of youth with ADHD and varying degrees of reading difficulties. Specifically, the study aimed to: 1.) To determine if ACTIVATE improves executive functions; 2.) To determine if ACTIVATE improves ADHD symptoms; 3.) To determine if ACTIVATE improves reading outcomes and; 4.) To determine if there are differential rates of improvement in outcome variables (i.e., reading progress, EFs and ADHD symptoms) for children with reading difficulties compared to those without reading difficulties.

We hypothesized the following in relation to the specific aims: 1.) After participation in ACTIVATE executive functions would improve; More specifically, we anticipated improvement in the domains of cognitive flexibility, processing speed, WM, sustained attention, and inhibition following intensive neurocognitive training; 2.) After participation in the ACTIVATE training program participant's ADHD symptoms (inattention symptoms) would improve; 3.) After participation in the ACTIVATE training program participant's reading outcomes, which include reading comprehension, sight word reading, and decoding would improve; and 4.) After participation in ACTIVATE children with co-occurring ADHD and reading difficulties would show greater improvements on outcome variables (i.e., reading progress, EFs, and ADHD symptoms). Findings revealed a reduction of ADHD symptoms for all participants. Improvements in sustained attention, EFs deficits (planning, organizing, problem-solving), cognitive flexibility, and reading outcomes are also identified for participants with pure ADHD. Lastly, on a task of sustained attention a group x time interaction was demonstrated, such that non-impaired readers' scores decrease from time 1 to time 2, whereas impaired readers' scores did not change from time 1 to time 2.

Bivariate correlations were conducted to identify whether ADHD deficits (symptoms of inattention and hyperactivity-impulsivity) are negatively related to reading impairment pre- and post-treatment. We also investigated whether a change in ADHD symptoms of inattention and/or hyperactivity-impulsivity is related to a change in reading outcomes. Bivariate correlations revealed associations between decoding and sight wording reading, as well as decoding and reading comprehension, consistent with current research (Aaron et al., 1999; Aaron et al., 2002; Lewandowski and Lovett, 2014). Our findings also revealed that ADHD deficits are not related to reading severity. This is surprising given that children with ADHD frequently exhibit difficulties with decoding, struggle to identify written words, and have deficits with reading comprehension (Fienup et al., 2015; McGrath et al., 2011; Miller et al., 2013; Willcutt et al., 2010).

Furthermore, the literature reports that 25-40% of children with ADHD experience reading difficulties (Willcutt & Pennington, 2000) and have an overlap of neural pathways (Kupietz, 1990; Rucklidge & Tannock, 2002; Willcutt et al., 2001). The range of children with reading difficulties in this sample is small and may have prevented the association between a change in ADHD symptoms and a change in reading severity from being identified. Of the eight participants identified as having a reading difficulty, two dropped out of the study. Moreover, reading difficulty is based on participants obtaining a standard score of 84 or lower on either one or both timed reading achievement tests (Word Recognition Fluency and/or Decoding Fluency), rather than a formal diagnosis of a reading disability, which may have impacted these findings.

We also conducted bivariate correlations to determine whether there was an association between parent rated measures and performance-based measures of EFs.

Neither parent rated EFs (BRIEF) nor objective measures of EFs revealed statistically significant correlation effects. The data supports current research, which has demonstrated that performance-based and rating measures of EF appear to have different underlying constructs (Toplak, West & Stanovich, 2013).

Aim 1 Executive Functions

The first aim of this project was to determine if ACTIVATE improves EFs. ACTIVATE is a computerized neurocognitive intervention that targets multiple EFs, which includes neurocognitive pathways most closely associated with ADHD, as well as the neurocognitive pathways also shared by children with ADHD and reading difficulties. Aim 1 is investigated by assessing multiple EFs, which included cognitive flexibility, processing speed, WM, sustained attention, and inhibition. To obtain a more broad analysis of EFs as a construct the BRIEF was also utilized. This measure examines several aspects of EFs including planning, organizing, self-monitoring, and emotion regulation and is based on parental report. We hypothesized that participants will exhibit improvements within EF following this multicomponent treatment intervention. Our hypothesis is in line with current research, which suggests that neurocognitive programs that target multiple domains will show the greatest improvement (Cortese et al., 2014 Rapport et al., 2013; Sonuga-Barke et al., 2014).

Cognitive Flexibility. Results revealed that during a cancellation task: (1) non-impaired readers exhibited higher Visual Scanning scores than impaired readers; and (2) participants' Visual Scanning scores improved as a result of ACTIVATE treatment. Similar findings were also identified on a connect-the-circle task (Number Sequencing) in that non-impaired readers also exhibited higher scores than impaired readers.

However, on the remaining Trails tasks 3-5 (which included connect-the-circle, letter-number sequencing, and motor tasks) significant effects were not found. This finding is unexpected, as Trails 4, which requires alternating between letters and numbers, is the only task to fully capture cognitive flexibility.

Given that cognitive flexibility is only targeted in four of the six games may assist in addressing these unanticipated results. Furthermore cognitive flexibility is not one of the primary EFs targeted (primary targets include sustained attention, category formation, pattern recognition and inductive thinking, and visual WM); it is only once the child makes significant gains within the designated targeted domain that the game adjusts to also include cognitive flexibility.

These findings should also be interpreted with caution, as over a third of the sample did not complete this measure at both baseline and post-treatment due to being younger than the required age. The literature suggests that youth with ADHD struggle with cognitive flexibility (Diamond, 2013); however, to date computerized neurocognitive interventions focus primarily on attention, WM, and inhibition (Klingberg et al., 2002; 2005; Horowitz-Kraus, 2013; Shalev et al., 2007). In order to address whether the use of computerized neurocognitive interventions leads to improvements in cognitive flexibility requires an increase of potency and that next generation programs specifically target this domain.

Parental Report of Executive Functions. Results revealed a decrease in scores on the Metacognition Index (MI) from pre- to post-treatment across all participants, indicating that children are better able to plan, organize, and engage in future problem-solving following ACTIVATE. These findings are in line with our hypothesis, as well as

the literature, suggesting that computerized neurocognitive programs that target EFs can result in clinical gains (Klingberg et al., 2002; 2005; Horowitz-Kraus, 2013; Shalev et al., 2007). Alternatively, on the Behavioral Regulation Index (BRI), which assesses set-shifting (cognitive flexibility) and emotion regulation, children did not improve across time or group. These results may be related to the fact cognitive flexibility is not one of the primary EFs targeted by ACTIVATE. Similar findings are reported with the D-KEFs, which also measures cognitive flexibility. Moreover, ACTIVATE's 8 targeted EFs do not include emotion regulation. Interestingly, the Global Executive Composite score, an average of both MI (3 scales) and BRI (5 scales), revealed that all children improved across time. Ultimately, this finding is encouraging, as it indicates a reduction of some EFs deficits following the treatment of ACTIVATE. Of note this study runs multiple comparisons, which raises the issue of alpha inflation.

Verbal WM. Results did not reveal a significant effect of time or group. There is substantial support that individuals with pure ADHD exhibit deficits in verbal WM (de Jong et al., 2009; Rucklidge & Tannock, 2002; Shanahan et al., 2006). Similarly, multiple studies demonstrate that youth with co-occurring ADHD and reading difficulties have verbal VM deficits (Rucklidge & Tannock, 2002; Willcutt et al., 2001). Importantly, research shows that when this domain is specifically targeted it can lead to clinically significant gains (Klingberg et al., 2002; 2005). A significant limitation of the ACTIVATE program is that it only targets visual spatial WM, which is a central reason for why improvements in verbal WM were not likely found.

Processing Speed. The literature supports that individuals with pure ADHD (Willcutt et al., 2005b) and co-occurring ADHD and reading difficulties have deficits in

processing speed (Rucklidge & Tannock, 2002; Willcutt et al., 2001). Notably, processing speed has been shown to play a key role in learning to read text both quickly and accurately (Mahone, 2011). Surprisingly no main effect of time or group was found. Similar to cognitive flexibility, processing speed is only targeted during ACTIVATE when a child has made significant advancements in domains of sustained attention or category formation. Perhaps lack of potency may explain why improvements in processing speed are not identified. Another possible explanation is that processing speed is not viewed as an EF closely associated with pure ADHD (Rapport et al., 2013; Sonuga-Barke et al., 2014), which may also account of the clinically insignificant findings.

Impulsivity. Statistical analyses revealed no main effect of time or group. The literature supports that individuals with ADHD have deficits in inhibitory control (Diamond, 2013). Furthermore, early neurocognitive interventions that target this domain report promising outcomes (Klingberg et al., 2002; 2005); however these have not been a uniform across studies (Chacko, Kofler & Jarrett, 2014). Recent meta-analyses (Cortese et al., 2014 Rapport et al., 2013; Sonuga-Barke et al., 2014) suggest that lack of consistency within the literature may be the result of the lack of target potency. Furthermore, inhibition is not one of the primary EFs targeted by ACTIVATE; this domain is only targeted in four games once the child advances in the primary domain. Thus the lack of potency may explain the unconfirmed treatment effects.

Sustained attention. A main effect of time was identified on a sustained attention task where the attentional demand was slightly lower (in comparison to the two other sustained attention tasks). However, a main effect of group was not identified**.** Several

neuropsychological deficits specific to ADHD have been identified including a deficit in sustained attention (Hanisch et al., 2004; Konrad et al., 2004). Interestingly, many current training programs generally do not target sustained attention (Sonuga-Barke et al., 2014; Rapport et al., 2013). However, a few studies that target sustained attention including the present study report encouraging results (Shalev et al., 2007**)**. For example, Shalev and colleagues (2007) demonstrate that an attentional training program that targets sustained attention leads to improvements in parent rated attention symptoms for youth with ADHD. Initial findings from this study are promising. However, in order to determine whether targeting sustained attention leads to improvements in ADHD behaviors and strengthens this EF requires further in-depth examination.

Aim 2 ADHD Symptoms

The second aim of this study was to determine if ACTIVATE improves ADHD symptoms. A measure of ADHD symptoms (inattention, hyperactivity-impulsivity) based on parental report was used to address this question. While the extant literature does not support improvements in ADHD symptoms (Chacko et al., 2013; Sonuga-Barke et al., 2014; Rapport et al., 2013), we hypothesized that the ACTIVATE intervention will lead to a reduction in inattentive symptoms because it targets multiple EFs and is longer in duration (3-4 months).

Inattention symptoms. Statistical analyses revealed a decrease in inattention scores for all participants. This finding is in line with current literature that novel interventions targeting multiple EFs that are longer in duration will lead to a reduction in inattentive symptoms (Cortese et al., 2014; Rapport et al., 2013; Sonuga-Barke et al., 2014).

Hyperactivity-impulsivity symptoms. The analyses revealed a decrease in participants' hyperactivity scores across time. This finding is interesting as ACTIVATE does not target hyperactivity directly. Additionally, response inhibition is not one of the primary EFs targeted by the ACTIVATE program. Finally, while the literature does not support that neurocognitive interventions leads to improvements in ADHD symptoms (Sonuga-Barke et al., 2014; Rapport et al., 2013) this finding is encouraging. However, a control condition is needed for further examination.

Aim 3 Reading Outcomes

The third aim of the current research was to determine if ACTIVATE improves reading outcomes. Children with ADHD frequently demonstrate difficulties with decoding, identification of written words, and reading comprehension ((Fienup et al., 2015; McGrath et al., 2011; Miller et al., 2013; Willcutt et al., 2010). As such, several aspects of reading are examined in this study including decoding, sight word reading, and reading comprehension. Based on current literature, which supports that multicomponent computerized neurocognitive interventions lead to improvements in reading outcomes for youth with pure ADHD and co-occurring ADHD and reading difficulties (Horowitz-Kraus, 2013; Shalev et al., 2007), we hypothesized that following participation in ACTIVATE reading outcomes would have improved.

Reading progress. No main effects of time were identified for reading outcomes (reading comprehension, sight word reading, or decoding). Alternatively, results confirm a main effect of group such that non-impaired readers exhibited higher Reading Comprehension, Letter Word Recognition (sight word reading) scores than impaired readers.

A main effect of group was not identified for Word Recognition Fluency and Decoding Fluency, which is surprising. There is substantial evidence showing that WM and processing speed play a role in decoding unfamiliar words (Gray & Climie, 2016; Mahone, 2011). Given that ACTIVATE targets processing speed and that visual spatial WM is the foremost EF targeted, we anticipated that participants with pure ADHD and those with ADHD and reading difficulties would benefit significantly from this program. One possible explanation for the unexpected results is that visual spatial WM should not be the primary EF targeted.

A recently conducted study of children identified with low WM deficits randomly assigned to either Cogmed (working memory training program) or a Control Condition (usual classroom teaching) show that while the Cogmed program temporarily improves visual spatial WM, it does not generalize to academic outcomes (Roberts, Quach, & Spencer-Smith, 2016). Based on the findings of this project and the Roberts' study (2016), perhaps the neurocognitive deficits (sustained attention, inhibition, WM, and processing speed) associated with ADHD and reading difficulties should be targeted more equally.

4. A Comparison of Level of Impairment (e.g., reading progress) Among Participant's with ADHD and Co-occurring ADHD and Reading Difficulties

Aim 4 was seeking to determine if there are differential rates of improvement in outcome variables (reading progress, EFs and ADHD symptoms) for children with reading difficulties compared to those without reading difficulties. Several neuropsychological studies demonstrate that youth with ADHD and reading difficulties share neurocognitive pathways and exhibit impairments in sustained attention, inhibition,

verbal and visual spatial WM, and processing speed (Kupietz, 1990; Rucklidge & Tannock, 2002; Willcutt et al., 2001). Importantly early neurocognitive interventions, which have targeted attention, WM and/or inhibition have reported encouraging results for youth with ADHD (Klingberg et al., 2002; 2005, Shalev et al., 2007).

Moreover, a recent study examines the treatment effects of a multicomponent computerized training program that targets four EFs (visual memory, split attention, memory, and spatial perception tasks) in adolescents with pure ADHD and co-occurring ADHD and reading difficulties (Horowitz-Kraus, 2013). Findings reveal that youth with co-occurring ADHD and reading difficulties exhibit greater clinically significant gains in EFs and reading ability, which implies that these youth have a unique set of neurocognitive features that require targeting multiple EFs.

Based on earlier, as well as recent studies, we hypothesized greater improvement in reading and EF outcomes for children with co-occurring ADHD and reading difficulties as ACTIVATE targets the EFs most closely associated with this population. However, no significant group x time interactions emerged for any of the four reading outcomes. Since individuals with ADHD and reading difficulties are more likely to experience a higher level of impairment (academic underachievement; Sexton et al., 2012) in comparison to children with pure ADHD; as posited by Poon & Ho (2014) perhaps neurocognitive deficits are more severe within this population and a stronger potency is required for treatment effects. One potential explanation for the non-significant findings is that the potency of this program may not sufficiently target domains of sustained attention, inhibition, verbal and visual spatial WM, and processing speed for youth with ADHD and reading difficulties. Furthermore, while Horowitz-Kraus

(2013) report improvements in EFs and reading ability this program targets memory vs. WM, which may have also impacted the findings.

It is well documented that individuals with co-occurring ADHD and reading difficulties experience deficits in sustained attention. Furthermore, the literature supports that reading is an effortful and complex task that requires sustained attention and deficits within this domain make reading difficult (Brock & Knapp, 1996). Therefore it is not surprising that studies explore the targeting of multiple attentional processes (e.g., split attention, selective attention and orienting of attention). These studies show significant improvement on reading outcomes in youth with ADHD (Horowitz-Kraus, 2013; Shalev et al., 2007). While multiple simultaneous attention is one of the 8 core EFs targeted by ACTIVATE, it is not one of the primary EFs targeted. It is only targeted once the child advances in the domain of sustained attention or category formation. Perhaps the later introduction of multiple simultaneous types of attention may account for the lack of beneficial findings. As such, future computerized neurocognitive interventions should consider an earlier introduction of multiple attentional processes, as well as an increase in potency.

In terms of differential rates of improvement in EF outcome variables for children with reading difficulties compared to those without reading difficulties, only one group x time interaction is found in the domain of sustained attention. Data revealed that non-impaired readers' scores decreased from time 1 to time 2, whereas impaired readers scores did not change from time 1 to time 2. Children with ADHD and reading difficulties appear to possess a unique set of neurocognitive features that appear to

require the targeting of multiple EFs (Horowitz-Kraus, 2013); however, further research is required to identify the correct potency and accurate target specification.

Since children with co-occurring ADHD and reading difficulties experience higher levels of impairments (poor grades and interpersonal difficulties; Sexton et al, 2012), we also anticipated that these children would experience a greater reduction of ADHD symptoms following ACTIVATE. The data revealed that participants with co-occurring ADHD and reading difficulties demonstrate a significant decrease in inattention symptoms from baseline to post-treatment. These results are encouraging as symptoms of inattention frequently result in off-task behavior in the classroom and failure to follow classroom instructions (Mash and Barkley, 2003). The literature shows that inattentive behaviors are strongly associated with reading fluency and comprehension, both of which require EF skills (planning, organizing, problem-solving; Gray & Climie, 2016; Pham, 2016; Semsa et al., 2009). Furthermore, neuropsychological studies have demonstrated that individuals with co-occurring ADHD and reading show impairments in EFs such as WM and sustained attention (Kupietz, 1990; Rucklidge & Tannock, 2002; Willcutt et al., 2001). Preliminary findings from this study suggest that ACTIVATE may lead to improvements in inattention, which is an important outcome given its relationship to reading. However, no significant group x time interaction emerges for hyperactive symptoms.

Taken together, initial findings from this study should be viewed positively, as participants with ADHD improved in several key areas of executive dysfunction. Participants demonstrate clinical gains in domains of cognitive flexibility, planning, organizing, problem-solving, and sustained attention. EF skills play a significant role in a

child's development of reading skills. According to the literature, sustained attention, organization, planning and problem-solving are needed for the analysis of a reading passage and decoding requires EF skills (Brock & Knapp, 1996; Semsa et al., 2009). One of the goals of this study was to explore whether strengthening EFs leads to improvements in reading outcomes for ADHD youth. In the context of this study, it is possible that strengthening EF skills (e.g., planning, organizing, and problem-solving) may contribute to improvements in reading comprehension and site word reading for youth with ADHD.

While it was hypothesized that ACTIVATE would improve WM and inhibition deficits, no significant findings were reported. Our hypothesis was formulated based on the literature's endorsement that novel interventions that target multiple EFs (sustained attention and central executive working memory) most closely associated with ADHD will be most effective (Rapport et al., 2013; Sonuga-Barke et al., 2014). Furthermore, early neurocognitive studies report promising results on outcomes of inhibition and WM (Klingberg et al., 2002; 2005; Green et al., 2012). Although this study's findings are somewhat disappointing, there is substantial research demonstrating that WM plays a key role in academic underachievement for youth with ADHD. More specifically, many youth with ADHD have a weakened WM capacity, which prevents the utilization of cognitive resources to engage in multiple reading processes (Gray & Climie, 2016; Pham, 2016; Semsa et al., 2009). By strengthening WM skills via a computerized neurocognitive intervention, the hope is to improve reading outcomes for ADHD youth, as well as those with co-occurring ADHD and reading difficulties. ACTIVATE is unique because it targets 8 core EFs, whereas most computerized neurocognitive programs cover

only a maximum of two EFs. Another distinctive feature is that ACTIVATE only targets visual spatial WM. Other programs identifying improvements in WM target both verbal and visual spatial WM (Klingberg et al., 2002; 2005). Only targeting visual spatial WM may account for the lack of clinical significant gains observed.

Notably, the findings from this study may offer some insight into current pathophysiological model of ADHD. Many models link ADHD to EF deficits. As an example, the Behavioral Inhibition Model identifies poor behavioral inhibition as the central deficit to ADHD (Barkley, 1997). In addition to poor behavior inhibition, individuals also experience four secondary EF deficits, which include difficulties with WM (e.g., holding information in mind), self-regulation (e.g., emotional self-control), internalization of speech (e.g., rule governed behavior, problem-solving/self-questioning), and reconstitution (e.g., analyses and synthesis of behavior; Barkley, 1997). In context of this study neither large effect sizes nor significant improvement were identified for impulsivity (inhibition) variables. The lack of improvement may be attributable to inadequate potency as only four of six games target inhibition (at a lower level). Based on our findings behavioral inhibition does not appear to be a central deficit in ADHD.

Sonuga-Barke (2003) also hypothesized that EFs contribute to the development of ADHD. More specifically, there are two distinct pathways involved in the development of the disorder. The first pathway involves the mesocortical branch of the DA system that projects to the PFC and is distinguished by cool EFs (e.g., planning and WM) and hot EFs (emotion regulation; Sonuga-Barke, 2003). The mesolimbic DA branch, which is linked to the nucleus accumbens mediates the second pathway. For the purposes of this

study we will focus on the first pathway, which provides some support of Sonuga-Barke's model (i.e., cool EFs). Specifically, the BRIEF a parent-rated measure of EFs revealed improvements in planning, organizing and WM, as well as large effect sizes.

Alternatively, Halperin and Shultz (2006) model hypothesized that the principal cause of ADHD is not PFC impairment, but rather impairment in arousal. Therefore, one can outgrow ADHD symptoms as EFs develop. In the context of this study, perhaps we did not see improvement in inhibition because these children may have out grown this deficit.

An alternative reason that may also account for the lack of neurocognitive improvement in this study is that additional subgroups may have developed as a result of prenatal exposure to environmental toxins (e.g., exposure to alcohol or tobacco smoke). Indeed, the literature identifies a link between prenatal exposure to alcohol and tobacco smoke with inattention and hyperactivity (Mick et al., 2002; Milberger et al., 1996; Nichols & Chen, 1981; Streissguth et al., 1995). Therefore, is it possible that exposure to the toxins may have interacted with neurological and genetic factors, thereby creating a unique subset of individuals with ADHD. As such, this may require pursuing/developing treatment interventions for this unique population.

Importantly, other factors to address the unexpected findings should also be considered. For example, while many cases of ADHD appear to result from genetic factors leading to structural and functional brain mal-development (Blokland et al., 2014; Kochunov et al., 2015; McKay et al., 2014; Peper et al., 2007), approximately 35% of individuals may have developed ADHD because of an environmental adversity, such as fetal distress (Nigg, 2006). These birth complications likely alter early fetal development

during pregnancy and may have led to the creation of another subgroup of individuals with ADHD. This may account for the lack of treatment effects not only for the present study, but other studies as well.

As discussed throughout this paper, there are multiple etiologies of ADHD and as such, several models exist in an attempt to better explain this complex disorder. Importantly, the multiple etiologies may relate to the different responses to neurocognitive treatments. Perhaps, the maintaining factors for ADHD are different and depend upon etiology. The triple pathway model (Sonuga-Barke, Bitsakou, & Thompson, 2010) focuses on cognitive (temporal processing) and motivational (inhibition and delay aversion) deficits. A particular strength of this model is that it helps to explain possible different patterns of deficit affecting some, but not all individuals with ADHD.

Given that research only partially supports ADHD models centered on the PFC and related circuitry, Halperin & Schultz (2006) hypothesize and demonstrate that ADHD may be due to noncortical dysfunction that manifests in ontogeny. No two individuals with ADHD present the same. For instance, as described by Sonuga-Barke and colleagues (2010) some children with ADHD exhibit impairments with delay aversion, whereas other struggle with inhibitory control. It is probable that there are unique subsets of children who have a different EF profile or neurochemical profile, and as such would require different treatment interventions. Taken together, the concept of multiple subgroups would account for the inconsistencies and lack of neurocognitive treatment effects.

Limitations and Future Clinical Directions

Overall, results from this present study can be viewed as encouraging; however there are significant limitations, which will be reviewed and discussed. First, efforts were made to recruit a large sample utilizing the same methods as previous projects. Our inability to recruit a large sample may be due to the intervention being significantly longer than past interventions, which were only five weeks. Perhaps families are unable or unwilling to make the lengthy commitment, as forty-three families contacted the lab but only twenty participated. Additionally, parents may be aware that the results of computerized neurocognitive treatment interventions for youth with ADHD are mixed (Etchells, 2016), resulting in reduced enthusiasm for study participation.

Another limitation is that the small sample size makes it difficult to determine true effects. However, the inclusion of effect sizes (partial eta squared) allows us to determine if the effect is small, medium, or large. For example, results from this study demonstrate that ACTIVATE has a large treatment effect on participants with pure ADHD in the areas of reading comprehension and sight word reading. Findings also reveal a large significant effect of the intervention on inattention (parent report) as participants with co-occurring ADHD and reading outcomes decrease from baseline to post-treatment. On an objective measure of sustained attention, a large treatment effect following ACTIVATE is found for participants with pure ADHD, such that their scores also decrease from pre- to post-treatment.

One of the primary goals of this study was to conduct an initial evaluation of ACTIVATE. We elected to implement an open uncontrolled evaluation and utilized mixed ANOVAs to analyze the data, which posed two significant limitations. First,

findings from a repeated measures variable indexing time in a mixed ANOVA may just reflect likelihood of a potential regression to the mean. More specifically, this statistical phenomenon can cause a natural variation in the repeated data to appear as though a real change has occurred. Secondly, we did not include a control group or placebo/sham group in the present study. To address these limitations and fully evaluate the effectiveness of this novel intervention will require future studies to conduct RCTs utilizing a control group and alternative methods of statistical analyses.

A few of the measures that were selected to assess outcomes also pose limitations. For example, we were unable to administer the cognitive flexibility measure (D-KEFS) to all participants because some of our participants were age 7 and this measure is for individuals 8 years and older. The Animal Sorting test from the NEPSY-II would have been a suitable alternative as the age range is 3-16 years of age. Furthermore, one of the primary EFs that is targeted (e.g., visual spatial WM) is unclear and therefore could not be measured. Therefore, utilizing a WM subtest that measures both verbal (Memory for Sentences and Last Word) and visual spatial WM (Block-span and Delayed response) such as Stanford-Binet Intelligence Scale, fifth edition would be highly beneficial.

Categorizing reading difficulties using a standard score of 84 or lower on either one or both timed reading achievement tests (Word Recognition Fluency and/or Decoding Fluency) is also a limitation. These four subtests were selected as individuals with a reading disability or difficulty frequently struggle with decoding pseudowords, wording reading, and reading comprehension. While this method facilitated the categorization of subgroups utilizing timed (Word Recognition Fluency and/or Decoding Fluency) versus untimed (Reading Comprehension and Letter Word Recognition) measures, we were

unable to make a formal diagnosis of a reading disability based on these subtests alone. According to the literature, approaches that rely on a single criterion to identify a reading disability are subject to measurement error, as well as poor stability over time (Johnson, Jenkins, & Petscher, 2010; Johnson, Jenkins, Petscher & Catts, 2009). For this reason a more comprehensive evaluation utilizing measures such as spelling, written expression, memory, and visual perception are needed to accurately diagnose a reading disability. However, for the purposes of this study we did not intend to focus on children with reading difficulties nor did we actively recruit for children with a reading disorder.

Lastly, there are also limitations associated with the ACTIVATE program. The program is novel in that it targets 8 core EFs (sustained attention, visual spatial WM, response inhibition, speed of information processing, cognitive flexibility, multiple simultaneous attention, category formation, and pattern recognition and inductive thinking). However, none of the EFs are equally targeted. Importantly, each game targets one primary EF (e.g., sustained attention and visual spatial WM) as the child advances the game adjusts to include other EFs (e.g., cognitive flexibility). A significant limitation is that some primary targets are included more than others. For example, visual spatial WM is the primary target for two games, whereas category formation is the primary target for only one game. Importantly, many neurocognitions specific to ADHD are not primary targets (e.g., cognitive flexibility, processing speed, and inhibition) and are only included once the child advances to a higher level. Finally, we did not measure three of the 8 core executive functions (multiple simultaneous attention, category formation, and pattern recognition and inductive thinking), which do not allow for the full evaluation of this novel intervention.

The literature endorses that novel interventions that target multiple EFs (sustained attention and central executive working memory) associated with ADHD, which are longer in duration will be most effective (Rapport et al., 2013; Sonuga-Barke et al., 2014). Notably, the ACTIVATE program is significantly longer as the training program takes 3-4 months to complete (depending how frequently the child plays the games per week). While ACTIVATE targets sustained attention, the potency may not be adequate for youth with ADHD as improvements are not identified across all measures of sustained attention. Additionally, individuals with ADHD have deficits in processing speed and cognitive flexibility. However, improvements within these domains are not identified. It is possible that these findings may be due to a lack of potency (neither cognitive flexibility nor processing speed are primary EFs that are targeted).

Another significant limitation is that ACTIVATE does not target verbal WM. Several studies show that individuals with pure ADHD have deficits in verbal WM (de Jong et al., 2009; Rucklidge & Tannock, 2002). There is also substantial support that in order to achieve beneficial outcomes, next generation interventions should target central executive WM, which includes both visual spatial and verbal WM (Rapport et al., 2013; Sonuga-Barke et al., 2014). Moving forward researchers should strongly consider targeting verbal WM to fully evaluate the effectiveness of computerized neurocognitive training programs for youth with ADHD. Importantly, individuals with co-occurring ADHD and reading difficulties exhibit neurocognitive deficits in sustained attention, inhibition, processing speed, and WM. However, participants did not demonstrate improvements in these domains; thereby suggesting that ACTIVATE's potency may not be adequate for this population.

Data from current literature including this study support that additional investigation of computerized neurocognitive training programs is warranted with a particular emphasis on programs that target multiple neurocognitive processes (Cortese et al., 2014; Rapport et al., 2013; Sonuga-Barke et al., 2014). It is noteworthy that this study reported encouraging findings including a reduction of ADHD symptoms, as well as improvements in sustained attention, EFs deficits (planning, organizing, problem-solving), cognitive flexibility, and reading outcomes for youth with pure ADHD.

While initial findings appear to show promise, they must be viewed with caution due to the small sample size. This study is an open uncontrolled evaluation and the merits of this novel intervention cannot be fully evaluated. Additionally, a RCT comparing ACTIVATE to a Treatment as Usual condition evaluating ACTIVATE's utility as a possible treatment intervention for youth with ADHD (Smith et al., 2016) reports no significant treatment effects on primary outcomes measures of verbal and visual spatial WM, sustained attention, and response inhibition.

Future research should also involve further exploration of alternative etiological mechanisms to better identify ADHD subgroups. A clearer understanding/identification of these subgroups will help facilitate whether ADHD is based on EF deficits or perhaps subcortical dysfunction. A clearer distinction of subgroups would not only allow for the identification of which children get EF training, but also the development of other interventions better suited to each subgroup's deficits. In order to determine whether computerized neurocognitive training can substitute or supplement pharmacological or behavioral interventions, requires larger sample sizes and utilization of RCTs,

identification of etiological mechanisms, as well as intensive research to evaluate potency and target specification.

APPENDIX

Table 1

Child/family demographic and clinical characteristics

Age, mean (SD) in years	8.4 (SD= 1.1)
Sex, No. of males (%)	15 (75%)
Full Scale IQ, mean (SD)	104 (15)
Medicated for ADHD, No. (%)	8(40%)
ADHD Subtype, No.	
Combined	10 (50%)
Inattentive	9 (45%)
Hyperactive/impulsive	1 (5%)
Reading difficulties	8 (40%)
Co-morbid ODD, No.	4 (20%)
Co-morbid CD, No.	0 (0%)
Ethnicity, No. *	
Hispanic or Latino	8
Not Hispanic or Latino	11
Race, No. *	
American Indian	0
Asian	3
Caucasian	5
African American/Black	5
Other	6
Socio-economic Index, Mean (SD) *	126,114 (82,584)
Socio-economic Range *	360,000 (40,000-400,000)
* Please note that these characteristics are missing information from one participant, who elected not to provide this information	

Table 2

Bivariate Correlations Between Baseline Inattention and Reading Outcomes

Variables	1	2	3	4	5
1. Inattention	----				
2. Letter Word Recognition	.14	----			
3. Reading Comprehension	-.14	.75**	----		
4. Word Recognition Fluency	.24	.75**	.71**	----	
5. Decoding Fluency	.11	.85**	.80**	.85**	----

* *p < .01

Table 3

Bivariate Correlations Between Baseline Hyperactivity and Reading Outcomes

Variables	1	2	3	4	5
1. Hyperactivity	----				
2. Letter Word Recognition	.10	----			
3. Reading Comprehension	.03	.75**	----		
4. Word Recognition Fluency	.20	.75**	.71**	----	
5. Decoding Fluency	.17	.85**	.80**	.85**	----

* *p < .01

Table 4

Bivariate Correlations Between Post Inattention and Reading Outcomes

Variables	1	2	3	4	5
1. Inattention	----				
2. Letter Word Recognition	.31	----			
3. Reading Comprehension	.40	.78**	----		
4. Word Recognition Fluency	.37	.91**	.80**	----	
5. Decoding Fluency	.26	.78**	.71*	.78**	----

* *p < .01
*p < .05

Table 5

Bivariate Correlations Between Post Hyperactivity and Reading Outcomes

Variables	1	2	3	4	5
1. Hyperactivity	----				
2. Letter Word Recognition	.16	----			
3. Reading Comprehension	.19	.78**	----		
4. Word Recognition Fluency	.36	.91**	.80**	----	
5. Decoding Fluency	.51	.78**	.71*	.78**	----

* * p < .01
* p < .05

Table 6

Bivariate Correlations Between Baseline Minus Post Inattention and Reading Outcomes

Variables	1	2	3	4	5
1. Inattention	----				
2. Letter Word Recognition	.11	----			
3. Reading Comprehension	.09	-.09	----		
4. Word Recognition Fluency	.03	.37	-.40	----	
5. Decoding Fluency	-.38	-.39	.40	-.42	----

* * $p < .01$
* $p < .05$

Table 7

Bivariate Correlations Between Baseline Minus Post Hyperactivity and Reading Outcomes

Variables	1	2	3	4	5
1. Hyperactivity	----				
2. Letter Word Recognition	-.24	----			
3. Reading Comprehension	-.27	-.09	----		
4. Word Recognition Fluency	-.16	.39	-.40	----	
5. Decoding Fluency	-.03	-.39	.41	-.43	----

* * $p < .01$
* $p < .05$

Table 8

Bivariate Correlations Between Baseline Inattention and EFs

Variables	1	2	3	4	5	6
1. Inattention	----					
2. WM	.36	----				
3. Processing Speed	.74	.17	----			
4. Commissions 0BI	.01**	.52	.97	----		
5. Commissions 1BI	.13	.84	.57	.37	----	
6. Commissions 2BI	.53	.32	.70	.55	.60	----

* * p < .01

* p < .05

Table 9

Bivariate Correlations Between Baseline Hyperactivty and EFs

Variables	1	2	3	4	5	6
1. Hyperactivity	----					
2. WM	.10	----				
3. Processing Speed	.32	.17	----			
4. Commissions 0BI	.02*	.52	.97	----		
5. Commissions 1BI	.12	.84	.57	.37	----	
6. Commissions 2BI	.99	.32	.70	.55	.60	----

* * $p < .01$

* $p < .05$

Table 10

Bivariate Correlations Between Post Inattention and EFs

Variables	1	2	3	4	5	6
1. Inattention	----					
2. WM	.84	----				
3. Processing Speed	.23	.01*	----			
4. Commissions 0BI	.47	.93	.46	----		
5. Commissions 1BI	.92	.68	.85	.01*	----	
6. Commissions 2BI	.72	.79	.54	.02*	.00**	----

* * p < .01

* p < .05

Table 11

Bivariate Correlations Between Post Hyperactivty and EFs

Variables	1	2	3	4	5	6
1. Hyperactivity	----					
2. WM	.70	----				
3. Processing Speed	.40	.01*	----			
4. Commissions 0BI	.53	.93	.46	----		
5. Commissions 1BI	.37	.68	.85	.01*	----	
6. Commissions 2BI	.32	.79	.54	.02*	.00**	----

* * $p < .01$

* $p < .05$

Table 12

Bivariate Correlations Between Post BRIEF - Behavioral Regulation Index (BRI) and EFs

Variables	1	2	3	4	5	6
1. BRIEF – BRI	----					
2. WM	.29	----				
3. Processing Speed	.47	.01*	----			
4. Commissions 0BI	.08	.93	.46	----		
5. Commissions 1BI	.02*	.68	.85	.01*	----	
6. Commissions 2BI	.15	.79	.54	.02*	.00**	----

* * p < .01
* p < .05

Table 13

Bivariate Correlations Between Post BRIEF - Metacognition Index (MI) and EFs

Variables	1	2	3	4	5	6
1. BRIEF – MI	----					
2. WM	.59	----				
3. Processing Speed	.72	.01*	----			
4. Commissions 0BI	.29	.93	.46	----		
5. Commissions 1BI	.22	.68	.85	.01*	----	
6. Commissions 2BI	.10	.79	.54	.02*	.00**	----

* * p < .01

* p < .05

Table 14

Bivariate Correlations Between Post BRIEF - Global Executive Composite (GEC) scores and EFs

Variables	1	2	3	4	5	6
1. BRIEF – GEC	----					
2. WM	.38	----				
3. Processing Speed	.90	.01*	----			
4. Commissions 0BI	.15	.93	.46	----		
5. Commissions 1BI	.07	.68	.85	.01*	----	
6. Commissions 2BI	.10	.79	.54	.02*	.00**	----

* * p < .01
* p < .05

Table 15

Results: Means and Standard Deviations from Outcome Measures

	Pre-Treatment		Post-Treatment	
	Impaired Readers	Non-Impaired Readers	Impaired Readers	Non-Impaired Readers
	M (SE)	*M (SE)*	*M (SE)*	*M (SE)*
D-KEFS Trails 1	5.20 (1.41)	9.83 (1.29)	7.20 (1.33)	11.67 (1.22)
D-KEFS Trails 2	7.20 (1.08)	11.67(.98)	8.20 (1.61)	12.00(1.47)
D-KEFS Trails 3	7.00(1.71)	8.33(1.56)	6.40(1.42)	11.00(1.30)
D-KEFS Trails 4	6.50(1.61)	10.00(1.32)	6.75(2.22)	10.33(1.82)
D-KEFS Trails 5	5.80(1.53)	50.00(4.99)	8.60(1.50)	9.67(1.36)
BRIEF – BRI	56.67(5.50)	50.00(4.99)	50.00(4.99)	55.40(3.86)
BRIEF – MI	71.83(5.03)	68.50(3.90)	68.50(3.90)	64.50(4.03)
BRIEF - GEC	67.17(4.99)	59.33(5.01)	59.33(5.01)	61.50(3.88)
DBD – Inattention	20.00(2.63)	17.70(2.04)	13.17(2.87)	16.30(2.23)
DBD – Hyperactivity	13.83(3.07)	13.60(2.38)	8.17(2.63)	11.10(2.04)
WISC-IV – WM	84.00(5.55)	98.60(4.30)	94.33(6.98)	97.20(5.40)
WISC-IV – PS	85.17(7.68)	102.40(5.95)	90.67(8.48)	100.30(6.57)
KTEA-3 – LWR	81.33(6.47)	113.40(5.01)	87.50(5.26)	111.30(4.08)
KTEA-3 – RC	85.00(4.88)	114.20(3.78)	86.83(4.03)	114.10(3.12)
TEC-Commissions 0BI	44.50 (3.96)	44.40(3.07)	39.33(4.78)	38.30(3.71)
TEC-Commissions 1BI	49.50(6.36)	42.70(4.93)	39.50(4.35)	41.20(3.37)
TEC-Commissions 2BI	43.00(5.97)	39.60(5.34)	49.00(6.35)	38.60(5.68)
TEC – Standard Score 0B	71.17(8.08)	53.60(6.26)	57.67(6.42)	44.50(4.97)
TEC – Standard Score 1B	55.67(8.20)	53.50(6.35)	63.17(7.08)	50.80(5.49)

TEC – Standard Score 2B	47.00(11.61)	63.67(9.48)	48.00(4.88)	45.17(3.98)
TEC – Standard Score 0BI	60.67(9.34)	56.90(7.23)	57.33(5.76)	46.60(4.74)
TEC – Standard Score 1BI	55.50(7.74)	54.70(6.00)	53.00(4.75)	45.80(3.68)
TEC – Standard Score 2BI	48.00(10.19)	58.00(9.11)	51.25(9.70)	45.20(8.67)

Note. BRIEF = Behavior Rating Inventory of Executive Function; D-KEFS = Delis-Kaplan Executive Function System; DBD = Disruptive Behavior Rating Scale; KTEA-3 = Kaufman Test of Educational Achievement, Third Edition; TEC = Tasks of Executive Control; WISC-IV = Wechsler Intelligence Scale for Children-Fourth Edition.

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AUTOBIOGRAPHICAL STATEMENT

Alyssa Chimiklis is an advanced clinical psychology doctoral student enrolled in the Clinical Psychology program @ Queens College within The Graduate Center, City University of New York. Her research and clinical interests include developing effective interventions for attention-deficit/hyperactivity disorder (ADHD) with a particular focus on identifying neurocognitive factors that may influence the development of ADHD and co-occurring learning difficulties. For her dissertation, she investigated the treatment effects of a novel computerized neurocognitive training program for children with ADHD and varying levels of reading difficulties. Alyssa is also interested in exploring how mindfulness/yoga interventions can influence higher order executive functions, as well as academic outcomes. For the past two years, she has been overseeing a pilot study examining the efficacy of a mindfulness/yoga program for children with increased levels of inattention and emotion dysregulation. She earned her B.S. in Communication from Boston University and her M.A. in Psychology from Queens College.