ATTENTION AND EXECUTIVE FUNCTIONS PERFORMANCE IN POSTSECONDARY STUDENTS WITH AD/HD AND DYSLEXIA

by

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ABSTRACT

There is a dearth of studies investigating attention and cognitive executive functions (EFs) in adults with Attention Deficit/Hyperactivity Disorder (AD/HD), dyslexia, and AD/HD with comorbid dyslexia. Of the available studies, few have compared cognitive performance based on comprehensive theoretical models of attention and EFs and addressed methodological limitations of past research (e.g., sample inclusion and task validity confounds). This dissertation reports the findings from two studies which examined attention performance and performance pertaining to EFs and related cognitive processes of vigilance and processing speed for four groups of postsecondary students, those with AD/HD, dyslexia, AD/HD with comorbid dyslexia, and normal controls. Using a diagnostically referred sample to ensure distinct disability groups and attention and EFs measures with demonstrated construct validity, cognitive task performance was examined in Study 1 based on Posner and Raichle’s (1994) model of attention which is composed of alerting, orienting, and executive attention networks. In Study 2, Pennington and Ozonoff’s (1996) conceptualization of EFs that includes inhibition, set shifting, and working memory components was applied to the students’ performance on attention, EFs (inhibition, set shifting, and working memory), vigilance, and processing speed measures. Results from the two studies showed that the groups with attention deficits (AD/HD and comorbid groups) exhibited vigilance, executive attention, and EFs deficits related to inhibition and set shifting. The groups with reading impairments (dyslexic and comorbid groups) displayed a specific EF deficit in auditory working memory and a processing speed response time deficit. The common etiology hypothesis, which posits that cognitive deficits in comorbid groups are the sum of deficits found in AD/HD and dyslexia alone, best described the performance of the comorbid...
group. The results are discussed with respect to identification/assessment, compensatory strategies, and educational interventions in postsecondary students with AD/HD and dyslexia. The studies emphasize that comparing cognitive performance based on comprehensive theoretical models of attention and EFs and addressing sample inclusion and task validity confounds can effectively delineate cognitive deficits in adults with AD/HD and dyslexia.
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<td>anterior cingulate cortex</td>
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<tr>
<td>AD/HD</td>
<td>attention deficit hyperactivity disorder</td>
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<td>ANT</td>
<td>Attention Network Test</td>
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<td>ARHQ-R</td>
<td>Adult Reading History Questionnaire – Revised</td>
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<td>CARE-SRI</td>
<td>College AD/HD Response Evaluation – Student Response Inventory</td>
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<td>CPT</td>
<td>continuous performance test</td>
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<td>DLPFC</td>
<td>dorsolateral prefrontal cortex</td>
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<td>EEG</td>
<td>electroencephalogram</td>
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<td>EFs</td>
<td>executive functions</td>
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<td>ERP</td>
<td>event-related potential</td>
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<td>fMRI</td>
<td>functional magnetic resonance imaging</td>
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<td>GPA</td>
<td>grade point average</td>
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<td>LDAC</td>
<td>Learning Disability Association of Canada</td>
</tr>
<tr>
<td>PET</td>
<td>positron emission tomography</td>
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<tr>
<td>PFC</td>
<td>prefrontal cortex</td>
</tr>
<tr>
<td>RAP</td>
<td>read, answer, and paraphrase</td>
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<td>SAS</td>
<td>sluggish attentional shifting</td>
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<td>TOWRE</td>
<td>Test of Word Reading Efficiency</td>
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<td>TPH2</td>
<td>tryptophan hydroxylase 2</td>
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VAW  visual attention window
WAIS-111  Wechsler Adult Intelligence Scales – Third Edition
WCST  Wisconsin Card Sorting Task
CHAPTER I: INTRODUCTION

Over the last two decades the number of students with Attention Deficit/Hyperactivity Disorder (AD/HD) and dyslexia attending postsecondary institutions has increased significantly in comparison to other disability groups (Henderson, 2001). Success in the postsecondary environment requires these students to be self-regulated learners (Ellis, 1993). Despite the importance of self-regulatory abilities to educational success, there is limited research related to the performance of postsecondary students (i.e., adults) with AD/HD and dyslexia on measures of attention and cognitive executive functions (EFs) which are thought to underlie self-regulated learning (Garon, Bryson, & Smith, 2008; Pennington & Ozonoff, 1996). The purpose of this dissertation is to determine the extent of cognitive deficits in postsecondary students with AD/HD, dyslexia, and AD/HD with comorbid dyslexia employing comprehensive theoretical models of attention and EFs (and related cognitive processes). Deficits in attention, EFs, vigilance, and processing speed have been reported in studies examining the cognitive etiology associated with AD/HD in children (Barkley, 1998; Barkley, DuPaul, & McMurray, 1990). However, the hypothesis that these deficits are present in postsecondary students with AD/HD is speculative (Weyandt & DuPaul, 2006). Research related to cognitive etiology in postsecondary students with AD/HD has found that they tend to perform similarly to non-AD/HD controls on a variety of cognitive tasks (see DuPaul, Weyandt, O’Dell, & Varejao, 2009). Deficits in attention, EFs, and processing impairments have also been found in dyslexic children (Catts, Gillespie, Leonard, Kail, & Miller, 2002; Chiappe, Hascher, & Siegel, 2000; Losier, McGrath, & Klein, 1996; Reiter,
Tucha, & Lange, 2005). With respect to dyslexic adults, there is a dearth of studies examining attention and EFs performance. Furthermore, the few available studies report conflicting results pertaining to attention and EFs deficits within adult dyslexic groups (e.g., Lacroix, Constantinescu, deAlmeida, Segalowitz, & von Grunau, 2005). Due to the high rate of comorbidity between AD/HD and dyslexia (about 15% - 40%; Dykman & Ackerman, 1991; Semrud-Clikeman et al., 1992; Wilcutt, Pennington, Olson, Chhabildas, & Huslander, 2005), it is imperative to contrast cognitive deficits found in these individual disorders to those of an AD/HD with comorbid dyslexia group to distinguish between deficits specific to AD/HD or dyslexia and deficits resulting from the combination of both disorders. Research involving comorbid children has indicated that their cognitive deficits are equivalent to the deficits found in AD/HD and dyslexia when considered individually (this is the common etiology hypothesis; Wilcutt, Pennington, Olson, Chhabildas, & Huslander, 2005). There is a paucity of studies testing this hypothesis in adults. However, there are a number of factors that make examination of cognitive deficits in AD/HD, dyslexic, and AD/HD with comorbid dyslexia groups challenging.

A significant challenge in delineating AD/HD and dyslexic cognitive etiology involves difficulties in measuring complex and multifaceted cognitive constructs such as attention and EFs. Previous studies have employed paradigms and administered tasks that measured only singular aspects of attention or EFs (Lee, Riccio, & Hynd, 2004). Few studies have employed cognitive tasks based on theoretical models of attention or EFs that provide adequate construct and ecological validity to comprehensively measure these cognitive domains. Furthermore, examination of vigilance and processing speed is
required to measure cognitive processes that both facilitate and integrate attention and EFs.

An additional challenge, due to the high rate of co-occurrence between AD/HD and dyslexia (Wilcutt et al., 2005), concerns how individuals are selected to be in the AD/HD and dyslexic groups. Research has demonstrated that diagnosis by a clinician is more effective than self- or questionnaire-referral to ensure pure AD/HD and dyslexic groups (i.e., excluding comorbid individuals) and to specify cognitive deficits in these disorders (Mahone et al., 2002; Taroyan, Nicolson, & Fawcett, 2007).

Further challenges pertain to the methodological limitations of past research examining cognitive etiology in these disability groups. One difficulty relates to the developmental/maturational confounds associated with attention and EFs measures. Most neuropsychological measures were conceptualized and developed for adults (e.g., Hervey, Epstein, & Curry, 2004); therefore, until late adolescence or early adulthood (when consistent levels of performance are attained) there is much fluctuation in performance on these measures due to developmental factors. Consequently, findings from adult attention and EFs research, as compared to children’s studies, can be analyzed without reference to variables associated with brain maturation, a developmental process often cited as a potential contributor to the more wide ranging attention and EFs deficits found in children’s research (Tannock, 1998). An additional confound is cognitive task impurity; in addition to the primary cognitive construct being measured by a task, there also exist a number of secondary, intertwined cognitive processes that affect performance. To minimize task impurity concerns, the implementation of attention and EFs measures with demonstrated construct validity is warranted. Also, the use of cognitive covariates to
minimize the influence of extraneous cognitive processes on performance further reduces task impurity difficulties.

In this dissertation, cognitive task performance in the disability groups is examined and contrasted based on Posner and Raichle’s (1994) theoretical model of attention networks and Pennington and Ozonoff’s (1996) and Miyake, Emerson, Witzki, and Howerton’s (2000) conceptualization of EFs, which provide a comprehensive basis for measurement of attention and EFs respectively. Two empirical studies are reported which examined adults to minimize developmental/maturational factors related to cognitive tasks and utilized diagnostically referred participants to mitigate sample inclusion confounds. The studies employed attention, EFs, vigilance, and processing speed measures with demonstrated construct validity and made use of cognitive covariates to decrease task impurity confounds. This dissertation addresses the critical need to delineate cognitive performance in adults with AD/HD, dyslexia, and AD/HD with comorbid dyslexia, thus assisting researchers and clinicians to identify more effectively cognitive deficits in adults with these disorders and inform educators on the cognitive domains most in need of remediation to assist these adults in attaining their educational goals.

Organization of the Dissertation

There are a number of constructs employed in the attention, EFs, AD/HD, and dyslexia literature; therefore, brief definitions of the main constructs used in the dissertation will be provided at the end of this chapter. The second chapter of the dissertation reviews current literature describing the cognitive etiology of AD/HD, dyslexia, and comorbid AD/HD and dyslexia in children and adults. Recommendations
from the literature to enhance the effectiveness of studies examining cognitive etiology in these groups are presented at the end of Chapter 2.

Chapter 3 presents the results of an empirical study investigating attention deficits in adults with AD/HD, dyslexia, and comorbid AD/HD and dyslexia. Cognitive task performance related to Posner and Raichle’s (1994) model of attention, including alerting, orienting, and executive attention components, was contrasted between disability and control groups.

Chapter 4 presents an empirical study comparing performance of disability and control groups on EFs tasks and the related non-EFs measures of vigilance and processing speed. Pennington and Ozonoff’s (1994) and Miyake et al.’s (2000) conceptualization of EFs was used as a framework to contrast performance between the groups. The primary components of this framework include inhibition, set shifting, and working memory processes. Lastly, Chapter 5 summarizes the study results within the context of an integrated cognitive framework that includes Posner and Raichle’s (1994) attention networks model and Pennington and Ozonoff’s (1996) conceptualization of EFs, and implications of the findings for research are discussed in relation to identification/assessment of these disabilities, compensation for cognitive deficits, and the effects of the identified deficits on educational interventions.

Definitions

1. **Attention** is both a form of alertness and a mechanism for providing priority (i.e., resource allocation) for cognitive processes (Raz & Buhle, 2006). Attention (i.e., visual attention) is a diversified system subserved by three interrelated attention networks (i.e., the alerting, orienting, and executive attention networks).
2. *Alerting attention* refers to the preparedness to respond and involves the rapid mobilization of cognitive resources to react to stimuli in the environment (Mezzacappa, 2004; Posner & Raichle, 1994).

3. *Orienting attention* is the ability to select and focus on specific information among multiple sensory stimuli (Raz, 2004). Orienting attention can be either overt or covert (e.g., with or without eye movements) and either exogenous (i.e., driven by external stimulus cues) or endogenous (i.e., driven by cognitive processing cues) (Treisman & Gelade, 1980).

4. *Executive attention* refers to the ability to monitor and resolve conflict between mental computations (e.g., disengaging focus and interference control) regardless of the modality of the stimuli (Raz, 2004). Executive attention is often deployed in situations involving decision making, error detection, or overcoming habitual responses.

5. *Executive functions* are cognitive processes that permit problem solving behaviour geared towards the attainment of a goal. Principal components of executive functions are inhibition, set shifting, and working memory processes (Pennington & Ozonoff, 1996).

6. *Inhibition* refers to the ability to deliberately suppress dominant automatic or prepotent responses (Huizinga, Dolan, & van der Molen, 2006; Miyake et al., 2000).
7. **Set shifting** is the ability to shift between mental states, operations, or tasks (Miyake et al., 2000).

8. **Working memory** is the ability to represent and manipulate information in mind (e.g., rules) over brief periods of time to guide decision making and behaviour (Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005). Working memory is a multicomponent system consisting of a central executive and phonological, visual-spatial, and episodic subsystems (Baddeley, 2007).

9. **Vigilance** describes the ability to sustain attention to a task for an extended period of time (Oken, Salinsky, & Elsas, 2006).

10. **Processing speed** is the speed of cognitive processes in the execution of tasks (e.g., attention and EFs tasks) that require high mental effort (Carrol, 1993).

11. **Attention deficit/hyperactivity disorder (AD/HD)** is a disorder with primary symptoms of hyperactivity, impulsivity, and inattentiveness (Barkley, 1998).

12. **Dyslexia** is a disorder characterized by significant difficulties in acquiring basic reading skills such as word identification and phonological (letter-word) decoding and which is not due to extraneous factors such as sensory acuity deficits, socioeconomic disadvantage and like factors (Vellutino, Fletcher, Snowling, & Scanlon, 2004).

13. **AD/HD with comorbid dyslexia** describes individuals who exhibit the behavioural and cognitive characteristics of both AD/HD and dyslexia.
CHAPTER 2: LITERATURE REVIEW: ATTENTION AND EXECUTIVE FUNCTIONS DEFICITS IN ADULT AD/HD AND DYSLEXIA

The past several decades represent a period of expanding access to postsecondary education. Postsecondary enrollment and graduation rates have risen for the United States population as a whole, but also for groups whose participation rates have historically been the lowest: ethnic minority students, mature students, and students with disabilities (Gregg, 2007). The rise in postsecondary students with Attention Deficit/Hyperactivity Disorder (AD/HD) and dyslexia has been dramatic, even when compared to other disability groups. Henderson (2001) estimated that approximately 40% of first year university students with disabilities in the United States had a diagnosis of either AD/HD or dyslexia. However, the percentage of college students with AD/HD or dyslexia may be a conservative number as not all students disclose their disability to postsecondary disability service providers due to the perceived social stigma of identification (Weyandt & Dupaul, 2006).

Students with AD/HD and dyslexia face many obstacles in the postsecondary environment. Ellis (1993) postulated that, in addition to challenges mastering course content, students with these disabilities must also be self-regulated learners; they need to be strategic problem solvers, able to reflect on prior experiences and knowledge, set goals, select and employ appropriate strategies for solving problems, and monitor the effectiveness of their problem solving behaviour. However, many students with AD/HD and dyslexia lack the skills to be self-regulated learners (Barkley, 1997; Butler, 1995). Research has demonstrated that attention and cognitive executive functions (EFs) form
the foundational skills required for self-regulated learning (Garon, Bryson, & Smith, 2008; Pennington & Ozonoff, 1996). Nevertheless, there is a dearth of studies examining these cognitive domains in postsecondary students or adults with AD/HD or dyslexia (Swanson & Hsieh, 2009; Weyandt & DuPaul, 2006).

Attention can be defined as both a form of alertness and a mechanism for providing priority (i.e., resource allocation) for cognitive processes (Raz & Buhle, 2006). Despite variability in the conceptualization of EFs, there is general consensus that EFs are composed of multiple components and are cognitive processes that permit problem solving behaviour geared towards the attainment of a future goal (Pennington & Ozonoff, 1996). Attention and EFs deficits have been found in a broad range of neuropsychiatric and developmental disorders including AD/HD and dyslexia in adults (Barkley, 1997; Barkley, DuPaul, & McMurray, 1990; Nigg, 2005; Pennington & Ozonoff, 1996; Swanson & Hsieh, 2009; Weyandt, Rice, Linterman, Mitzlaff, & Emert, 1998).

The purpose of this thesis is to investigate the cognitive etiology associated with AD/HD, dyslexia, and AD/HD with comorbid dyslexia in a postsecondary (adult) cohort. Posner and Raichle’s (1994) attention networks model and Pennington and Ozonoff’s (1996) conceptualization of cognitive EFs will serve as templates in which cognitive performance will be examined and contrasted.

Purpose and Organization of Literature Review

The purpose of this chapter is to synthesize research on attention and EFs deficits associated with AD/HD, dyslexia, and comorbid AD/HD and dyslexia in postsecondary students and adults. Cognitive processes that are yoked with attention and EFs (i.e., vigilance and processing speed) will also be examined in this adult population. Although
the primary focus of this review is on adult research, some discussion of children with these disorders is necessary due to the greater number of cognitive studies with this population. There are several critical reasons to review and examine literature on attention, EFs, vigilance, and processing speed deficits in adults with AD/HD, dyslexia, and comorbid AD/HD and dyslexia. First, there is limited research available examining the cognitive mechanisms underlying these disorders in adults. Detection of attention and EFs deficits associated with these disorders can assist in helping afflicted students become more engaged, self-regulated postsecondary learners. Second, most cognitive and neuropsychological tests were conceptualized and developed for use with adults; therefore these measures may more accurately determine cognitive etiology. Lastly, results of cognitive studies utilizing adult samples can be analyzed without reference to brain maturation, a developmental process often referred to as a potential confound in studies of children (Tannock, 1998).

The following sections provide definitions and prevalence rates of AD/HD, dyslexia, and comorbid AD/HD and dyslexia, an overview of attention, EFs, vigilance, and processing speed and how these cognitive domains are integrated. A review of research pertaining to attention, EFs, vigilance, and processing speed etiology associated with AD/HD, dyslexia, and comorbid AD/HD and dyslexia in children and adults is then presented. The final section provides recommendations for future research examining the cognitive mechanisms underlying these disorders.
Definitions and Prevalence of AD/HD, Dyslexia, and AD/HD with Comorbid Dyslexia

Attention Deficit Hyperactivity Disorder (AD/HD)

AD/HD is a disorder characterized by a broad array of cognitive, neuropsychological, behavioural, and emotional indicators (American Psychiatric Association, 2000; Faraone et al., 2005). The primary symptoms of this disorder throughout the lifespan include hyperactivity, impulsivity, and inattentiveness (Barkley, 1998). Confirmatory factor analyses have consistently demonstrated that AD/HD is best characterized by separate symptom dimensions of hyperactivity/impulsivity and inattention (Wilcutt & Pennington, 2000). These results support current AD/HD diagnostic guidelines as outlined in the American Psychiatric Association’s Diagnostic and Statistical Manual – Fourth Edition Text-Revision (DSM-IV-TR; American Psychiatric Association, 2000) which lists three subtypes of AD/HD in children and adults: predominantly inattentive type, predominantly hyperactive/impulsive type, and a combined type which includes symptoms of inattention, hyperactivity, and impulsivity. According to Nigg (2005) however, the combined type appears to be more aligned to symptoms of hyperactivity/impulsivity rather than to inattention symptoms.

Barkley (1997) and Nigg, Wilcutt, Doyle, and Sonuga-Barke (2005) theorized that children with the AD/HD hyperactive/impulsive type and combined type exhibit proximal deficits in EFs. Support for this hypothesis is obtained from structural and functional neuroimaging research and through meta-analyses of EFs deficits in children with AD/HD hyperactive/impulsive type and combined type in comparison to non-AD/HD children (Nigg, 2005). Conversely, Barkley (1997) argued that the AD/HD predominantly
inattentive type is associated with a different set of cognitive deficits which include slow processing speed and poor vigilance. Research with children has demonstrated that the AD/HD predominantly inattentive type is characterized by slow retrieval and information processing and low levels of alertness (Barkley et al., 1990; Lahey, Schaughency, Frame, & Strauss, 1985; Lahey, Schaughency, Hynd, Carlson, & Piacentini, 1987; Nigg, Blasky, Huang-Pollock, Wilcutt, Hinshaw, & Pennington, 2002). However, the hypothesis that attention, EFs, vigilance, or processing speed deficits are core impairments in adult AD/HD requires further consideration (Weyandt & DuPaul, 2006).

There is ample evidence for the diagnostic continuity of AD/HD throughout the lifespan regardless of AD/HD subtype. It is estimated that 50% - 70% of children with AD/HD continue to manifest symptoms in adulthood (Barkley, 1998). AD/HD is estimated to affect 5% - 10% of children and 4% of adults worldwide (Faraone et al., 2000). Adults with AD/HD exhibit a pattern of psychological dysfunction, psychosocial disability, psychiatric comorbidity, and school failure that resembles features of childhood AD/HD (Biederman et al., 2006). Postsecondary students with AD/HD tend to have lower GPAs, are more likely to be on academic probation, and less likely to graduate from postsecondary education than their non-AD/HD peers (Heiligenstein, Guenther, Levy, Savins, Fulwiler, 1999; Murphy, Barkley, & Bush, 2002; Wolf, 2001). Additionally, postsecondary students with AD/HD experience greater psychological distress and employ fewer academic coping behaviours (e.g., time management, organizational skills, and monitoring personal stress) than non-AD/HD students (Kern, Rasmussen, Byrd, & Wittschen, 1999; Turnock, Rosen, & Kaminiski, 1998; Weyandt & DuPaul, 2006). Furthermore, Biederman et al. (2008) found that AD/HD adults with EFs
deficits had significantly poorer educational and vocational outcomes when compared to AD/HD adults without EFs impairments.

*Dyslexia*

Dyslexia is characterized by an unexpected reading difficulty in children and adults who otherwise possess the intelligence, motivation, and class instruction necessary for accurate and fluent reading (Shaywitz & Shaywitz, 2005). Dyslexic children and adults typically display difficulties in word recognition, grapheme-phoneme decoding, and spelling. A convergence of research has indicated that many of these difficulties result from a deficit in the phonological component of language (Lyon, Shaywitz, & Shaywitz, 2003). The view that a phonological deficit is the sole cognitive impairment in developmental dyslexia is difficult to reconcile considering that numerous studies have found that attention problems and dyslexia co-occur more frequently than explained by chance (Dykman & Ackerman, 1991; Gilger, Pennington, & Defries, 1992; Semrud-Clikeman, Biederman, Sprich, Krifcher, Norman, & Faraone, 1992; Shaywitz, Fletcher, & Shaywitz, 1994; Wilcutt & Pennington, 2000). Furthermore, research has demonstrated that adult dyslexics exhibit performance deficits on EFs tasks measuring cognitive set shifting and working memory (Brosnan et al., 2002; Swanson & Hseih, 2009; Vasic, Lohr, Steinbrink, Martin, Wolf, 2008; Weyandt et al., 1998). In addition to attention and EFs deficits, processing speed impairments commonly found in dyslexic children (e.g., Kirby, Georgiou, Martinussen, & Parrila, 2010) also extend to adults with dyslexia (Stoet, Markey, & Lopez, 2007).

Most word reading theories do not specify the attention and EFs processes involved, assuming that they are peripheral mechanisms that are not an integral part of the
reading process (Coltheart, Curtis, Atkins, & Haller, 1993; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Harm & Seidenberg, 1999; Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McCleland, 1989). However, Ans, Carbonnel, and Valdois (1998) have provided a theoretical account of how visual attention processes operate in reading. Additional support for the role of attention in reading is provided by LaBerge and Brown (1989) who found that competent word reading requires sustained attention for analysis of strings of letters and words. Furthermore, selective attention is critical for fast and accurate control of eye fixations during word reading (Inhoff, Pollatsek, Posner, and Rayner, 1989; Lachter, Forster, & Ruthruff, 2004; Lachter, Ruthruff, Lien, & McCann, 2006). Also, EFs are required for reading as they allocate attention to pertinent information that facilitates the reading process while inhibiting irrelevant or competing information (McCann, Remington, & Van Selst, 2000; Rayner & Pollatsek, 1989; Shaywitz & Shaywitz, 2008).

Developmental dyslexia is among the most common of learning disabilities with adult prevalence estimates ranging from 5% to 17% (Shaywitz, 1998; Stoet et al., 2007). The academic ramifications of dyslexia for postsecondary students include inaccurate and dysfluent word recognition, poor spelling skills, slow rates of reading, and poor reading comprehension. Dyslexic postsecondary students also employ immature and ineffective strategies to circumvent problematic word recognition and spelling abilities compared to age matched controls (Bruck, 1990, 1993; Kirby, Silvestri, Allingham, Parrila, & LaFave, 2008; Shaywitz & Shaywitz, 2005).
AD/HD with Comorbid Dyslexia

The overlap between AD/HD and dyslexia is substantial. The prevalence of dyslexia in individuals with AD/HD is significantly higher than would be expected by chance, with the rate of comorbidity falling between 25% and 40% (Dykman & Ackerman, 1991; Semrud-Clikeman et al., 1992). Conversely, 15% to 40% of individuals with dyslexia meet criteria for AD/HD (Wilcutt, Pennington, Olson, Chhabildas, & Huslander, 2005). Consequently, in AD/HD or dyslexia research it is important to investigate the contribution of each disorder to the obtained findings to establish what deficits are specific to AD/HD or dyslexia, and which result from the combination of both disorders (i.e., inclusion of a comorbid group). The preponderance of research in children indicates that core cognitive impairments associated with AD/HD and dyslexia contribute to the cognitive etiology of the comorbid group (Narhi & Ahonen, 1995; Wilcutt et al., 2001). The common etiology hypothesis (Wilcutt, Doyle, Nigg, Faraone, & Pennington, 2005) states that if attention, EFs, vigilance, or processing speed deficits are present in the comorbid group they should be essentially the sum of the deficits in both AD/HD and dyslexia alone. The mental health ramifications of comorbid AD/HD and dyslexia were examined by Crawford, Kaplan, and Dewey (2006) who found that this group of individuals displays poorer psychosocial health pertaining to quality of life when compared to individuals with either AD/HD or dyslexia.

Overview of Attention

Visual attention will serve as a lens through which to describe components of attention in more detail. Researchers have comprehensively investigated the anatomy, development, and cognitive correlates of vision, making it the most pertinent perceptual
system for the analysis of attention (Raz & Buhle, 2006). Posner and Raichle (1994) provided a theoretical account of visual attention in which there exist multiple networks each responsible for different aspects of attention. Each network operates as an organ system that has its own anatomy, neural circuitry, and cellular systems. Fan, McCandliss, Sommer, Raz, and Posner (2002) further refined this attention model by demonstrating that although the attention networks are independent systems they also co-operate and work closely together. The attention networks are termed alerting, orienting, and executive networks. Table 1 provides an overview of attention tasks described in this review.

Alerting Attention

Alerting attention refers to the preparedness to respond (Mezzacappa, 2004) and incorporates both phasic and tonic alertness components. Although both components contribute to alerting attention, Posner and Raichle (1994) primarily emphasize and expand on the role of phasic alertness; therefore, phasic alertness will be reviewed in this attention section while tonic alertness or vigilance will be discussed later in the non-executive functions section. Phasic alertness refers to the rapid mobilization of cognitive resources to process an unexpected stimulus (e.g., warning signal) and is a foundational form of attention on which other networks of attention bootstrap. The Attention Network Test (ANT; Fan et al., 2002) is a frequently used task that measures the efficiency of Posner and Raichle’s (1994) attention networks. The efficiency of the alerting network (i.e., phasic alertness) on the ANT (Fan et al., 2002) is measured by subtracting reaction time to a target in a cue condition that provides temporal but not location information from reaction time to a target in a non-cue condition. Neuroimaging studies have
Table 1.

*Cognitive Tasks Listed in Literature Review, Task Descriptions, and Citation(s) of a Study Using Task*

<table>
<thead>
<tr>
<th>Cognitive Domain</th>
<th>Task</th>
<th>Task Description</th>
<th>Citation(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Alerting Attention</em></td>
<td>Phasic Attention Warning Signal Task (e.g., Attention Network Test (ANT) alerting task)</td>
<td>This task measures how quickly an individual can attain maximum alertness by comparing reaction times for target selection in conditions with and without a warning signal</td>
<td>Booth et al. 2007</td>
</tr>
<tr>
<td><em>Orienting Attention</em></td>
<td>Exogenous Spatial Cueing Task</td>
<td>Spatial cueing tasks measure orienting attention by presenting an overt spatial cue (e.g., flashing cue) then comparing participant’s reaction time to targets either in the same position as the cue (valid condition) or in an alternative location (invalid condition).</td>
<td>Huang-Pollock &amp; Nigg, 2003</td>
</tr>
<tr>
<td></td>
<td>Endogenous Spatial Cueing Task (e.g., ANT orienting task)</td>
<td>Same as above except the spatial cues are symbolic in format (e.g., arrows)</td>
<td>Huang-Pollock &amp; Nigg, 2003</td>
</tr>
<tr>
<td><em>Executive Attention</em></td>
<td>Perceptual/Spatial Inhibition (e.g., ANT Flanker Task)</td>
<td>In the Flanker task participant’s reaction times in determining the direction of a central target surrounded congruent and incongruent flankers are compared.</td>
<td>Konrad et al. 2009</td>
</tr>
<tr>
<td></td>
<td>Cognitive Inhibition (e.g., Stroop Test)</td>
<td>In the Stroop test, participants must respond to the colour of ink (e.g., red) while ignoring the colour word (e.g., blue)</td>
<td>Van Mourik et al. 2008</td>
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<tr>
<td>Cognitive Domain</td>
<td>Task</td>
<td>Task Description</td>
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<tr>
<td><strong>Executive Functions – Inhibition of Prepotent Response</strong></td>
<td>Simple Measure (e.g., GO-NO/GO task)</td>
<td>Randomly alternating stimuli are presented (i.e., target and non-target visual designs). A participant is instructed to make a response when he or she sees the target design but not the non-target design. The target design is presented more often to create a prepotency toward responding.</td>
<td>Ossmann &amp; Mulligan, 2004</td>
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<td></td>
<td>Complex Measure (e.g., Stop Signal, Stop-Change Tasks)</td>
<td>Stimuli (e.g., an “X” and an “O”) are presented with the instruction to press a corresponding key as quickly as possible depending on which letter appears, creating a prepotent tendency to respond on most trials. On a minority of trials there is a signal to which the participant is not to respond. In the stop-change paradigm, the participant must make a different response when the signal appears, rather than no response.</td>
<td>Nigg, 2001</td>
</tr>
<tr>
<td><strong>Executive Functions – Set Shifting</strong></td>
<td>Attention/Perceptual Shifting (e.g., Card Sorting Task)</td>
<td>A participant sorts cards based on a specific dimension (e.g., shape) and receives positive or negative feedback related to their sorting choices. At a set point in the task, undisclosed to the participant, the sorting rule changes, so that a sorting rule that previously received positive feedback now receives negative feedback. The participant must then determine the new sorting rule (e.g., based on color) and sort accordingly.</td>
<td>Seidman, 2006; Weyandt et al. 1998</td>
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<td></td>
<td>Motor Response Shifting (e.g., Trail Making Test)</td>
<td>The Trail Making Test (B) requires the subject to switch between numbers (1-13) and letters (A-L). The subject must draw lines joining encircled numbers and encircled letters, alternately starting with 1 and ending with L, in correct sequence. Time taken to complete trail B (switching task) is the measure of motor set-shifting ability.</td>
<td>Murphy, 2001</td>
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<tr>
<td>Cognitive Domain</td>
<td>Task</td>
<td>Task Description</td>
<td>Citation(s)</td>
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<tr>
<td>Executive Functions –</td>
<td>Auditory Working Memory (e.g.,</td>
<td>In these tasks individuals must recall a sequence of information in reverse order</td>
<td>Vasic et al. 2008</td>
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<td>Working Memory</td>
<td>Backward Digit Span)</td>
<td>or after a delay in time.</td>
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<td></td>
<td>Visual-Spatial Working Memory (e.g.,</td>
<td>A participant must recall visual-spatial information after a short delay</td>
<td>Hervey et al. 2004</td>
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<td></td>
<td>Spatial Delayed Response Tasks)</td>
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<tr>
<td>Non-Executive Functions –</td>
<td>Continuous Performance Test (CPT) (</td>
<td>The CPT measures the ability to respond to an infrequent target over an extended</td>
<td>See et al. 1995</td>
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<tr>
<td>Vigilance (Tonic Attention)</td>
<td>simultaneous discrimination)</td>
<td>period of time. This is a comparative judgement task in which all the information</td>
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<td></td>
<td>Continuous Performance Test (CPT) (</td>
<td>needed to distinguish targets and non-targets is presented in the stimuli.</td>
<td>See et al. 1995</td>
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<tr>
<td></td>
<td>successive discrimination)</td>
<td>Same as above except a successive CPT requires absolute discrimination of targets</td>
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<td></td>
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<td>from a non-targets with a standard retained in working memory (e.g. detection of</td>
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<td></td>
<td></td>
<td>“X” targets from “O” non-targets)</td>
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<tr>
<td>Non-Executive Functions –</td>
<td>Simple Processing Speed (e.g., Simple</td>
<td>Simple reaction time tasks require ongoing attention to a single stimulus with a</td>
<td>Hervey et al. 2004</td>
</tr>
<tr>
<td>Processing Speed</td>
<td>Reaction Time Tasks)</td>
<td>single motor response. For example, a participant is shown a target digit and</td>
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<td>asked to circle the identical digit within a series of digits.</td>
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<tr>
<td></td>
<td>Complex Processing Speed (e.g., Complex</td>
<td>Participants are required to make a decision or association regarding a more</td>
<td>Hervey et al. 2004</td>
</tr>
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<td></td>
<td>Reaction Time Tasks)</td>
<td>complex stimulus with a single motor response. An example of this task is when a</td>
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<td>participant is shown a multi-digit target and asked to circle this same target</td>
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<td>within a series of digit sequences of equal length</td>
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</table>
reported specific activity in right hemisphere frontal and parietal brain regions when individuals employ phasic alerting. Also, the norepinephrine system, which stems from the locus coerulus of the midbrain, is critical to efficient phasic alertness (Posner & Rothbart, 2007). Developmentally, the alerting network matures throughout adolescence and into adulthood (Raz, 2004)

Orienting Attention

Orienting attention, the most studied attention network in Posner and Raichle’s (1994) model, is the ability to select specific information among multiple sensory stimuli (Raz, 2004). Orienting attention can be further delineated as overt or covert (i.e., with or without eye movements) and either exogenous (e.g., peripheral cues that draw attention to a specific location) or endogenous (e.g., processing symbolic cues such as a central arrow that points to target locations) (Treisman & Gelade, 1980). The ANT (Fan et al., 2002) indexes covert, endogenous orienting attention by measuring reductions in reaction time to a target following a cue which gives information on the location but not the timing of the target (Posner & Cohen, 1980).

Orienting attention is facilitated through biased neural competition. For example, orienting to a specific type of target (e.g., faces) results in amplification of neural activity where this computation is carried out in the brain (i.e., the fusiform face area) along with concurrent inhibition of irrelevant neural activity (Carmel & Bentin, 2002; Corbetta, Miezin, Dobmeyer, Shulman, & Petersen, 1991; Fuentes, 2004). The superior parietal cortex contributes to endogenous, covert attention while the frontal eye fields and superior colliculus are critical for exogenous, overt orienting (Posner & Rothbart, 2007). The cholinergic neurotransmitter system, which stems from the basal forebrain, has an
important role in orienting attention through its interaction with the parietal cortex (Raz, 2004). From a developmental perspective, orienting as measured by the ANT (Fan et al., 2002) appears to form as early as age four (Raz, 2004).

**Executive Attention**

Raz (2004) argued that the primary role of executive attention is to monitor and resolve conflict (e.g., through the use of inhibitory capabilities) between mental computations regardless of the modality of the stimuli. Consequently, executive attention is often deployed in situations involving decision making, error detection, or overcoming habitual responses.

Executive attention is commonly measured in tasks that involve conflict, such as the Stroop (Stroop, 1935) and Flanker (Eriksen & Eriksen, 1974) tasks. In the Stroop task, participants must respond to the colour of ink (e.g., red) while ignoring the colour word (e.g., blue) (Bush, Luu, & Posner, 2000). Flanker tasks involve conflict between a central target and surrounding flankers that may be congruent or incongruent with the target (Botvinick, Braver, Barch, Carter, & Cohen, 2001). In the ANT (Fan et al., 2002) flanker task, subtracting response times for congruent from incongruent target trials provides a measure of the executive attention network’s efficiency in conflict resolution (Raz & Buhle, 2006). Neuroimaging studies have identified the anterior cingulate cortex (ACC) and the dorsolateral prefrontal cortex (DLPFC) as two frontal lobe regions that are critical to the functioning of executive attention (Fan et al., 2002; Fan, Flombaum, McCandliss, Sommer, Raz, & Posner, 2003; see Fuster (2000) for a different point of view). The ACC and DLPFC are target areas of the ventral tegmental dopaminergic neurotransmitter system (Raz & Buhle, 2006). From a developmental perspective, adult performance levels
on executive attention tasks such as the Stroop and Flanker measures are not obtained until mid to late adolescence (Huizinga, Dolan, & vander Molen, 2006).

Overview of Executive Functions

Pennington and Ozonoff (1996) and Miyake, Freidman, Emerson, Witzki, and Howerter (2000) found three primary components of EFs: inhibition of prepotent responses, mental set shifting, and working memory. Although moderately correlated, these constituent components are separable constructs as they differentially predict performance on a variety of complex neuropsychological tasks (Fisk & Sharp, 2004; Huizinga et al., 2006). A review of research on EFs indicates at minimum 60 tasks that have been employed as measures of different aspects of EFs (Pennington & Ozonoff, 1996). Only the most common measures of EFs (i.e., continuous performance tests, Wisconsin Card Sorting Test, and digit span tasks) are elaborated upon below in reference to EFs component processes of inhibition, set shifting, and working memory. Refer to Table 1 for a description of EFs tasks described in the review.

Inhibition

Inhibition refers to the ability to deliberately inhibit dominant automatic or prepotent responses. Thus the essence of inhibition resides in the suppression of a response (Huizinga et al., 2006; Miyake et al., 2000). Inhibition impairments have been associated with a wide variety of neuropsychiatric disorders including AD/HD and dyslexia, therefore this EFs component has been examined extensively (Simmonds, Pekar, & Mostofsky, 2008). One of the challenges in examining inhibition is the multitude of tasks available to measure this construct. Additionally, many response inhibition tasks are confounded with working memory demands (Garon et al., 2008).
Factor analyses of inhibition tasks have consistently demonstrated that these tasks cluster into two distinct factors: simple and complex inhibition measures (Carlson & Moses, 2001; Murray & Kochanska, 2002). Simple inhibition tasks involve minimal working memory demands while complex inhibition measures require moderate working memory capabilities. An example of a simple inhibition measure is the GO-NO/GO task (Miyake et al., 2000). This type of inhibition task has two constituent stimuli: a GO stimulus and a NO/GO stimulus. Participants are instructed to respond rapidly (e.g., with the press of a key or button) to presentation of the GO stimulus only. Response inhibition is measured by the ability to withhold responding to the NO/GO stimulus. Commission errors on this task, responding to the NO/GO stimulus, are cited as evidence of disinhibition (Braet et al., 2008; Nigg, 2001). Typically, a GO-NO/GO task is weighted towards GO stimuli in order to build a prepotency to respond thereby increasing the inhibitory effort required to withhold responding to the NO/GO stimuli (Simmonds et al., 2008). Conversely, complex inhibition tasks may utilize multiple GO cues or involve frequent updating of stimulus-response associations which increase the working memory demands for task completion (Fassbender et al., 2004; Wager, Sylvester, Lacey, Nee, Franklin, & Jonides, 2005). One example of a simple inhibition task is the Test of Variables of Attention (TOVA; Greenburg, Kinschi, Corman, 2000), a continuous performance test (CPT) which utilizes a GO-NO/GO paradigm to measure inhibition. CPTs are reaction time tasks requiring the discrimination of predetermined targets from distracting non-targets over an extended period of time. Errors of commission (i.e., response to a non-target stimulus) are recorded by most CPTs and are considered a measure of disinhibition (Llorente, Amado, Voigt, Berreta, Fraley, & Lensen, 2001). Use of the TOVA is advantageous in comparison of
AD/HD and dyslexic populations on response inhibition efficiency as this test employs visual geometric figures as stimuli (other CPTs often use letter stimuli) thus minimizing the confound of letter knowledge and naming for dyslexic groups.

Functional Magnetic Resonance Imaging (fMRI) pertaining to performance on response inhibition tasks has consistently demonstrated frontal lobe activation (Mostofski et al., 2003; Rubia et al., 2001; Wager et al., 2005). More specifically, the simple format of the GO-NO/GO task, which allows examination of inhibition under conditions in which other cognitive processes are minimized, has been shown to activate the frontal cortex in both children and adults (Casey et al., 1997; Kiefer, Marzinzik, Weisbrod, Scherg, & Spitzer, 1998). Alternatively, fMRI studies of complex inhibition tasks, which demand more working memory resources, have shown wider activation patterns including both frontal and parietal brain regions (Simmonds et al., 2008). Developmentally, inhibitory control is found to increase throughout childhood and to reach adult levels of performance in early adolescence (Huizinga et al., 2006; Williams, Ponesse, Schachar, Logan, & Tannock, 1999)

*Set Shifting*

Set shifting is the ability to shift between mental states, operations, or tasks (Miyake et al., 2000). Set shifting performance was first demonstrated to be impaired in patients with frontal lobe damage by Milner (1963). Currently, set shifting deficits are found in a variety of disorders ranging from schizophrenia and Parkinson’s disorder to AD/HD and dyslexia (Everett, Lavoie, Gagnon, & Gosselin, 2001; Owen et al., 1993; Stemme, Deco, Busch, & Schneider, 2005). An important distinction about set shifting relates to the type of mental shift required; set shifting can occur at the
attention/perceptual or response levels. Attention/perceptual shifts involve perceiving different aspects of a stimulus while response shifting pertains to shifting motor responses (Dias, Robbins, & Roberts, 1996; Nagahama, Kukuyama, & Shibasak, 2002). Research has indicated that attention/perceptual and response shifting are dissociable processes with the former shift type activating lateral prefrontal brain regions while the latter shift type engages medial prefrontal areas (Rushworth, Walton, Kennerley, & Bannerman, 2004; Slyvester et al., 2003).

The Wisconsin Card Sorting Task (WCST; Heaton, 1981) and its shortened version, the WCST-64 (Kongs, Thompson, Iverson, & Heaton, 2000), are psychometrically equivalent attention/perceptual set shifting tasks with extensive clinical and research use (Axelrod, Greve, Goldman, 1994; Butler, Retzlaff, & Vanderploeg, 1991; Robinson, Kester, Saykin, Kaplan & Gur, 1991). For both versions of the WCST a participant sorts cards based on a specific dimension (e.g., shape) and receives positive or negative feedback related to their sorting choices. At a set point in the task, undisclosed to the participant, the sorting rule changes, so that a sorting that previously received positive feedback now receives negative feedback. The participant must then determine the new sorting rule (e.g., based on color) and sort accordingly. Shifting failures appear as perseverative errors or continuing to respond according to the previous set of rules (Anderson, 2002). Previous studies have indicated that a key symptom of frontal lobe impairment is perseverating behaviour or repeating the same response in conditions where this response is no longer appropriate (Luria, 1966).

Posner and Raichle (1994) found that set shifting performance is dependent upon frontal lobe functioning, specifically the anterior cingulate cortex. Furthermore,
neuroimaging studies utilizing the WCST have consistently reported metabolic or neural activations primarily in the frontal or prefrontal cortical regions (Barcelo, Escera, Corral, & Perianez, 2006; Lie, Specht, Marshall, & Fink, 2006; Gonzalez-Hernandez et al., 2002; Gonzalez-Hernandez, Cedeno, Pita-Alcorta, Galan, Aubert, & Figueredo-Rodriguez, 2003). From a developmental perspective, set shifting flexibility continues to improve until adolescence (Huzinga, et al., 2006).

**Working Memory**

Working memory, a limited capacity system, is defined as the ability to maintain and manipulate information over brief periods of time (Best, Miller, & Jones, 2009). The most influential account of working memory is that of Baddeley and Hitch (1974). Extensive neuropsychological, neuroanatomical, neuroimaging, and factor analytic investigations have supported the Baddeley and Hitch (1974) working memory model. This model views working memory as a multicomponent system consisting of phonological and visual-spatial subsystems. Within these individual subsystems, there is passive short-term memory storage of modality-specific information (i.e., information held in sequential, untransformed fashion), and the central executive that provides oversight of short-term storage abilities. The central executive provides active manipulation of information in short term memory and has been referred to as the working memory component of the model (Baddeley, 1986; Baddeley & Logie, 1999). More recently, the episodic buffer was added as a further component of this working memory model (Baddeley, 2000). The episodic buffer, a short term memory storage system controlled by the central executive, holds multi-modal information within time sequences such as chronological order (Baddeley, 2007). Although research has
demonstrated that short-term memory and working memory are correlated, distinct anatomical sites are associated with each type of memory. The phonological and visual-spatial short-term memory systems have been connected to posterior brain regions whereas working memory has associations with the frontal cortex (Baddeley, 2002).

Backward span tasks are commonly used to assess working memory. In these tasks, individuals must recall a sequence of information in reverse order. Auditory versions of the task include backward recall of word and digit sequences. In neuroimaging studies, backward span tasks have been found to activate ventrolateral and dorsolateral prefrontal cortex regions (Luciana, Conklin, Hooper, & Yarger, 2005). Spatial delayed response tasks are also often used to measure visual-spatial working memory capacity. An example of such a task is the Visual Matrix subtest of the Swanson Cognitive Processing Test (SCPT; Swanson, 1996) in which a participant must recall symbols located on a matrix after a short delay during which the respondent answers a simple question. The length of the delay and amount of information to be maintained are two factors that can increase working memory demands for this task (Luciana et al., 2005). Spatial delayed response tasks have been strongly associated with the ventrolateral and dorsolateral prefrontal cortex in both human and primate studies (Funahashi, Bruce, Goldman-Rakic, 1989; Luciana et al., 2005).

Working memory capacity has been found to gradually develop throughout childhood and into adolescence (Brocki & Bohlin, 2004; Gathercole, Pickering, Ambridge, & Wearing, 2004). Short-term and working memory components are in place by the age of six; however, the capacity of each component increases linearly to adolescence (Gathercole et al., 2004).
Related Non-Executive Cognitive Functions

Vigilance

The term vigilance describes the ability to sustain attention to a task for a period of time (Davies & Parasuraman, 1982; Parasuraman, 1998) and is most closely related to Posner and Raichle’s (1994) tonic alertness component of the alerting attention network (Oken, Salinsky, & Elsas, 2006). Vigilance performance declines over time and this is known as vigilance decrement (Mackie, 1984). Typically, decrement appears in the first 15 minutes of a task; if task demand conditions are high, vigilance decrement can appear as rapidly as five minutes (Helton et al., 2007; Rose, Murphy, Byard, & Zikzad, 2002).

Signal detection theory has been adapted for use in measuring vigilance (Green & Swets, 1966; MacMillan & Creelman, 1991). In this theoretical model, vigilance decrement is indexed as a decline in the percentage of correctly detected signals over time (i.e., through the calculation of errors of omission to target stimuli). Two important determinants of signal detection vigilance measures are the distinction between simultaneous and successive discrimination tasks and signal event rate (Warm, 2008). Successive discrimination requires an individual to compare current input with a standard retained in working memory to separate target and non-target signals. Conversely, simultaneous discrimination refers to a vigilance task in which all the information needed to distinguish targets from non-targets is presented in the stimuli themselves. Consequently, successive discrimination vigilance tasks are far more memory capacity demanding than simultaneous vigilance tasks (Caggiano & Parasuraman, 2004). Event rate refers to the presentation rate of target to non-target signals. Vigilance resource allocation is greater when there is a high event rate (i.e., target appears more frequently),
thus vigilance decrement is more pronounced in the context of a high event rate (See, Howe, Warm, & Dember, 1995). An example of a vigilance task is the Test of Variables of Attention (TOVA; Greenberg et al., 2000). The TOVA is a simultaneous discrimination task that requires participants to respond to rare targets in the presence of more frequent non-targets over an extended period of time. This test measures vigilance decrement through the calculation of omission errors (i.e., subject does not respond to a designated target) in both stimulus frequent and infrequent modes (i.e., high and low event rates respectively). Refer to Table 1 for an overview of vigilance tasks described in this review.

Integral anatomical components associated with vigilance include the locus coreleus brain region and the norepenephrine neurotransmitter system. From a developmental perspective, vigilance improves in efficiency throughout adolescence and into adulthood (Raz, 2004).

**Processing Speed**

Processing speed is defined by Carroll (1993) as the speed of cognitive processes in the execution of tasks when high mental efficiency (i.e., attention and focused concentration) is required. Salthouse (1994) indicated that processing speed is limited in quantity, enables or enhances cognitive performance such that performance increases as greater processing speed resources become available, and is relevant to a wide variety of cognitive processes. Hale (1990) and Ferguson and Bowey (2005) found that developmental increases in processing speed underlie all facets of cognitive development. Also, processing speed tasks have been consistently found to be significantly associated with measures of attention and EFs (Kail & Salthouse, 1994).
Current processing speed research indicates that in order to comprehensively examine this cognitive construct both simple and complex reaction time tasks are required (Chiaravalloti, Christodoulou, Demaree, & Deluca, 2003). Simple processing speed tasks require ongoing attention to a single stimulus with a single motor response. For example, a participant is shown a target digit and asked to circle the identical digit within a series of digits (Kirby, 2005). In complex processing speed tasks participants are required to make a decision or association regarding a more complex stimulus with a single motor response. An example of this task is when a participant is shown a multi-digit target and asked to circle this same target within a series of digit sequences of equal length (Kirby, 2005). Refer to Table 1 for a description of processing speed tasks elaborated on in this review.

Luciana et al. (2005) found that there is limited research examining the neural basis of processing speed. It has been found that individual differences in processing speed may be due to differences in white matter physiology, specifically mylenation. Increased mylenation would result in faster (or less variable) nerve conduction which would result in greater processing speed (Birren & Fischer, 1995; Luciana et al., 2004). Kail and Salthouse (1994) concluded that the development of processing speed follows a consistent trajectory whereby speed increases throughout childhood and adolescence, reaches a peak in young adulthood, and declines slowly thereafter.

Integration of Attention and Executive Functions

There is research to support both unitary and componential views of EFs. Miyake et al. (2000) argued that a common mechanism underlies important developmental changes to the dissociable EFs components of inhibition, set shifting, and working
memory. The attention system, which supports additional control over thoughts and behaviours, has been postulated as the common mechanism. The ability to maintain and orient attention and focus on a task while ignoring irrelevant information (i.e., executive attention) have been argued to be necessary first steps in goal directed behaviour (Akshoomoff, 2002; Sarter, Gehring, & Kozak, 2006). Therefore, attention networks, such as described by Posner and Raichle (1994), would appear to play an integral role in the development of EF components.

Research on the development of EFs in children indicates that the maturation of attention processes forms the foundation for EFs abilities during the preschool period. Sethi, Mischel, Aber, Shoda, and Rodriguez (2000) found that differences in attention during infancy predict later ability to inhibit responses. Also, varying the attention demands in set shifting tasks significantly affects performance in this cognitive domain for young children (Zelazo, Muller, Frye, & Marcovitz, 2003). Furthermore, Epsey and Bull (2005) reported that performance in attention control tasks has been found to differentiate preschoolers with low and high working memory span.

Baddeley (1986), Norman and Shallice (1988), and Garon et al. (2008) argued that EF components do not appear to develop in parallel but rather upon already existing attention networks. For example, Garon et al. (2008) found that the ability to orient attention and achieve a state of focused attention (alerting processes) is critical for the maturation of individual EFs components. Consequently, an important recommendation for future research investigating cognitive deficits in AD/HD and/or dyslexia would include concurrent examination of both attention networks and EFs components to delineate both distal and proximal cognitive impairments associated with these disorders.
Overview of Attention, Executive Functions, and Related Non-Executive Cognitive Deficits in AD/HD

Attention Deficits

A number of studies have investigated attention deficits associated with AD/HD using Posner and Raichle’s (1994) taxonomy of attention networks. Sergeant, Guerts, Huijbregts, Scheres, and Oosterlaan (2003) theorized that energetic factors (e.g., alerting attention) are the core cognitive deficits in AD/HD. They stated that individuals with AD/HD exhibit deficits in energetic maintenance and allocation of resources which then lead to secondary deficits in executive functions. AD/HD alerting attention deficits were substantiated through a meta-analysis by Huang-Pollock and Nigg (2003) which found that AD/HD children displayed slower and more variable alerting response times when compared to non-AD/HD children (effect size discrimination was not reported).

Regarding orienting attention deficits associated with AD/HD, Berger and Posner (2000) found that there is little empirical evidence to support the role of orienting network in AD/HD pathology. The strongest cognitive deficits associated with AD/HD and related to Posner and Raichle’s attention model have been reported for the executive attention network, particularly in conflict or interference tasks such as the Stroop or Flanker tasks (Sergeant et al., 2003). Van Mourik, Oosterlaan, and Sergeant (2005) conducted a meta-analysis of 17 studies employing AD/HD children, adolescents, and adults compared to non-disabled peers to assess the effect size discrimination of an executive attention task (i.e., Stroop Test). The effect size of the Stroop interference score in differentiating AD/HD individuals from their non-ADHD peers was small ($d = .35$). However, Nigg (2005) reviewed three studies that examined the ability of the Stroop interference score to
differentiate AD/HD boys from a non-AD/HD cohort and found a medium effect size discrimination (composite $d = .65$).

Studies utilizing the Attention Network Test (ANT; Fan et al., 2002) with AD/HD children (9-12 years of age) have shown consistent deficits in alerting and executive attention networks when compared to non-AD/HD children of equivalent age (Adolfsdottir, Sorenson, & Lundervold, 2008; Booth, Carlson, & Tucker, 2007; Konrad et al., 2009; Johnson et al., 2008). A search for adult AD/HD research employing the ANT revealed that no peer reviewed studies have been published.

Executive Functions Deficits

The small body of work examining EFs in AD/HD preschool children (3-5 years of age) compared to other preschoolers indicates that AD/HD children display inhibitory and working memory deficits (Byrne, DeWolfe, & Bawden, 1998; Mariani & Barkley, 1997; Valera & Seidman, 2006). Studies with older AD/HD children (5-7 years of age) report similar EFs impairments (Berlin & Bohlin, 2002; Hanisch, Konrad, Gunther, & Hepertz-Dahlmann, 2004; Kalff et al., 2002). The most extensively studied segment of AD/HD children are elementary school aged children (6-12 years of age). Studies with this group of AD/HD children have consistently demonstrated weak performance on inhibition, set shifting, and working memory tasks (for reviews see Barkley, Grodzinsky & DuPaul, 1992; Pennington & Ozonoff, 1996; Seidman, Doyle, Fried, Valera, Crum, & Matthews, 2004). Despite the plethora of studies on elementary children with AD/HD, there is limited research on teenagers with this disorder. The general consensus of this research however indicates that the executive dysfunctions that characterize this disorder in childhood extend to the teenage years (Fischer, Barkley, Edelbrock, & Smallish, 1990;
Response inhibition is considered to play a critical role in AD/HD. Barkley (1997) has theoretically linked the ability to inhibit responses to various EFs impairments in children and adults with AD/HD. Hervey, Epstein, and Curry (2004) reviewed 33 studies in their meta-analysis on cognitive deficits associated with AD/HD adults (18 years of age and older) and found that errors of commission on continuous performance tests (CPT), an index of disinhibition, displayed a moderate effect size ($d = 0.63$) in discriminating AD/HD adults from non-AD/HD adults. Furthermore, Hervey et al. (2004) found that a high event rate as opposed to a low event rate on a CPT was more effective in discriminating adults with AD/HD from non-AD/HD adults. Boonstra, Oosterlaan, Sergeant, and Buitelaar (2005) reviewed 13 studies comparing adults with AD/HD to non-AD/HD adults on CPT errors of commission and found a similar effect size ($d = 0.64$) discriminating between these groups. Woods, Lovejoy, and Ball (2002) reviewed 35 AD/HD adult studies and found that CPT errors of commission in this age group were consistent with the pediatric and adolescent literature in demonstrating inhibition deficits. Despite the consistent findings of significant errors of commission on CPTs for adults with AD/HD, a potential confound associated with the cited studies is that they seldom indicate whether the CPT tasks employed were simple or complex measures. Previous research (Carlson & Moses, 2002; Murray & Kochanska, 2002) has found that complex CPTs compared to simple CPTs demand more cognitive resources (e.g., working memory) for task completion and as such could affect research findings.
The Wisconsin Card Sorting Task (WCST; Heaton, 1981) is considered in the cognitive literature as one of the premier measures of set shifting (Seidman & Bruder, 2003). More specifically, the perseveration score on the WCST is a traditional measure of the inability to flexibly shift cognitive set (Koren et al., 1998). Research has demonstrated that the WCST perseveration score displays adequate discrimination in differentiating children with AD/HD from non-AD/HD peers (Barkley et al., 1992); however, in a review of studies on AD/HD adults, Siedman (2006) found only one study indicating WCST set shifting deficits while seven studies reported normal WCST set shifting abilities. Consistent with Seidman (2006), the Hervey et al. (2004) meta-analysis reported trivial effect sizes ($d = 0.12$) for the WCST perseveration score in discriminating AD/HD adults from non-AD/HD adults. Mahone et al. (2002) argued that the composition of the AD/HD sample is a crucial factor in determining whether the WCST perseveration score is effective in discriminating AD/HD from non-AD/HD adults. Mahone et al. (2002) found that diagnostically-referred AD/HD samples as opposed to self- or questionnaire-referred participants more consistently demonstrated set shifting deficits on the WCST.

Hervey et al. (2004) found that AD/HD adults have working memory deficits relative to non-AD/HD controls. In this meta-analysis, verbal working memory as measured by Backward Digit Span (Weschler, 1994), exhibited a small effect size ($d = 0.31$) discriminating AD/HD adults from non-AD/HD adults. Conversely, AD/HD adults demonstrated no significant performance difficulties on visual-spatial working memory tasks (e.g., memory of visual figures) ($d = 0.12$) when compared to non-AD/HD adults. The results are consistent with a deficit in the functioning of the phonological loop but not the visual-spatial sketchpad. A review of AD/HD adult studies by Boonstra et al.

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(2005) replicated the Hervey et al. (2004) findings. Despite the cited findings, theoretical and empirical research indicates that a variety of factors, such as attention and inhibition deficits or poor memory strategy selection may lead to memory difficulties in AD/HD adults (Hervey et al., 2004). Hervey et al. (2004) prefaced their results by stating that the findings of memory deficits must be replicated controlling for attention and/or inhibition abilities.

Related Non-Executive Functions Cognitive Deficits in AD/HD

Vigilance Deficits

The importance of examining vigilance in adult AD/HD populations was reinforced by Biederman, Mick, and Faraone (2000) who found that although symptoms of hyperactivity and impulsivity may wane with age, symptoms of inattention, which are closely associated with vigilance deficits, are more likely to remain stable across the lifespan. Traditionally, vigilance is measured by errors of omission on CPTs which reflect instances when an individual is not attending to target stimuli. In their meta-analysis of adult AD/HD research, Hervey et al. (2004) and Boonstra et al. (2005) found that the range of effect sizes across studies discriminating adult AD/HD samples from non-AD/HD cohorts on CPT errors of omission was in the medium to large range ($d = 0.50$ and $d = 0.76$ respectively). Two further studies found that AD/HD adults demonstrated greater errors of omission compared to control groups on the TOVA continuous performance test. Weyandt, Mitzlaff, and Thomas (2002) reported that AD/HD postsecondary students exhibited more errors of omission on the TOVA compared to non-AD/HD students. Forbes (1998) demonstrated that AD/HD adults displayed more errors of omission on the TOVA than a non-AD/HD adult control group. Berger and Posner
(2000) commented that relatively consistent findings have emerged in studies examining AD/HD adults and CPT errors of omission which indicate difficulty in the regulation of vigilance. What is lacking in the vigilance literature is elaboration of the type (i.e. successive or simultaneous) of CPT utilized in research. For example, if a successive CPT as opposed to a simultaneous CPT is employed, working memory abilities should be a controlled covariate. Additionally, CPT event rates must be stated explicitly because low and high event rates demand different levels of vigilance resources and as such could influence whether vigilance decrements are observed.

*Processing Speed Deficits*

In their review of the limited processing speed research with adult AD/HD groups, Shanahan et al. (2006) reported that processing speed impairments are evident across studies. However, the Hervey et al. (2004) meta-analysis found the effect sizes differentiating adult AD/HD samples from non-AD/HD controls on processing speed measures (i.e., both simple and complex tasks) to be in the small range. The Wood et al. (2002) review of adult AD/HD research indicated that the processing speed index of the Wechsler Adult Intelligence Scale – Third Edition (WAIS-III; Wechsler, 1994) displayed mixed results in distinguishing AD/HD adults from non-AD/HD adults (Jenkins et al., 1998; Seidman et al., 1995). With the exception of the Hervey et al. (2004) meta-analysis, the type of processing speed task (i.e., simple vs. complex) was not specified in this body of research. Hervey et al. (2004) stated that complex as opposed to simple processing speed tasks demand more processing speed resources; thus they are more likely to demonstrate processing speed deficits. The lack of processing speed task specificity represented in research and the dearth of studies employing processing speed tasks with
adults hinders the synthesis of research on processing speed and adult AD/HD populations.

Summary of Attention, Executive Functions, and Related Non-Executive Functions Deficits Associated with AD/HD

Studies examining attention deficits in AD/HD children have reported consistent alerting and executive attention network impairments (refer to Table 2). The limited studies on ADHD adults replicate these findings. Research utilizing the Attention Networks Test (Fan et al., 2002), a computer based reaction time task specifically designed to measure Posner and Raichle’s (1994) three networks of attention, has also reported alerting and executive attention deficits in AD/HD children. Research employing the ANT with AD/HD adults has not been undertaken. Research on EFs impairments in AD/HD children indicates that inhibition set shifting and verbal/visual-spatial deficits are consistently displayed. The research literature is less conclusive regarding EFs deficits in AD/HD adult samples (see Table 2). Research with AD/HD adults indicates moderate to large deficits in response inhibition as demonstrated on CPTs, mixed results pertaining to set shifting impairments, and verbal as opposed to visual-spatial working memory deficits. There are consistent findings attesting to moderate CPT vigilance deficits for AD/HD adults. The few studies on processing speed have indicated that impairments in this cognitive domain have not been found across all AD/HD adult studies.
Table 2.  

*Summary of Attention and EFs Deficits in Postsecondary Students and Adults with AD/HD or Dyslexia*

<table>
<thead>
<tr>
<th>Disorder</th>
<th>Cognitive Etiology</th>
<th>Illustrative Data</th>
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</thead>
<tbody>
<tr>
<td><strong>Attention Deficit Hyperactivity</strong></td>
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<tr>
<td>Disorder (AD/HD)</td>
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<tr>
<td>Alerting</td>
<td></td>
<td>Booth et al., 2007*; Beyer et al., 2000*; Huang-Pollock et al., 2003*; Johnson et al., 2008*; Sergeant et al., 2003</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Executive</td>
<td></td>
<td>Beyer et al., 2000*; Konrad et al., 2009*; Johnson et al., 2008*; Nigg, 2005*; Van Mourik et al., 2008</td>
</tr>
<tr>
<td>Inhibition</td>
<td></td>
<td>Barkley, 1997; Boonstra et al., 2005; Hervey et al., 2004; Woods et al., 2002</td>
</tr>
<tr>
<td>Set Shifting</td>
<td></td>
<td>Seidman, 2006</td>
</tr>
<tr>
<td>Working Memory</td>
<td></td>
<td>Boonstra et al., 2005; Hervey et al., 2004</td>
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<tr>
<td>Vigilance</td>
<td></td>
<td>Boonstra et al., 2005; Forbes, 1998; Hervey et al., 2004; Weyandt et al., 2002</td>
</tr>
<tr>
<td>Processing Speed</td>
<td></td>
<td>Hervey et al., 2004; Shanahan et al., 2006</td>
</tr>
<tr>
<td>Dyslexia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orienting</td>
<td></td>
<td>Brannan et al., 1978; Buckholz et al., 2007; Facoetti et al., 2000, 2001, 2003*; Iles et al., 2000; Roach et al., 2004</td>
</tr>
<tr>
<td>Executive</td>
<td></td>
<td>Bednarek et al., 2004*; Brosnan et al., 2002; Buckholz et al., 2007; Hari et al., 1999</td>
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<tr>
<td>Set Shifting</td>
<td></td>
<td>Weyandt et al., 1998</td>
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<tr>
<td>Working Memory</td>
<td></td>
<td>Brosnan et al., 2002; Savage et al., 2007; Smith-Spark et al., 2003; Swanson et al., 2009; Vasic et al., 2008</td>
</tr>
<tr>
<td>Processing Speed</td>
<td></td>
<td>Bresnitz et al., 2003; Shanahan et al., 2006; Stoet et al., 2007; Stodley et al., 2006</td>
</tr>
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</table>

*Note:* * research with children (listed due to limited adult studies).
Attention, Executive Functions, and Related Non-Executive Functions Cognitive Deficits in Dyslexia

There is general consensus that the brain structures of individuals with dyslexia differ from those of non-dyslexics. Studies of dyslexic children and adults have reported anomalies in the left posterior regions of the brain which are associated with language functions (Duffy, Denckla, Bartels, & Sandini, 1980; Eckert, 2004; Paulescu et al., 1996; Rumsey et al., 1994). Further differences in brain anatomy for dyslexic children have also been reported in medial/frontal lobe regions (through EEG and ERP studies) and in supplementary motor areas and the premotor cortex (through PET recordings) (Eckert, 2004; Paulescu et al., 1996). Neuropsychological and cognitive research with dyslexic children has substantiated the cited anatomical findings by reporting attention and EFs impairments in addition to phonological processing deficits.

Attention Deficits

A review of literature based on Posner and Raichle’s (1994) attention network model revealed only one previous study examining alerting attention performance in dyslexic children. Bednarek et al. (2004) found no evidence of alerting attention impairments in their dyslexic sample of children. Orienting attention deficits have been the most consistently demonstrated attention impairment found in dyslexic children. Valdois, Bosse, and Tainturier (2004) suggested that dyslexic children have anomalies in orienting attention because they tend to analyze visual patterns globally rather than in a focused mode. Research supporting poor orienting attention in dyslexic children has been found on spatial cueing tasks (Bucholz & Aimola-Davies, 2007; Facoetti et al., 2003; Facoetti, Paganoni, & Lorusso, 2000; Facoetti & Molteni, 2001). Spatial cueing tasks test
the ability to covertly orient attention by presenting a spatial cue followed by a target either in the same position as the cue (valid condition) or in an alternative location (invalid condition). Individuals with normal orienting attention exhibit a cue effect for this task: response times in the valid cue condition are faster than in the invalid condition. The few studies of executive attention performance in dyslexic children have indicated a pattern of problematic performance on flanker tasks when compared to age matched non-dyslexic children (Bednarek et al., 2004; Brosnan et al., 2002; Bucholz & Aimola-Davies, 2007). A drawback to the cited findings is that most studies measuring attention performance in dyslexic children used small samples of children. The results from these limited studies are in need of replication on larger samples of dyslexic children.

In the only study located examining alerting attention performance in adult dyslexics, Bucholz and Aimola-Davies (2007) found no alerting performance deficits in dyslexic adults when compared to non-dyslexic adults. Replicating the results found in research with dyslexic children, dyslexic adults have demonstrated orienting attention impairments on spatial cueing tasks (Brannan & Williams, 1987; Bucholz & Aimola-Davies, 2007; Roach & Hogben, 2004; Iles, Walsh, & Richardson, 2000). Mirroring the literature concerning dyslexic children, there is evidence of executive attention deficits in dyslexic adults, difficulties with interference or response competition control when performing a task (Brosnan et al., 2002; Buckholz & Aimola-Davies, 2007; Hari, Valta, & Utela, 1999). A potential confound for all of the noted attention results in dyslexic adults is sample composition. Research has demonstrated that attention problems and dyslexia co-occur more frequently than explained by chance (Dykman & Ackerman, 1991; Gilger et al., 1992; Semrud-Clikeman et al., 1992; Shaywitz et al., 1994; Wilcutt &
Pennington, 2000). Sample inclusion criteria excluding comorbid attention deficits were not employed in the majority of the cited studies demonstrating attention deficits in dyslexic adults. Therefore, attention impairments found in dyslexic adults may be the result of this confound as opposed to inherent attention processing deficits.

**Executive Functions Deficits**

The literature review related to inhibition impairments in dyslexic children demonstrated mixed results. Several studies reported that dyslexic children performed poorly on CPTs measuring response inhibition (Tarnowski, Prinz, & Nay, 1986; Wilcutt et al., 2001). However, Taroyan, Nicolson, and Fawcett (2007) questioned whether children with dyslexia would show CPT inhibition deficits in the absence of AD/HD symptoms. With a small group of dyslexic adolescents, screened to exclude AD/HD symptoms, Taroyan et al. (2007) found no evidence of CPT response inhibition impairments.

A review of research on set shifting deficits in dyslexic children also indicated mixed results. Narhi, Rasanen, Metsapelto, and Ahonen (1997) and Kelly, Best, and Kirk (1989) reported that dyslexic children in comparison to non-dyslexic children exhibited set shifting deficits. However, employing more rigorous sample selection (i.e., dyslexic children were screened to exclude AD/HD characteristics), Helland and Asbjørnsen (2000) found that dyslexic children did not display a significantly higher number of perseverative errors on the WCST than a control group. Furthermore, Reiter, Tucha, and Lange (2005) using a card sorting task similar to the WCST found that dyslexic children performed better than controls (i.e., made fewer perseverative errors).
Working memory is the most extensively studied EF in dyslexic children. There is strong support for working memory deficits in dyslexic children when compared to non-dyslexic children (e.g., Chiappe, Hascher, & Siegel, 2000; Swanson & Hsieh, 2009; Wilcutt et al., 2001). More specifically, dyslexic children tend to display consistent difficulties with verbal working memory span tasks that measure phonological loop storage capacity (Helland & Asbjornsen, 2004; Roodenrys & Stokes, 2001; Wilcutt et al., 2005). There are conflicting findings as to whether working memory impairments in dyslexic children extend more generally to the visual-spatial sketchpad (Smith-Spark, Fisk, Fawcett, & Nicolson, 2003; Swanson & Hsieh, 2009; Jeffries & Everatt, 2004).

There are relatively few studies of EFs performance in adults with dyslexia. With respect to CPT response inhibition performance and as noted previously, Taroyan et al. (2007) found no significant differences between a group of adolescent dyslexics (i.e., mean age of 16 years and with no AD/HD symptomatology) compared to age equivalent non-dyslexic controls. Similarly, Weyandt et al. (1998) found no response inhibition difficulties for a group of dyslexic postsecondary students when compared to age-and education-matched controls on the TOVA CPT. Due to the association of attention deficits and dyslexia, there is a critical need for additional studies utilizing more rigorous sample inclusion criteria (i.e., exclusion of individuals with comorbid attention deficits) to substantiate the limited findings reviewed.

A literature review on set shifting performance in adults with dyslexia revealed only one study. Weyandt et al. (1998) employing the WCST found that a postsecondary dyslexic group displayed a significantly higher number of perseverative errors (reflective of set shifting flexibility difficulties) when compared to non-dyslexic postsecondary
students. A confound to these findings is the use of dyslexic adults who had not been adequately screened to exclude comorbid attention deficits. Replication of this study’s findings utilizing postsecondary dyslexic students without attention deficits is critical to evaluate whether a pure dyslexic sample experiences set shifting deficits.

Similar to EFs research with dyslexic children, working memory is the most examined EFs domain in adults with dyslexia. There is broad consensus that dyslexic adults experience verbal working memory deficits as measured by Backward Digit Span tasks (e.g., Vasic et al., 2008; Brosnan et al., 2002). Swanson and Hsieh (2009) in their meta-analysis of adult dyslexic research, found a moderate to large effect size \( d = 0.62 \) discriminating dyslexic adults from non-dyslexic controls on verbal working memory measures with phonological awareness performance employed as a covariate. Although there is some support for visual-spatial working memory deficits in dyslexic adults (Smith-Spark et al., 2003; Swanson, 1999), the magnitude of visual-spatial deficits as reported by Swanson and Hseih (2009) is in the low range \( d = 0.39 \). Savage, Lavers, and Pillay (2007) argued that when dyslexic samples are defined narrowly, excluding broad language and comorbid attention deficits, specific verbal working deficits as opposed to visual-spatial working memory impairments are evidenced. Therefore the conflicting findings of which component(s) of working memory are impaired in dyslexic adults may be contingent upon how dyslexic samples are selected.

Related Non-Executive Cognitive Functions Deficits in Dyslexia

*Vigilance and Processing Speed Deficits*

A review of vigilance research on dyslexic children and adults produced only one relevant study. Taroyan et al. (2007) found that dyslexic adolescents displayed no
vigilance deficits (i.e., CPT errors of omission) compared to a non-dyslexic control group. Research on processing speed has found that dyslexic children exhibit deficits in this cognitive domain both on linguistically based processing speed measures and on tasks thought to be less dependent on linguistic abilities (Catts, Gilespie, Loenard, Kail, & Miller, 2002; Wilcutt et al., 2005). The very limited research on adults with dyslexia replicates these findings. Several studies have found that both adolescent and adult dyslexics process information in both auditory and visual modalities at a slower rate than normal readers (Breznitz & Misra, 2003; Shanahan et al., 2006; Stoet et al., 2007; Stodley & Stein, 2006). From the research cited on processing speed, there is a need for further research with adult dyslexics utilizing both simple and complex processing tasks to further elaborate the specificity of deficits. Previous research has also indicated that dyslexic adults exhibit naming speed deficits (Chiappe, Stringer, Siegel, & Stanovich, 2002; Vukovic, Wilson, & Nash, 2004). Naming speed, also known as Rapid Automatized Naming, refers to the speed at which individuals can name sets of stimuli (Wolf, O’Rourke, Gidney, Lovett, Cirino, & Morris, 2002). There is considerable debate over what constitutes naming speed (see Kirby et al., 2010); however, Kail, Hall, & Caskey (1999) have argued that general processing speed is an essential component of naming speed. If general processing speed is found to be a critical cognitive factor in naming speed, naming speed tasks could provide an alternate mode of examining processing speed performance in dyslexic adults.
Summary of Attention, Executive Functions, and Related Non-Executive Functions Deficits in Dyslexia

The review of literature pertaining to attention deficits indicates that both orienting and executive attention impairments are evident for dyslexic children and adults (refer to Table 2). Research with dyslexic children indicates mixed results related to inhibition and set shifting deficits, and strong support for specific verbal working memory impairments (see Table 2). A review of the adult dyslexic literature found no support for inhibition deficits and limited support for set shifting difficulties. Similar to the findings for dyslexic children, specific verbal working memory deficits were displayed in adults with this disorder. The lack of research on vigilance performance in dyslexic adults precludes a summary related to deficits in this cognitive domain. Research examining processing speed in dyslexic adults replicates children’s findings of impairments in this domain (Refer to Table 2). The cited findings of attention and EFs deficits for dyslexic children and adults must be prefaced however with the following caveats. The dearth of studies examining attention, EFs, vigilance, and processing speed in adult dyslexic populations together with vague sample inclusion criteria (specifically the failure to exclude comorbid attention deficits and disorders) limits the generalizability of the findings.

Attention, Executive Functions, and Related Non-Executive Cognitive Functions Deficits in AD/HD with Comorbid Dyslexia

The majority of research pertaining to the cognitive deficits exhibited by children with comorbid AD/HD and dyslexia (comorbid group) supports the common etiology hypothesis, that the cognitive deficits displayed in the comorbid group are the sum of
deficits associated with AD/HD and dyslexia alone (Wilcutt et al., 2005). No previous studies were found examining attention, EFs, vigilance, and processing speed deficits in comorbid adults; therefore, this review will focus on child and adolescent comorbid research. Support for the common etiology hypothesis is provided by Wilcutt et al. (2005) who found that a comorbid group of children demonstrated similar levels of inhibition and phonological processing deficits to those of AD/HD and dyslexic groups respectively. Further support has been obtained for this hypothesis from studies reporting that comorbid groups display the additive combination of attention and EFs deficits associated with each individual disorder (Pisecco, Baker, Silva, & Brooke, 2001; Swanson et al., 1999).

A less supported alternative hypothesis explaining cognitive deficits associated with the comorbid group is the cognitive subtype hypothesis (Rucklidge & Tannock, 2002). This hypothesis argues that the comorbid condition is a third disorder due to etiological influences that are distinct from factors in AD/HD and dyslexia. This hypothesis is supported when the comorbid group displays a different or more severe form of AD/HD or dyslexia. Similar to the literature review on studies examining the common etiology hypothesis, there were no adult studies found reporting cognitive subtype hypothesis findings and limited studies involving children and adolescent samples. Support for this hypothesis is provided by Rucklidge and Tannock (2002) who found that an adolescent comorbid group displayed similar inhibition and working memory deficits to those of AD/HD-only and dyslexic-only age matched groups but also exhibited significantly more impaired naming speed abilities than either the AD/HD or dyslexic groups. Wilcutt et al. (2001) found that comorbid children displayed a greater
severity of inhibition and phonological processing impairment compared to AD/HD and dyslexic groups.

The difficulty in generalizing cognitive research findings in comorbid populations is the limited research that is available. In addition to the limited number of studies, Wilcutt and Pennington (2000) found that a major confound in this research is the influence of AD/HD subtypes. Comparing cognitive performance of comorbid and AD/HD-only groups who exhibit different AD/HD subtype patterns (i.e., impulsive vs. inattentive) could contribute to the heterogeneity of cognitive deficits seen in studies addressing the cognitive subtype hypothesis.

Conclusions and Future Directions

This review has examined research delineating attention, EFs, vigilance, and processing speed deficits in adults with AD/HD, dyslexia, and AD/HD with comorbid dyslexia (refer to Table 2). The literature on attention network deficits in AD/HD and dyslexic children and adults indicated points of divergence and convergence. Orienting attention deficits were found to be specific to dyslexic populations while alerting impairments were predominately displayed in AD/HD groups. However, both AD/HD and dyslexic groups experienced executive attention deficits. These results are in need of replication in adult samples. Research comparing attention network deficits in adult AD/HD with comorbid dyslexia groups to adult AD/HD-only and dyslexic-only groups is also needed. With respect to EFs deficits, AD/HD adults displayed more extensive etiology (i.e., inhibition, set shifting, and verbal working memory domains were affected) compared to dyslexic adults who exhibited a specific EFs deficit related to language storage (i.e., auditory working memory). Analysis of research pertaining to domains of
vigilance and processing speed indicates a partial dissociation of deficits between these two disorders. Vigilance deficits are consistently experienced in AD/HD adult populations; however, in dyslexic populations adolescent research indicates no vigilance difficulties. Conversely, processing speed impairments are strongly associated with adult dyslexic populations while AD/HD adult samples experience only minimal deficits in processing speed. The preponderance of literature on comorbid children suggests that EFs deficits are the sum (i.e., common etiology) of deficits found in AD/HD-only and dyslexic-only groups. Currently, this finding cannot be extended to the adult comorbid population due to the dearth of available studies.

Future investigations examining the cognitive deficits associated with these disorders would benefit from addressing both theoretical and methodological limitations of past research. The following recommendations would address these limitations and more effectively specify the attention, EFs, vigilance, and processing speed deficits associated with these disorders.

1. There is a critical need for more attention, EFs, vigilance, and processing speed research with adult AD/HD, dyslexic, and comorbid populations. This research would be beneficial because attention and EFs do not reach developmental maturity until adolescence or early adulthood; therefore, future studies employing adults with these disorders can do so without the confound of brain maturation (Tannock, 1998).

2. Because attention and EFs are multicomponential constructs, future research would benefit from employment of attention and/or EFs tasks based on theoretical models as opposed to tasks gauging a singular aspect
of either attention or EFs. Posner and Raichle’s attention network model (1994) and Miyake et al.’s (2000) primary components of EFs provide the necessary breadth and depth to comprehensively measure attention and EFs. Additionally, EFs development is contingent upon existing attention networks (Garon et al., 2008), therefore inclusion of both attention and EFs tasks in future studies would allow the identification of distal and proximal cognitive deficits associated with AD/HD and dyslexia. For example, it was only when Sergeant, Guerts, and Oosterlaan (2002) employed an integrated cognitive model consisting of lower order energetic processes (e.g., alerting attention) and higher order EFs to examine cognitive deficits associated with AD/HD that this disorder was seen as a condition with dual routes of cognitive etiology (both alerting and EFs deficits) as opposed to solely EFs deficits (Barkley, 1997).

3. Future studies should include diagnostically-referred AD/HD, dyslexic, and comorbid adults as opposed to self- or questionnaire-referred samples. Due to the frequent comorbidity of AD/HD and dyslexia (Wilcutt & Pennington, 2000) diagnostic inclusion in either of these groups is the most efficient option to ensure purer AD/HD and dyslexic samples. Mahone et al. (2002) and Taroyan et al. (2007) argued that on measures that best reflect the cognitive etiology associated with each disorder (i.e., inhibition, attention, and vigilance measures for AD/HD and phonological, working memory, and processing speed tasks for dyslexia) diagnostically-referred sample performance, as opposed to that of self- or questionnaire-
referred participants, provides more explicit cognitive discrimination compared to non-disabled control samples. The use of diagnostically referred AD/HD-only and dyslexic-only research groups can also be problematic when examining cognitive etiology. Reading and attentional deficits are thought to be the result of common gene abnormalities with pleiotropic influences; therefore, removal of dyslexic participants with attention deficits or AD/HD individuals with reading deficits in cognitive etiological research of dyslexia and AD/HD respectively, can result in a skewed profile of the cognitive deficits associated with each disorder. Until the common genetic and cognitive mechanisms that underlie the association between AD/HD and dyslexia are more accurately specified (Wilcutt et al., 2005), cognitive measurement difficulties related to exclusion of comorbid samples in both dyslexic and AD/HD research will continue to exist. (Wilcutt et al., 2005). In reference to the comparison of comorbid to AD/HD only groups, the utilization of diagnostic samples would be the most efficient method of ensuring equivalent AD/HD subtypes to test the common etiology and cognitive subtype hypotheses.

4. Attention and EFs measures suffer from construct validity problems including task impurity. For example, there are substantial differences related to the cognitive processes involved in simple/complex and simultaneous/successive CPTs that measure response inhibition and vigilance respectively (Carlson & Moses, 2001; Caggiano & Parasuraman, 2004; Murray & Kochanska, 2002). Similarly, processing speed tasks must
be specified as simple or complex tasks because the latter tasks demand more cognitive resources than the former (Chiaraveilloti et al., 2003). To further address task impurity concerns, control of cognitive correlates associated with attention or EFs variables (based on theoretical research) is advised to provide purer examination of cognitive processes. For example, short term memory is often a covariate when gauging working memory span (Baddeley, 2002) and working memory is frequently employed as a covariate when measuring inhibition (Garon et al., 2008).

The study of the cognitive etiology associated with postsecondary students and adults with AD/HD and/or dyslexia is still in its infancy compared to the vast amount of research on children with these disorders. The results of this literature review indicate that AD/HD adults as opposed to dyslexic adults experience more dispersed attentional network deficits, ranging from energetic attentional processes (e.g., alerting and vigilance) with anatomical connections to the brain stem, to executive attention impairments which originate in the frontal cortex. Conversely, dyslexic adults experience selective and executive attention impairments which stem primarily from frontal and parietal cortex anomalies. AD/HD adults also experience executive functions deficits associated with a broader area of the frontal cortex (i.e., the orbitofrontal, medial, and lateral frontal cortex areas) when compared to dyslexic adults who experience core deficits in auditory memory which has connections primarily to the lateral prefrontal cortex.

Few empirical studies elucidating the cognitive etiology of AD/HD, dyslexia, and comorbid AD/HD and dyslexia have been conducted with adults. Research with adult
populations is needed to minimize the influence of brain maturation on reported findings as evident in child studies. Even fewer studies have employed measurement tasks based on comprehensive cognitive theoretical models to provide sound ecological validity, addressed the confounds of sample inclusion criteria, and adhered to construct validity parameters of attention and EFs tasks. Further studies with AD/HD and dyslexic adult populations overcoming these limitations are critically needed, not only to delineate the deficits associated with these disorders, but also to provide direction for educational remediation.
CHAPTER 3: PERFORMANCE OF POSTSECONDARY STUDENTS WITH AD/HD AND DYSLEXIA ON THE ATTENTION NETWORKS TEST

Attention is not a unitary faculty of the human cognitive system; rather, it is a diversified system subserved by multiple interrelated attention networks and is present in every aspect of human behaviour. The attention system is anatomically separate from the cognitive data processing systems; therefore, attention networks implement a cognitive function that is domain general. These networks carry out energetic and selective control functions regardless of the content of the material for processing (Fernandez-Duque & Posner, 2001). Consequently, attention can be viewed as a neural organ system; it interacts with other parts of the cognitive system but maintains its own identity.

Posner and Raichle (1994) posited a theoretical organ account of visual attention in which there exist multiple networks each responsible for a different aspect of attention. According to the model advanced by Posner and Raichle, attention networks within the cognitive system can be broadly categorized into alerting, orienting, and conflict resolution (executive) networks, each with different yet interrelated functions. The alerting network is anatomically associated with the locus coeruleus of the midbrain and maintains connections to the right frontal lobe and parietal cortex. This network of attention plays a critical role in maintaining readiness to react to stimuli in the environment. The orienting system has anatomical foci in the parietal lobes, parts of the midbrain, and thalamus and is responsible for focusing on a target or stimulus. The third component, the executive network, involves regions of the prefrontal cortex and basal ganglia and is responsible for executive control of attention such as disengaging focus.
and interference control. The orienting system has anatomical foci in the parietal lobes, parts of the midbrain, and thalamus and is responsible for focusing on a target or stimulus. Posner and Raichle’s model was used in this study to examine attention performance of groups with attention deficit/hyperactivity disorder (AD/HD) and AD/HD with comorbid dyslexia. Additionally, this model was employed to analyze whether attention impairments are present in dyslexic populations, as reported in some research (Brannan & Williams, 1987; Facoetti, Paganoni, & Lorusso, 2000; Hari, Valta, & Utela, 1999).

Attention Deficit/Hyperactivity Disorder

Attention Deficit/Hyperactivity Disorder (AD/HD) is a developmental, neurobehavioural disorder characterized by a broad array of cognitive, neuropsychological, behavioural, and emotional indicators (American Psychiatric Association, 2000). The primary symptoms of this disorder throughout the lifespan include hyperactivity, impulsivity, and inattentiveness (Barkley, 1998). The current diagnostic guidelines, as outlined in the Diagnostic and Statistical Manual (DSM-IV-TR; American Psychiatric Association, 2000) focus on both cognitive (e.g., inattention and forgetfulness) and neurobehavioral (e.g., fidgeting and impulsivity) symptoms, and describe three subtypes of AD/HD in children and adults: the predominantly inattentive type, the predominantly hyperactive/impulsive type, and the combined type which includes symptoms of inattention, hyperactivity, and impulsivity. According to Nigg (2005), however, the combined type appears to be more closely related to the characteristics of hyperactivity and impulsivity rather than to inattentive symptoms.
Clinical and empirical research indicates that approximately 50%-70% of children with AD/HD exhibit the primary symptoms of the disorder well into adulthood (Barkley, 1998). AD/HD affects between 2% and 12% of elementary school children and approximately 4% of adults (Sagvolden, Aase, Borga-Johansen, & Russell, 2005). Furthermore, it is estimated that AD/HD is prevalent in 2% to 4% of the postsecondary population (DuPaul et al., 2001; Heiligenstein, Conyers, Berns, & Smith, 1998).

Henderson (1999) and Guthrie (2002) indicated that the greatest increase in disabilities on postsecondary campuses is in students with hidden disabilities such as AD/HD and dyslexia. They reported that two out of five postsecondary students with disabilities have AD/HD or a learning disability. Postsecondary students with AD/HD obtain a lower grade point average, are less likely than their non-AD/HD peers to graduate, and demonstrate more significant levels of psychological distress and aggression than non-AD/HD students (Weyandt & DuPaul, 2006).

Barkley (1997) theorized that the AD/HD hyperactive/impulsive type and combined type are associated with proximal deficits in executive functions (e.g., executive attention). Support for this hypothesis is obtained from structural and functional neuroimaging research and through meta-analyses of executive functions deficits in children with AD/HD hyperactive/impulsive type and combined type in comparison to non-AD/HD children (Nigg, 2005). According to Nigg, Wilcutt, Doyle, and Sonuga-Barke (2005), current research indicates that executive functions deficits are viable core cognitive impairments in children with the hyperactive/impulsive type and combined type of AD/HD. Barkley (1997) stated that the AD/HD predominantly inattentive type is associated with a different set of cognitive deficits which include
processing speed and sustained attention (analogous to alerting attention) impairments. Research with children has demonstrated that the AD/HD predominantly inattentive type is characterized by slow retrieval and information processing and low levels of alertness (Barkley, DuPaul, & McMurray, 1990; Lahey, Schaughency, Frame, & Strauss, 1985; Lahey, Schaughency, Hynd, Carlson, & Piacentini, 1987; Nigg, Blasky, Huang-Pollock, Wilcutt, Hinshaw, & Pennington, 2002).

Research examining the performance of AD/HD groups utilizing Posner and Raichle’s (1994) attention networks model has been infrequent and limited to studies of children. Booth, Carlson, and Tucker (2007) administered a children’s version of the Attention Networks Test (Rueda et al., 2004), a computer-based reaction time task which measures Posner and Raichle’s three networks of attention, to participants between the ages of 7 and 13 ($M = 9.5$ years) and found that the AD/HD combined type displayed alerting attention deficits in comparison to the AD/HD predominantly inattentive type. There were no significant differences found between the AD/HD subtypes on orienting and executive attention networks or between the AD/HD subtypes and control participants on alerting, orienting, or executive attention networks. Additionally, Huang-Pollock, Nigg, and Halperin (2006) found alerting network deficits in 7 to 12 year-old AD/HD combined type participants but not in the AD/HD inattentive type compared to control group performance.

As noted above, neuroimaging studies demonstrate executive attention deficits in AD/HD children while studies utilizing tasks based on Posner and Raichle’s (1994) attention model display alerting attention deficits for this same group (e.g., Barkley, 1997; Booth et al., 2007; Huang-Pollock et al., 2006; Nigg, 2005). However, the
hypothesis that executive or alerting attentional deficits are the core impairments in AD/HD adults is speculative. Weyandt and DuPaul (2006) conducted a literature review of the cognitive/neuropsychological functioning of postsecondary college students with AD/HD and found few differences between AD/HD postsecondary students and control participants on alerting, orienting, and executive attention measures (Lintermann & Weyandt, 2001; Weyandt, Lintermann, & Rice, 1995; Weyandt, Rice, Lintermann, Mitzlaff, & Emert, 1998).

**Dyslexia**

Dyslexia, or specific reading disability, is characterized by significant difficulties in acquiring basic reading subskills such as word identification and phonological (letter-word) decoding in individuals with at least average intelligence and whose reading problems are not due to extraneous factors such as sensory acuity deficits, socioeconomic disadvantage and like factors (Vellutino, Fletcher, Snowling, & Scanlon, 2004). Developmental dyslexia is among the most common of learning disabilities, with adult population prevalence estimates ranging from 5% to 17.5% (Shaywitz, 1998; Stoet, Markey, & Lopez, 2007). The major symptom pattern defining dyslexia (a basic deficit in word recognition) persists well into adulthood (Bruck, 1990, 1992, 1993; Hatcher, Snowling, & Griffiths, 2002). The academic ramifications of dyslexia from a postsecondary perspective include inaccurate and dysfluent word recognition and spelling skills, and poor reading comprehension abilities. Additionally, dyslexic postsecondary students employ immature and ineffective strategies for word recognition and spelling compared to age matched controls (Bruck, 1990, 1993).
Structural and functional neuroimaging studies indicate that multiple brain regions play a distinctive role in dyslexia including, parietal, inferior frontal, and cerebellar networks (Stoet et al., 2007). Analysis of dyslexic anatomy and neurophysiology provides important information about the etiology of dyslexia; however, it is not sufficient for a full understanding of the deficit. Therefore, behavioral analyses of dyslexic performance are required to identify which cognitive processes are impaired and to determine how these impairments might be related to identified neural networks.

Research has demonstrated that phonological awareness plays an important role in reading progress and achievement (Castles & Coltheart, 2004; Goswami & Bryant, 1990; Wagner & Torgesen, 1987). There is robust evidence that individuals with developmental dyslexia have phonological impairments (Bradley & Bryant, 1983; Pennington, Orden, Smith, Green, & Haith, 1990; Scarborough, 1990; Shaywitz et al., 1999). Furthermore, the persistence of phonological deficits is evident in adults with dyslexia (Bruck, 1992; Campbell & Butterworth, 1985; Fawcett & Nicolson, 1995; Hatcher et al., 2002; Ramus et al., 2003; Shaywitz et al., 1999). The view that a phonological deficit is the sole cognitive impairment in developmental dyslexia is difficult to reconcile considering the numerous studies that show attention problems and dyslexia co-occur more frequently than explained by chance. It has been estimated that 15% to 40% of children with dyslexia also have AD/HD and approximately 25% to 40% of children with AD/HD are estimated to have dyslexia (Dykman & Ackerman, 1991, Gilger, Pennington, & DeFries, 1992; Semrud-Clikeman et al., 1992; Shaywitz, Fletcher, & Shaywitz, 1994; Wilcutt & Pennington, 2000). Additionally, the co-existence of attention problems and dyslexia occurred in samples ascertained from clinical settings (Semrud-Clikeman et al.) and in
samples recruited from the community (Fergusson & Horwood, 1992; Wilcutt & Pennington, 2000).

Most word reading theories do not specify the attention processes involved, assuming that they are peripheral mechanisms that are not an integral part of the reading process (Coltheart, Curtis, Atkins, & Haller, 1993; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Harm & Seidenberg, 1999; Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McCleland, 1989). Ans, Carbonnel, and Valdois (1998) however, provided a theoretical account of how visual attentional processes operate in reading. An important feature of their model is the visual attention window (VAW) through which information from the orthographic input is extracted. Similar to the dual route mode of reading (Coltheart et al., 2001), they postulated that reading can take place through two types of reading procedures: global and analytic. In the global reading mode, the VAW extends over the whole sequence of an input-letter string. When shifting to an analytic mode, the VAW narrows down to focus attention on the first part of the orthographic input. Analytic processing then proceeds through a narrow VAW which shifts from left to right focalizing attention on the different parts of the input successively.

Hari and Renvall (2001) proposed the sluggish attentional shifting (SAS) theory of dyslexia in which sluggish attentional capture and prolonged attentional dwell time co-occurs with impaired phonological processing to produce behavioural manifestations of dyslexia. This theory proposes that initial attention engagement difficulties (i.e., orienting difficulties) lead to difficulties in attention disengagement (i.e., executive deficits). Facoetti et al. (2000) used a spatial cueing task (analog to the Attention Networks Test orienting task) to provide support for sluggish attentional shifting deficits in dyslexic
individuals. Their study found that dyslexic children did not show the expected validity effect on this task. The validity effect indicates that subjects respond faster and more accurately to a target presented at a previously cued location rather than in an uncued location. Facoetti et al. (2000) concluded that dyslexic children distribute their attention resources more diffusely because of difficulties in narrowing the attentional focus (attention capture deficits). Brannan and Williams (1987) found similar results using the same task for children and adults with poor reading skills when compared to matched subjects with good reading skills. Additionally, Hari et al. (1999) found that once dyslexic adults’ attention is engaged it cannot easily be disengaged or shifted.

The studies investigating attention (primarily visual attention) deficits in dyslexic populations have produced mixed results and often do not employ a theoretically driven model of attention within which to compare dyslexic performance. For example, Hari et al. (1999) found that dyslexic adults display difficulties shifting attention compared to nondisabled readers. A contradictory result has been reported with average readers showing more attention shifting difficulties than dyslexic readers (Lacroix et al., 2005). Furthermore, the concept of attention is complex as it occurs at different levels of processing and is associated with varying cueing mechanisms. Orienting attention at the perceptual level is the moving of attention between different peripheral scenes. Posner and Rothbart (2007) described this type of attention as overt because these shifts (in the form of voluntary eye movements or gaze direction) can be seen by an external observer. This shifting of attention can be triggered primarily through exogenous cueing. Conversely, one can keep gaze at the same stimulus while orienting attention shifts between different features of the same stimulus or shifts attention between different aims.
it may associate with the same stimulus (endogenous cueing). Therefore, although these preliminary results indicate the presence of attention deficits in dyslexic populations, it is unclear which attention networks are impaired and if these individuals experience difficulties with exogenous or endogenous cues. Furthermore, a literature search has indicated that there are no published studies that have examined adult dyslexic performance on tasks employing Posner and Raichles’s (1994) model of attention.

Attention Deficit/Hyperactivity Disorder with Comorbid Dyslexia

The inclusion of an AD/HD with comorbid dyslexia (comorbid) group in this study is essential in understanding attention deficits in AD/HD and dyslexia. Research indicates that core cognitive impairments associated with both ADHD and dyslexia contribute to the cognitive etiology of the comorbid group (Narhi & Ahonen, 1995; Wilcutt et al., 2001). Furthermore, the common etiology hypothesis (Wilcutt, Doyle, Nigg, Faraone, & Pennington, 2005) states that if attention deficits are present in the comorbid group they should be the sum of attention deficits associated with both AD/HD and dyslexia alone. A literature search revealed no prior research comparing comorbid performance to ADHD and dyslexic populations on tasks using Posner and Raichle’s (1994) model of attention.

Rationale for the current study

The current study is intended to investigate the attention mechanisms underlying AD/HD, dyslexia, and AD/HD with comorbid dyslexia. Posner and Raichle’s (1994) model of three attention networks provides a theoretically sound basis for examining attention performance in these groups. This study provides a performance comparison of AD/HD, dyslexic, comorbid, and control groups on alerting, orienting, and executive
attention domains. It is hypothesized that the AD/HD group will display deficits in alerting and executive attention networks as reported in literature. Analysis of the dyslexic group’s performance on the ANT should specify which attention network (orienting or executive network), if any, is impaired. The comorbid group analysis is exploratory as there are no existing studies comparing this group using Posner and Raichle’s (1994) attention networks.

Method

Participants

The 73 participants in this study were undergraduate students recruited from Trent University, in Peterborough, Ontario and attending the 2006 summer, 2006 fall, or the 2007 winter academic sessions. There were 22 males and 51 females. Copies of the Research Ethics Board approvals to commence testing with these students are found in Appendices A and B. Additionally, all students provided informed consent prior to testing.

The students with disabilities were registered with the Disability Services Office at Trent University and were recruited through a disability services list serve announcement asking for volunteers. Students with disabilities formed the following groups: AD/HD, which included both the predominately inattentive type and the predominantly hyperactive/impulsive/combined types ($n = 23$, 11 of whom were male), students with dyslexia ($n = 19$, 5 of whom were male), and AD/HD with comorbid dyslexia (comorbid, $n = 10$, 4 of whom were male). The mean chronological ages of the AD/HD, dyslexic, and comorbid groups were respectively, 23.26 years ($SD = 3.17$), 21.89 years ($SD = 2.05$), and 22.0 years ($SD = 2.62$). The control group consisted of 21
student volunteers (2 of whom were male) who were recruited through posters placed throughout the university detailing the study and requesting volunteers. The mean chronological age of this group was 20.38 years ($SD = 3.18$).

**Diagnostic Group Exclusionary Criteria**

The focus of the study is on delineating the attention performance of AD/HD, dyslexic, and comorbid groups; therefore, potential participants with a documented brain injury or sensory deficit (i.e., hearing and/or vision impairments) were excluded from the sample. Participants had to have a standard score of 85 or greater on an intellectual measure to be included in the study. Estimated intellectual ability was assessed in this study through the composite score obtained from administration of the Vocabulary and Block Design tests (Sattler, 1992) of the Wechsler Adult Intelligence Scale – Third Edition (Wechsler, 1994).

**Diagnostic Criteria for Group Assignment**

For the AD/HD group a regulated health provider in the Province of Ontario (i.e., a psychologist or psychological associate) provided a current psychoeducational assessment and diagnosis of AD/HD. The psychoeducational assessment included a structured clinical interview based on Diagnostic and Statistical Manual – Fourth Edition –Text Revision (American Psychiatric Association, 2000) criteria for AD/HD and corroboration of *DSM-IV-TR* (2000) criteria with parent and teaching rating scales. Additionally, a standardized IQ test (primarily WAIS-Third Edition), tests of information processing, and a full battery of achievement tests assessing all aspects of reading, writing, and math were administered. Only students with an affirmed *DSM-IV-TR* (2000) diagnosis (i.e., the presence of six or more symptoms in at least one of the two symptom
groups of inattention or hyperactivity/impulsivity) were included in the AD/HD group. Inclusion in the dyslexic group required a diagnosis of dyslexia or specific reading disability by a psychologist or psychological associate as stated in a current psychoeducational assessment. Although the tests used by individual clinicians differed, the diagnosis of dyslexia or specific reading disability was guided by the Learning Disability Association of Canada’s (LDAC, 2002) discrepancy based definition. The LDAC definition states that impairment in one or more psychological processes (e.g., phonological processing) related to learning, in combination with otherwise average abilities essential for thinking and reasoning, and unexpectedly low academic achievement (e.g., in reading) are required for a diagnosis of a learning disability. The comorbid group was similarly diagnosed and consisted of students with an affirmed AD/HD diagnosis based on DSM-IV-TR (2000) criteria and a confirmed diagnosis of dyslexia or specific reading disability as stated on a psychoeducational assessment. For inclusion into the control group, students had to (a) exhibit no at-risk or high-risk scores on the College AD/HD Response Evaluation - Student Response Inventory (CARE-SRI; Glutting, Sheslow, & Adams, 2002) Factor and DSM-IV scales employing both gender and general norms, (b) score below the cut-off scores established by LeFly and Pennington (2000) on the Adult Reading History Questionnaire-Revised (ARHQ-R; Parrila, Corkett, Kirby, & Hein, 2003; see also Kirby et al., 2008) indicating that no significant reading difficulties were present, and (c) exhibit average or better scores in comparison to age normative data on the Test of Word Reading Efficiency Phonemic Decoding and Sight Word subtests (Wagner, Torgesen, & Rashotte, 1996) and on the
Rapid Naming subtest of the Comprehensive Test of Phonological Processing (Wagner, Toregesen, & Rashotte, 1999).

**Measures**

*The College AD/HD Response Evaluation – Student Response Inventory* (CARE-SRI; Glutting et al., 2002) is a 59 item self-rating scale designed to provide information relevant to the assessment of AD/HD at the university level. Requiring approximately 15 min to complete, a student indicates on a 3-point scale whether he or she “agrees,” “disagrees” or is “undecided” that the item content applies. The CARE-SRI provides two different systems for interpreting results: factor scores and DSM-IV scores. Items comprising the factor scores were determined through factor analyses of ratings of university students with AD/HD; the factors are the Inattention, Hyperactivity, and Impulsivity scales. A sample item from the Inattention scale is “I start out doing one thing and end up doing something else,”; from the Hyperactivity scale “I fiddle with things near where I am standing,” and from the Impulsivity scale “I blurt out answers before questions have been completed.” The DSM-IV scores on the CARE-SRI were derived from diagnostic criteria of the *DSM-IV* (1994). The CARE-SRI has two DSM-IV scales: Inattention scale and the Hyperactivity/Impulsivity scale. A sample question from the DSM-IV Inattention scale is “I am forgetful in daily activities.” From the DSM-IV Hyperactivity/Impulsivity scale a sample question is “I fidget with my hands or feet and squirm in my seat.”

The CARE-SRI manual (Glutting et al., 2002) indicates that the alpha coefficients for the factor based Inattention, Hyperactivity, and Impulsivity scales are .82, .87, and .77, respectively. The alpha coefficients for CARE-SRI DSM-IV Inattention and
Hyperactivity/Impulsivity scales are .63 and .65. For the current sample, the alpha coefficients for the factor based Inattention, Hyperactivity, and Impulsivity scales were .83, 83, and .80, respectively. The alpha coefficients for the current sample on the DSM-IV Inattention and Hyperactivity/Impulsivity scales were .73 and .82.

The Adult Reading History Questionnaire – Revised (ARHQ-R: Parrila et al., 2003) is based on the Adult Reading History Questionnaire (ARHQ) developed by Lefly and Pennington (2000) which in turn is a revised version of Finucci, Whitehorse, Isaacs, and Child’s (1984) Reading History Questionnaire. In the ARHQ-R, respondents are asked about their reading and spelling ability, reading speed, attitudes toward school and reading, additional assistance they received, repeating grades or courses, effort required to succeed, and print exposure. These types of questions are asked separately for elementary school, secondary school, and for postsecondary education. Fifteen questions are specific to elementary school experience, 19 questions focus on secondary school, and 22 questions target postsecondary education. For each item, scores vary between 0 and 4, and high scores indicate less reading activity or more reading difficulty. The three scales can be analyzed separately or in combination. For this study, only the postsecondary items were utilized. Scoring for this questionnaire is based on the proportion of the total points possible for the postsecondary items. For example, a participant whose responses to the 22 postsecondary items were given a total of 55 points out of a maximum of 88 (22 questions x 4 points each) would obtain a score of .63 (55/88). Lefly and Pennington (2000) reported the alpha coefficient of the original ARHQ to be .94 and the test-retest reliability over a two year period to be .87. For the
current sample, the alpha coefficient of the Postsecondary Basic Reading Scale of the ARHQ-R was .79. Refer to Appendix C for a copy of this questionnaire.

*The Attention Network Test (ANT; Fan, McCandliss, Sommer, Raz, & Posner, 2002)* is an individually administered computer test developed to provide a behavioral measure of the three attention networks within a single task. The ANT is a combination of a spatial cueing task (Posner & Cohen, 1980) and a flanker task (Eriksen & Eriksen, 1974). In each ANT trial, the participant looks at a fixation point in the centre of the screen and waits for a stimulus to appear. The stimulus is a row of five horizontal arrows and the participant’s task is to report the direction (left or right) in which the centre target arrow points by pressing one key for left and a different key for right. The response time is recorded. Four arrows surround the target arrow, two on each side, and are called flankers. These flanker arrows point either in the same direction as the target arrow (the congruent condition) or in the opposite direction (incongruent condition). The stimulus row can be present at one of two locations, either above the fixation point or below it. The stimulus may be preceded by a cue (cued condition) or not (no cue condition); the cue is an asterisk and may indicate the correct position of the following stimulus. The cue may be presented at the centre location (centre cue location), at the top or bottom location where the stimulus row is to appear (spatial cue condition), or at both the top and bottom locations (double cue condition). The centre cue and double cue conditions provide information about when the stimulus will occur, but not where (refer to Figure 1).

Each ANT trial consists of five events (see Figure 1). First there is a fixation period (i.e., focus on a cross in centre of screen) prior to the cued and no cue conditions for a random variable duration (400-1600 milliseconds). In the cued conditions, a
Figure 1. Attention Network Test cue/target conditions and trial sequence

(A) The 4 cue conditions

- No cue
- Center cue
- Double cue
- Spatial cue

(B) The 3 target conditions

- Congruent
- Incongruent
- Neutral

1. Fixation cross (duration $D = 400-1600 \text{ ms}$)
2. Cue (100 ms)
3. Fixation cross (400 ms)
4. Target (RT < 1700 ms)
5. Fixation cross (3500 $- D - RT \text{ ms}$)
warning cue along with the fixation cross is presented for 100 milliseconds, while in the no cue condition just the fixation cross is visible. There is a short period of 400 milliseconds after the cued or no cue conditions and then the target and flankers appear simultaneously. The target and flankers are presented until the participant responds, but not for longer than 1700 milliseconds. After a participant makes a response, the target and flankers disappear immediately and there is a post-target fixation period which is based on the duration of the first fixation and response time (3500 milliseconds minus duration of the first fixation minus response time). After this interval, the next trial begins. The fixation cross stays at the centre of the screen during the whole trial. The five target and flanker stimuli are presented in one of two locations, either 1.06 degrees above or below the fixation point. Target location is always uncertain except in the spatial cue condition which indicates where the target will appear (endogenous orienting cueing). A complete ANT testing session consisted of 24 trials with full feedback practice and three experimental blocks of trials with no feedback. Each experimental block consisted of 96 trials (4 cue conditions x 2 target locations x 2 target directions x 3 flanker conditions x 2 repetitions). The presentation of trials was in a random order.

The ANT paradigm adapts the following formulas to measure the efficiency of each of the three attention networks. Alerting attentional efficiency is measured by no cue response time minus double cue response time for correct responses only. Subtracting response time obtained in the double cue condition that provides information on when but not where the target will occur from response time in the no cue condition provides a measure of alerting as influenced by the presence of a warning cue. A higher alerting response time is desirable as it indicates an increased difference between cued and
noncued conditions, demonstrating a greater ability to use warning cues. Orienting attention network efficiency is measured by the centre cue response time minus the spatial cue response time for correct responses only, because the spatial cue but not the central cue exhibits valid information about where a target will occur. A high orienting response time is desirable as it indicates a greater ability to utilize orienting cues. Executive attention efficiency is measured by response time in the incongruent condition minus response time in the congruent condition, because this provides a measure of the length of time needed for conflict resolution (determining the direction of the centre arrow when surrounded by flankers). A higher executive attention response time is indicative of more difficulty in conflict resolution, therefore, lower executive attention response times indicate greater efficiency of this attentional network. At the conclusion of the ANT an overall mean response time for correct responses across all cue and flanker conditions is calculated. Additionally, the number of errors made in each cue and flanker condition is recorded with the average percentage of correct responses across each cue and flanker condition contributing to the overall accuracy percentage. Fan et al. (2002) found that the test-retest reliability coefficients for normal adults (across two ANT administrations in a 24 hour period) was .52 for the alerting attentional network, .61 for the orienting network, and .77 for the executive network. We will refer to the ANT dependent variables as Alerting, Orienting, and Executive response times, Overall time (overall mean response time) and Accuracy (Accuracy percentage).

The Phonemic Decoding Efficiency subtest (Form A) of the Test of Word Reading Efficiency (Wagner, Torgesen, & Rashotte, 1996) measures the number of pronounceable nonwords that can be accurately decoded within 45 seconds. The
The dependent measure is the total number of nonwords correctly pronounced within 45 seconds. Alternate form reliability is .94 for individuals 18 to 24 years of age (Wagner et al., 1996).

The *Sight Word Efficiency* subtest (Form A) of the Test of Word Reading Efficiency (Wagner et al., 1996) assesses the number of printed familiar words that can be accurately identified within 45 seconds. The dependent measure is the total number of words correctly pronounced within 45 seconds. Alternate form reliability is .93 for individuals 18 to 24 years of age (Wagner et al., 1996).

The *Rapid Digit Naming* subtest of the Comprehensive Test of Phonological Processing (Wagner, Torgesen, & Rashotte, 1999) is a 72 item subtest that measures the speed with which an individual can name digits. The dependent measure is the total number of seconds taken to name all the digits in both stimulus sets. This test is a measure of rapid automatized naming abilities. Test-retest reliability (14 day interval) for individuals 18 to 24 years of age is .90 (Wagner et al., 1999).

**Procedure**

The testing was completed in one session lasting 45 minutes. The tests were administered in a quiet room removed from distractions and possible interruptions. All AD/HD students were asked to be off psychostimulant medication for at least 24 hours prior to testing as research indicates improved performance on EFs measures for AD/HD individuals taking psychostimulants (Kempton et al., 1999). The first author administered the questionnaires and ANT to the study participants.

The Attention Network Test stimuli were presented via E-prime, a commercial experiment application, on a Dell personal computer running Windows 2000, with a 14
35.6 centimeter monitor. Participants viewed the screen from a distance of 65 centimeters and responses were collected via two input keys on a keyboard. The study participants read the on-screen instructions and were instructed to focus on a centrally located fixation cross throughout the task (to minimize eye movement) and to respond as quickly and accurately as possible to stimuli. During the practice trials, but not the experimental trials, participants received feedback from the computer on their speed and accuracy. The practice block took approximately 2 minutes and each experimental block took approximately 5 minutes to complete.

Results

Data Preparation

All dependent measures (Alerting, Orienting, and Executive response times, Overall Time, and Accuracy) were examined for missing values and fit between their distributions and the assumptions of analyses of variance and analyses of covariance. One participant from the comorbid group did not take the Attention Network Test; therefore, missing values were replaced by group means. Since the missing data cannot safely be assumed to reflect randomness and to not diminish the statistical power of the analyses, missing values were imputed as opposed to being deleted (Little & Rubin, 1987). Imputing missing values with group means is recommended by Tabachnick and Fidell (2007) when other approaches of estimating missing values (i.e., regression) are not applicable and as a method of maintaining within-group variance. All dependent variables were examined for extreme values (i.e., scores > 2.5 standard deviations from the mean of each study group) as suggested by Tabachnick and Fidell (2007). Two cases were categorized as outliers on Alerting response times, two other cases on Orienting
response times, and two further cases on Executive response times. Outlier response
times were transformed by assigning a raw score to the outlier that was one unit larger (or
smaller) than the next most extreme score in the distribution (Tabachnik & Fidell, 2007).
All dependent variables were screened for violations of the normal distribution. Alerting,
Orienting, and Overall Time variables displayed a normal distribution pattern. The
Shapiro-Wilks and Kolmogorov-Smirnov Lillefors tests of normality were significant (p
< .01) for Executive response time and Accuracy, indicating that the assumption of
normality was not achieved.

Statistical Analyses

Separate univariate analyses of variance and analyses of covariance (if required)
were completed for Alerting, Orienting, and Overall Time variables. Partial eta squared
(\( \eta_p^2 \)) is reported for all group comparisons to convey effect size for univariate analyses of
variance and analyses of covariance. Partial eta squared has the following effect size
conventions: small (.05), medium (.10), and large (.20) (Cohen, 1969). The Executive
and Accuracy variables violated assumptions associated with a univariate analyses,
therefore nonparametric Mann Whitney \( U \) tests were used to examine group performance.
Effect sizes for Mann Whitney \( U \) tests were calculated based on the following formula: \( r = \frac{\text{standard score}}{\sqrt{\text{total number of observations}}} \) (Field, 2005). Cohen (1988)
provides the following guidelines to evaluate effect size: small, \( r = 0.1 \); medium, \( r = 0.3 \);
large, \( r = 0.5 \).

Diagnostic and Descriptive Measures

ANOVAs and Tukey-Kramer post hoc comparisons pertaining to the
demographic and descriptive characteristics of the participants are summarized in Table
3. Diagnostic groups did not differ on estimated full-scale IQ, $F(3, 69) = 1.03, p = .38, \eta^2_p = .04$. However, the diagnostic groups did exhibit differences in age, $F(3, 69) = 3.72, p = .02, \eta^2_p = .14$. Post-hoc comparisons with the Tukey-Kramer procedure to control for Type 1 error revealed that the AD/HD group (without comorbid dyslexia) displayed a significantly higher mean age ($p < .01$) in comparison to the control group. The higher mean age of AD/HD participants is within range of previous research that indicates that students with disabilities enter university at an older age than their non-disabled peers (Foreman, Dempsey, Robinson, & Manning, 2001). To investigate the effect of age differences on performance, the sample was stratified into groups representing one standard deviation below the mean age (under 19 years), within one standard deviation (20 to 24 years), and above one standard deviation of the mean age (25 years and older), and the performance of these groups on alerting, orienting, and executive attention measures and on Overall Time and Accuracy was compared. Analyses of variance and Mann Whitney U tests indicated that the three groups did not differ statistically. A Pearson chi-square test indicated that there was a significant difference in gender distribution across the groups, $X^2 (3, N = 73) = 8.25, p = .04$. Pairwise comparisons indicated that the control group had a significantly greater female to male ratio compared to the AD/HD group, $t(42) = 2.93, p < .01$ and to the comorbid group, $t(29) = 2.01, p \leq .05$. The higher participation rate of female compared to male students was unexpected. This result can be attributed in part to the greater number of females in the nondisabled student population at Trent University, and to the higher volunteer rate of females for psychological research in postsecondary institutions (Martin & Marcuse, 1958; Rosenthal, 1965).
Table 3.
Demographic Variables, IQ & Symptom Severity Information by Diagnostic Group

<table>
<thead>
<tr>
<th>Variable</th>
<th>Comorbid (n = 10)</th>
<th>AD/HD (n = 23)</th>
<th>Dyslexia (n = 19)</th>
<th>Normal (n = 21)</th>
<th>Df</th>
<th>F</th>
<th>η²</th>
<th>p</th>
<th>Contrasts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age in Years</td>
<td>22.00</td>
<td>23.26</td>
<td>21.89</td>
<td>20.89</td>
<td>3.69</td>
<td>3.72</td>
<td>.14</td>
<td>.02</td>
<td>A&gt;N</td>
</tr>
<tr>
<td>Estimated FSIQ</td>
<td>106.89</td>
<td>111.78</td>
<td>105.26</td>
<td>108.52</td>
<td>3.69</td>
<td>1.03</td>
<td>.04</td>
<td>.38</td>
<td>—</td>
</tr>
<tr>
<td>Sex Rates Female</td>
<td>60.0%</td>
<td>52.2%</td>
<td>73.7%</td>
<td>90.5%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>N&gt;A,C</td>
</tr>
<tr>
<td>Care DSM-IV Scales</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hyperactive-Impulsive</td>
<td>12.40</td>
<td>9.39</td>
<td>4.53</td>
<td>3.33</td>
<td>3.60</td>
<td>3.29</td>
<td>3.69</td>
<td>18.29</td>
<td>.44 &lt;.01</td>
</tr>
<tr>
<td>Inattention</td>
<td>11.90</td>
<td>12.66</td>
<td>7.32</td>
<td>2.10</td>
<td>4.19</td>
<td>2.30</td>
<td>3.69</td>
<td>33.89</td>
<td>.60 &lt;.01</td>
</tr>
<tr>
<td>Care Factor Scales</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hyperactivity</td>
<td>17.40</td>
<td>15.13</td>
<td>10.16</td>
<td>4.14</td>
<td>6.47</td>
<td>4.65</td>
<td>3.69</td>
<td>22.96</td>
<td>.50 &lt;.01</td>
</tr>
<tr>
<td>Impulsivity</td>
<td>14.30</td>
<td>11.83</td>
<td>4.16</td>
<td>2.95</td>
<td>4.11</td>
<td>3.01</td>
<td>3.69</td>
<td>19.33</td>
<td>.46 &lt;.01</td>
</tr>
<tr>
<td>Inattention</td>
<td>28.60</td>
<td>26.74</td>
<td>17.42</td>
<td>7.00</td>
<td>6.40</td>
<td>5.46</td>
<td>3.69</td>
<td>35.54</td>
<td>.61 &lt;.01</td>
</tr>
<tr>
<td>ARHQ-R PSBRS Ratio</td>
<td>.64</td>
<td>.47</td>
<td>.60</td>
<td>.47</td>
<td>.14</td>
<td>.10</td>
<td>.69</td>
<td>8.82</td>
<td>.28 &lt;.01</td>
</tr>
<tr>
<td>TOWRE Phonemic Decoding</td>
<td>38.60</td>
<td>59.00</td>
<td>37.79</td>
<td>58.76</td>
<td>4.77</td>
<td>10.91</td>
<td>5.16</td>
<td>33.66</td>
<td>.59 &lt;.01</td>
</tr>
<tr>
<td>TOWRE Sight Recognition</td>
<td>84.40</td>
<td>99.39</td>
<td>81.26</td>
<td>99.62</td>
<td>5.48</td>
<td>11.48</td>
<td>6.11</td>
<td>21.29</td>
<td>.48 &lt;.01</td>
</tr>
<tr>
<td>CTOPP Rapid Digit Naming</td>
<td>28.83</td>
<td>21.08</td>
<td>26.03</td>
<td>20.16</td>
<td>3.46</td>
<td>4.43</td>
<td>3.69</td>
<td>12.76</td>
<td>.36 &lt;.01</td>
</tr>
</tbody>
</table>

Note. ADHD = attention deficit / hyperactivity disorder; FSIQ = Full scale IQ; CARE = College ADHD Response Evaluation; ARHQ-R = Adult Questionnaire - Revised; PSBRS = Post Secondary Basic Reading Scale; TOWRE = Test of Word Reading Efficiency; CTOPP = Comprehensive Test of Phonological Processing; η² = partial eta squared; C = comorbid; A = AD/HD; D = dyslexia; N = normal.
Table 3 also provides a description of the diagnostic groups based on their self-reported symptoms of AD/HD on the CARE-SRI scales and self-reported symptoms of reading difficulties as indexed by the responses on the ARHQ-R Postsecondary Basic Reading Scale. Higher means on the CARE-SRI and ARHQ-R scales are associated with greater symptoms and difficulties. Consistent with diagnostic grouping, the AD/HD and comorbid groups displayed significantly higher symptoms on all CARE-SRI scales compared to the dyslexic and control groups. The comorbid group did not differ statistically from the AD/HD group on the CARE-SRI scales, however, there was a trend for the comorbid group to have higher means. The dyslexic and comorbid groups displayed significantly higher self-reported reading difficulties compared to the AD/HD and control groups on the ARHQ-R Postsecondary Basic Reading Scale. The comorbid and dyslexic groups did not differ statistically on the ARHQ-R; however, there was a trend for the comorbid group to report more reading difficulties. To substantiate reading difficulties in the comorbid and dyslexic groups, a series of ANOVAs with Tukey-Kramer post hoc comparisons (refer to Table 3) indicated that dyslexic and comorbid groups displayed significant deficits in comparison to the AD/HD and control groups on the TOWRE Phonetic Decoding Efficiency test and TOWRE Sight Word Efficiency test. Additionally, the dyslexic and comorbid groups were significantly slower on the C-TOPP Rapid Digit Naming test compared to the AD/HD and control groups.

Two discriminant analyses were conducted to explore the ability of the CARE-SRI scales and the ARHQ-R Postsecondary Basic Reading scale to classify groups. In the first, classification by the ARHQ-R Postsecondary Basic Reading scale and the CARE-SRI DSM-IV Inattention and DSM-IV Hyperactivity/Impulsivity scales was carried out
for the groups. Three discriminant functions were derived with a significant overall
Wilk’s lambda, \( \Lambda = .24, \chi^2 (9, N = 73) = 97.79, p < .01 \). Removal of the first discriminant
function resulted in a significant Wilk’s lambda, \( \Lambda = .64, \chi^2 (4, N = 73) = 30.27, p < .01 \),
and with removal of the first and second discriminant functions, the Wilk’s lambda
remained significant, \( \Lambda = .88, \chi^2 (1, N = 73) = 8.92, p < .01 \). The structure matrix of
correlation coefficients between predictors and discriminant functions indicated that the
CARE-SRI DSM-IV Inattention scale demonstrated the strongest relationship with the
first discriminant function (\( r = .93 \)). The second discriminant function exhibited a high
correlation (\( r = .99 \)) with one predictor only: ARHQ–R Postsecondary Basic Reading
scale. The CARE-SRI DSM-IV Hyperactivity/Impulsivity scale had the only strong
correlation with the third discriminant function (\( r = .76 \)). The group centroids indicated
that the AD/HD group displayed its highest mean on the first discriminant function, while
the dyslexic group exhibited its highest mean on the second discriminant function. The
comorbid group recorded high means on all three discriminant functions. Using the
discriminant functions to predict clinical group membership resulted in 71.2% of the
individuals in the sample being classified correctly. In order to take into account chance
agreement, a kappa coefficient was computed and a value of .60 was obtained, a moderate
value (Landis & Koch, 1977).

In the second discriminant analysis, classification by ARHQ-R Postsecondary
Basic Reading scale and CARE-SRI factor-based Inattention, Hyperactivity, and
Impulsivity scales was carried out. Again three discriminant functions were significant, \( \Lambda \\
= .21, \chi^2 (12, N = 73) = 104.86, p < .01 \) for the first, \( \Lambda = .66, \chi^2 (6, N = 73) = 28.19, p < \\
.01 \) for the second, and \( \Lambda = .91, \chi^2 (2, N = 73) = 6.70, p = .04 \) for the third. The
inattention and hyperactivity scales correlated highly with the first discriminant function ($r = .86$ and $.69$ respectively), while the ARHQ-R Postsecondary Basic Reading scale demonstrated the strongest relationship with the second discriminant function ($r = .99$). The impulsivity scale displayed the highest correlation with the third discriminant function ($r = .78$). The AD/HD group exhibited the highest mean on the first discriminant function, and the dyslexic group displayed the highest mean on the second discriminant function. The comorbid group recorded high means on all three discriminant functions. Predicting clinical group membership with the derived discriminant functions resulted in 68.5% of the individuals in the sample being classified correctly which resulted in a moderate kappa coefficient of .57 (Landis & Koch, 1977).

The results of the discriminant analyses indicate that both the AD/HD and comorbid groups exhibit self-reported inattention and hyperactivity characteristics; however, only the comorbid group displays significant impulsivity symptoms. Both the dyslexic and comorbid groups were associated with problematic reading histories, though only the comorbid group experienced attentional difficulties.

**Correlations**

Table 4 provides the Pearson correlation coefficients (Spearman’s rank correlation coefficients provided similar results) between the demographic and ANT variables. The demographic variables of participant age and full-scale IQ were not significantly correlated with performance on any of the ANT measures. Gender was significantly correlated with executive attention response times (i.e., female study participants exhibited longer executive attention response times than males), as consistent with previous research (Mezzacappa, 2004; Urbanek et al., 2009). Mann Whitney $U$ tests for
this study indicated that female study participants displayed longer ranked Executive
response times than male participants ($M = 148.83$ vs. $M = 111.68$ respectively, $p = .02$). The correlation matrix provides partial support for the functional independence of the
attention networks (Fan et al., 2002) with the notable exception of executive and orienting
attention. The significant correlation between these two attention networks has been
argued to be the result of the mediating effect of inhibitory mechanisms on covert
orienting and executive attention performance (Fuentes, 2004; Lupianez et al., 2004).
Executive response times also display a significant correlation with Overall time. Wang
and Fan (2007) attribute this correlation to the strong influence of longer response times
in the incongruent condition on overall mean response time. Table 2 also indicates that
higher Alerting and Orienting response times and lower Executive response times (all
noted response times are reflective of more proficient processing) are significantly
correlated with higher Accuracy.

**Covariates**

Covariates were employed in this study based on theoretical grounds, to control
for significant associations between the covariate and dependent variables that have been
reported in previous research, and on statistical significance as a correlate. Full-scale IQ
and age were not used as covariates as they were not significantly correlated with any of
the attention measures; however, gender was employed as a covariate for executive
attention response times (Table 4). Orienting response times displayed a significant
correlation with Executive response times; therefore, they served as covariates for each
other in univariate analyses (Fuentes, 2004; Lupianez et al., 2004).
Table 4.

Correlations between Demographic Variables and ANT Dependent Variables.

<table>
<thead>
<tr>
<th></th>
<th>Gender</th>
<th>Age</th>
<th>FSIQ</th>
<th>Alerting</th>
<th>Orienting</th>
<th>Executive</th>
<th>Overall Time</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>—</td>
<td>—</td>
<td></td>
<td>—</td>
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<td>—</td>
<td>—</td>
<td>—</td>
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<tr>
<td>Age</td>
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<td>FSIQ</td>
<td>—</td>
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<td></td>
<td>—</td>
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<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Alerting</td>
<td>—</td>
<td>—</td>
<td></td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Orienting</td>
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<td>—</td>
<td></td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Executive</td>
<td>—</td>
<td>—</td>
<td></td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Overall Time</td>
<td>—</td>
<td>—</td>
<td></td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
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</tr>
<tr>
<td>Accuracy</td>
<td>—</td>
<td>—</td>
<td></td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

*Note.* FSIQ = Full Scale Intelligence Quotient.

* p < .05, two-tailed. **p < .01, two-tailed.

Diagnostic Group Performance on the Attention Networks Test

Means and standard deviations for all ANT dependent variables are presented in Table 5. Lower means on Alerting, Orienting, and Accuracy measures are indicative of weaker performance, while higher means on the remaining measures (i.e., Executive and Overall Time) represent performance difficulties. The group main effects with Bonferroni post hoc comparisons for Alerting, Orienting, and Overall time are also shown in Table 3. Group main effects obtained by ANCOVAs are reported in the text. Mann Whitney *U* tests displaying significant group rankings on Executive and Accuracy variables are
displayed in Table 3. Mann Whitney $U$ tests demonstrating marginal performance (i.e., tests that did not reach the conventional level (.05) of significance) rankings between groups are described in the text.

ANOVA comparisons group performance on alerting and orienting tasks (see Table 5) were nonsignificant. Furthermore, controlling for the effect of Executive performance on Orienting response times, the group main effect remained nonsignificant, $F(4,68) = .99, p = .40, \eta^2_p = .04$. Analysis of Executive attention performance (refer to Table 5) indicated that the comorbid group exhibited significantly longer ranked Executive response times in comparison to the AD/HD group ($p = .04$). The comorbid group also demonstrated marginally longer ranked Executive response times (mean rank of 19.90) when compared to the control group (mean rank of 14.14, $Z = 1.65, p = .09, r = .28$) and a trend for longer ranked Executive response times (mean rank of 18.70) in comparison to the dyslexic group (mean rank of 13.05, $Z = 1.70, p = .09, r = .32$). To further substantiate performance deficits on executive attention measures in the comorbid group, parametric analyses (i.e. ANCOVA) of executive attention performance was conducted with gender as a covariate and the results indicated that the comorbid group exhibited deficits similar to Mann Whitney $U$ test findings. A group main effect was found related to Overall Time as demonstrated in Table 5. Post hoc comparisons indicate that the comorbid group had significantly longer Overall Times than the AD/HD ($p \leq .01$) and control ($p = .02$) groups. Group performance pertaining to Accuracy on the ANT was examined with Mann Whitney $U$ Tests (see Table 3). The results indicated that the comorbid group displayed significantly lower ranked Accuracy in comparison to the AD/HD ($p = .03$) and control ($p = .02$) groups.
Table 5.

**Attention Networks Test Results by Group**

<table>
<thead>
<tr>
<th>Variable</th>
<th>ADHD (n = 23)</th>
<th>Dyslexia (n = 19)</th>
<th>Comorbid (n = 10)</th>
<th>Normal (n = 21)</th>
<th>df</th>
<th>F</th>
<th>η²</th>
<th>p</th>
<th>Contrasts (Mean Rank)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alerting (msec.)</td>
<td>31.26</td>
<td>25.53</td>
<td>22.00</td>
<td>34.95</td>
<td>3.69</td>
<td>.99</td>
<td>.04</td>
<td>.40</td>
<td>n.s.</td>
</tr>
<tr>
<td>Orienting (msec.)</td>
<td>46.26</td>
<td>52.53</td>
<td>46.67</td>
<td>57.62</td>
<td>3.69</td>
<td>1.04</td>
<td>.04</td>
<td>.38</td>
<td>n.s.</td>
</tr>
<tr>
<td>Overall Time (msec.)</td>
<td>565.70</td>
<td>589.05</td>
<td>633.11</td>
<td>568.10</td>
<td>3.69</td>
<td>3.89</td>
<td>.15</td>
<td>&lt;.01</td>
<td>C&gt;A,N</td>
</tr>
<tr>
<td>Executive (msec.)</td>
<td>125.70</td>
<td>137.74</td>
<td>172.89</td>
<td>127.71</td>
<td>62.00</td>
<td>2.08</td>
<td>.36</td>
<td>.04</td>
<td>C&gt;A (22.30&gt;14.70)</td>
</tr>
<tr>
<td>Accuracy (percentage)</td>
<td>97.70</td>
<td>96.05</td>
<td>94.67</td>
<td>98.14</td>
<td>49.00</td>
<td>2.42</td>
<td>.43</td>
<td>.02</td>
<td>N&gt;C (18.67&gt;10.40)</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>U</th>
<th>Z</th>
<th>R</th>
<th>p</th>
<th>Contrasts (Mean Rank)</th>
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</thead>
<tbody>
<tr>
<td>62.00</td>
<td>2.12</td>
<td>.37</td>
<td>.03</td>
<td>A&gt;C (19.30&gt;11.70)</td>
</tr>
</tbody>
</table>

*Note:* msec. = milliseconds; η² = partial eta squared; U = Computed value of Mann Whitney test; n.s. = nonsignificant; C = comorbid; A = AD/HD; N = normal.
Discussion

This study investigated attention performance in postsecondary students with AD/HD, dyslexia, and AD/HD with comorbid dyslexia utilizing Posner and Raichle’s (1994) model of attention networks. Attention performance was measured by the Attention Networks Test (Fan, et al., 2002) which is designed to provide individual measures of the efficiency of each of the attentional networks (i.e., alerting, orienting, and executive attention networks). Previous research indicates that the AD/HD group would display deficits in both alerting and executive attention networks (e.g., Barkley, 1997; Huang-Pollock et al., 2006; Nigg, 2005). The dyslexic group’s performance on the ANT should provide some clarification on which attention network, if any, is impaired as previous research addressing this question is mixed (e.g., Hari et al., 1999; Lacroix et al., 2005). The comorbid group analysis, although exploratory, should provide information related to the similarity (common etiology hypothesis) of this group’s attention performance to either AD/HD or dyslexia.

The hypothesis that AD/HD postsecondary students would perform poorly on alerting and executive attention tasks was not supported. No alerting performance deficits were noted for the AD/HD group despite self-reporting significant inattention symptoms which underlie alerting impairments. Fernandez–Duque and Posner (2001) provided a rationale for this lack of effect as they argued that in order to gain a complete theoretical account of the alerting attention network, two types of tasks must be used, warning signal tasks and continuous performance tasks. Warning signal tasks (analogous to the ANT alerting task) test how quickly a person can attain maximum alertness in the perceptual field as induced by a warning cue (exogenous alerting). Alerting or readiness can also be
achieved by an incentive to process an expected target (endogenous alerting). Continuous performance tasks provide a measure of endogenous alerting by requiring participants to detect relatively rare and generally weak targets or by using a task that requires continual responding. Therefore, the current study’s finding of no alerting effects may be the result of utilizing an alerting task that does not capture all components of alerting attention.

Additionally, previous research that found AD/HD alerting deficits on the ANT utilized samples of children (mean age of 10 years). Reuda et al. (2004) found that on warning signal alerting tasks, children and adults encode target relevant information at equivalent rates; however, children make less use of the warning aspect of the cue. The mitigation of this developmental confound in this study through the use of adult AD/HD participants could account for the lack of significant alerting effects for this group.

Also contrary to previous research findings with AD/HD children, the adult AD/HD group in this study did not exhibit executive attention performance deficits. Executive attention as measured by the ANT consists of a flanker task that requires study participants to inhibit inappropriate response tendencies (impulse control) elicited by irrelevant information (Nigg, 2000). Discriminant functions analyses indicated that the AD/HD group self-reported significant inattention and hyperactivity symptoms but did not self-report significant impulsivity characteristics. Therefore, the lack of Executive attention effects may be the result of the AD/HD group not experiencing significant impulse control difficulties.

A further aim of this study was to examine attention performance in a group of postsecondary students with dyslexia. The results indicate that this group did not experience performance difficulties on any of the attention network tasks. A significant
confound in studies attempting to determine the cognitive etiology associated with dyslexia relates to inclusion criteria; dyslexic samples with comorbid attention problems or broad based language deficits are frequently included in research instead of participants with dyslexia only (Ramus, Pidgeon, Frith, 2003; Wimmer, Mayringer, Raberger, 1999). For example, in the Facoetti et al. (2000) and Hari et al. (1999) studies that found attention deficits in dyslexic groups, sample inclusion was not rigorously controlled to exclude these comorbidities. Therefore, utilization of diagnostically referred dyslexic participants without comorbidities in this study may have minimized inclusion confounds resulting in no significant group effects on attention tasks.

The exploratory analysis related to the attention performance of the comorbid group indicated longer executive attention response times in comparison to the AD/HD group and marginally longer executive attention response times than the dyslexic and control groups. Furthermore, the comorbid group exhibited longer overall response times and lower accuracy on the ANT compared to the AD/HD and control groups. This result is contrary to the common etiology hypothesis and appears to suggest that comorbid attention performance is distinct from that of the AD/HD group. However, discriminant functions analyses demonstrated that the comorbid group self-reported more impulsivity symptoms in comparison to the AD/HD group and poor impulse control is consistent with greater difficulties on the executive attention task of the ANT. Support for this finding is provided by Nigg (2001) who found that AD/HD groups with significant impulsivity symptoms exhibit deficits in executive attention tasks (i.e., flanker or Stroop tests). Further support is obtained from genetic research which has found that carriers of the TPH2 genotype (tryptophan hydroxylase 2 gene is a marker of low impulse control and
studies have demonstrated an association between TPH2 gene variations and AD/HD) display longer executive attention response time and reduced accuracy on the ANT compared to subjects without this genotype (Reuter, Ott, Vaitl, & Hennig, 2007). Wang and Fan (2007) found that longer executive attention response time is the result of difficulties resolving the conflict surrounding the direction of the target arrow in incongruent flanker conditions. In their computer modeling analysis of the ANT, Wang, Fan, and Johnson (2004) showed that in an incongruent flanker condition the attention system can employ recoding and/or refocusing strategies to determine the direction of the target arrow. However, as exhibited in this study, the comorbid group appears to have difficulties regulating these strategies as reflected by their processing costs: reduced accuracy and longer overall response times (Castellanos & Tannock, 2002; Kuntsi, Oosterlan, & Stevenson, 2001).

In conclusion the results from this study indicate that participants with AD/HD and greater self-reported impulsivity symptoms display executive attention impairments, reduced accuracy, and longer overall response times on the ANT. This finding indicates that the anterior cingulate cortex, a region of the prefrontal cortex activated by flanker tasks, is a likely anatomical site of attention deficits in this group (Nigg, 2001). The dyslexic group, contrary to previous research indicating prefrontal cortex and parietal lobe attention network deficits, did not display performance deficits on the ANT.

Future Directions and Limitations

The Attention Networks Test, which is based on Posner and Raichle’s (1994) model of attention networks, was used in this study to measure attention performance. Although the ANT has received strong empirical support it does not represent all facets of
attention. Future studies examining alerting attention should draw on the work of Sergeant, Oosterlaan, and van der Meere (1999) and implement tonic measures of alertness and wakefulness during sustained mental activity (e.g., continuous performance measure) to complement the ANT phasic alerting task (e.g., warning signal measure) to gain a more comprehensive understanding of alerting processes. The ANT provides a measure of covert orienting attention or the voluntary movement of attention utilizing endogenous (valid, predictive) cues. However, to gain a more complete picture of orienting attention, a task of overt attention or orienting to sudden changes in the perceptual field elicited by exogenous cues is required as well (Huang-Pollock & Nigg, 2003). Lastly, the ANT provided a measure of executive attention (flanker task) which required the ability to suppress competing responses that interfere with the completion of a primary task. However, to gain a more thorough view of executive attention future studies should implement measures of behavioural inhibition (i.e., the ability to suppress prepotent responses as measured by a stop task) and cognitive inhibition (i.e., suppress nonpertinent ideation to protect working memory/attention as demonstrated by negative priming tasks; Nigg, 2001). Additionally the modular components associated with the executive attention network such as working memory and cognitive set shifting should also be examined (Miyake, Freidman, Emerson, Witzki, & Howerter, 2000).

The findings obtained in this study were limited by the small sample size resulting in limited statistical power to detect potentially smaller effects that might be experienced in adults who have partially compensated for their attention problems. A further limitation was the gender distribution of the study groups which included more female than male participants. With the small sample size and unequal gender distribution per
study group the statistical power to detect gender differences related to ANT performance was low. Therefore, generalizing the findings from this study across sexes must be interpreted cautiously. Also, the primary investigator was not blind to group assignment when collecting questionnaire and cognitive data. This presents a potential threat to the internal validity of the study. The limited reliability of the ANT (test-retest correlations in the range of .52-.77; Fan et al., 2002) could have influenced findings in this study. The interpretation of the ANT is based on difference scores, which have problems of low reliability (Redick & Engle, 2006). Lastly, the findings for the AD/HD and AD/HD with comorbid dyslexia groups may have been influenced by stimulant medication that some of the students were taking as part of their treatment plan. Despite the request for students to refrain from medication on the days of testing, a complete medication washout period must be utilized to determine the performance of these groups on the ANT.

Notwithstanding the limitations noted, the main strength of the study was the use of stringent inclusion criteria to examine attention performance of AD/HD and dyslexic postsecondary students. The results from this study indicate, as found in previous research, that individuals with attention deficits and greater self-reported impulsivity symptoms display deficits in Executive attention performance as opposed to AD/HD individuals without impulsivity characteristics. The exclusion of individuals with comorbid attention problems and broad language deficits from the dyslexic group resulted in findings that dyslexic adults did not experience attention network performance impairments on ANT tasks.
CHAPTER 4: EXECUTIVE FUNCTIONS IN POSTSECONDARY STUDENTS WITH AD/HD AND DYSLEXIA

To cope successfully with changing environmental conditions, individuals must be able to evaluate and select from a menu of many possible actions. These actions are often framed within a prospective context and compete with alternative actions (Pennington, 2002). Executive functions (EFs) are the cognitive processes that maintain an appropriate problem solving set to attain a future goal (Welsh & Pennington, 1988). Although EFs are difficult to operationalize, as demonstrated by Sergeant, Geurts, and Oosterlan (2002) who found 33 separate definitions of the term, the seminal work of Pennington and Ozonoff (1996) provides a theoretically sound foundation for the conceptualization of EFs. Executive functioning is a broad umbrella term for a group of higher order cognitive abilities which includes the principal components of inhibition, set shifting, and working memory (Pennington & Ozonoff, 1996).

Inhibition is the ability to deliberately inhibit dominant, automatic, or prepotent responses, and control interfering stimuli or competing responses (Logan & Cowan, 1984). Heaton, Chelune, Talley, Kay, and Curtis (1993) described set shifting as the ability to shift cognitive set (e.g., to redirect focus) in response to changing environmental situations. Working memory is the ability to represent and manipulate information in mind (e.g., rules) to guide decision making and behaviour (Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005). Working memory is differentiated from short term memory, which primarily deals with the maintenance or the hold function of information online (Baddeley, 2003).
Miyake, Freidman, Emerson, Witzki, and Howeter (2000) demonstrated that although moderately correlated, inhibition, set shifting, and working memory are separable constructs which differentially predict performance on many complex neuropsychological tasks. Neuroimaging studies support the Miyake et al. (2000) finding as they indicate that these three components of EFs have different anatomical foci within the prefrontal cortex (PFC). The ability to inhibit responses relies on the orbitofrontal PFC (Aron, Robbins, & Poldrack, 2004), cognitive set shifting is contingent on medial PFC activation (Rushworth, Walton, Kennerley, & Bannerman, 2004), and the ability to manipulate information (i.e., working memory) depends on activation of the lateral PFC (Narayanan, et al., 2005).

Developmental studies pertaining to EFs indicate that inhibitory control increases throughout childhood and reaches an adult level of performance at approximately 12 to 15 years of age (Huizinga, Dolan, & van der Molen, 2006). The cost of cognitive set switching between tasks decreases as children grow older, with adult levels of performance being attained around the age of 12 (Kray, Eber, & Lindenberger, 2004). Working memory capacity develops gradually throughout childhood and into adolescence (Luciana, Conklin, Hooper, & Yarger, 2005).

Optimal EFs performance requires support from vigilance and processing speed. Vigilance consists of endogenous arousal and exogenous alerting processes that provide the activation necessary to effectively engage EFs (Sergeant, Guerts, Huijbregts, Scheres, & Oosterlan, 2003). Neuroimaging studies have found that activity in frontal and parietal regions when individuals achieve and maintain the alert state (Raz, 2004). Salthouse (2005) suggested that processing speed represents a major underlying factor related to
EFs performance. More specifically, Shanahan et al. (2006) posit that processing speed allows integration of lower perceptual cognitive processes with higher order EFs to maximize overall cognitive efficiency. There are distinct components of processing speed which include simple and complex processing speed factors (Shanahan et al., 2006). Simple processing speed tasks require ongoing processing to a single stimulus with a simple response. Complex processing speed tasks are similar to simple tasks except that they require a decision regarding the quality of the stimulus being processed (Chiaravalloti, Christodoulou, Demaree, & DeLuca, 2010) and the holding of more information in working memory.

Cognitive executive dysfunction has been found in a broad range of neuropsychiatric and developmental disorders including AD/HD and dyslexia in adults (Barkley, 1997; Hynd & Semrud-Clikeman, 1989; Pennington & Ozonoff, 1996; Weyandt, Rice, Linterman, Mitzlaff, & Emert, 1998). Therefore, using Pennington and Ozonoff’s (1996) conceptualization of EFs, this study examines performance on inhibition, set shifting, and working memory tasks in adults with AD/HD, dyslexia, and ADHD with comorbid dyslexia (comorbid group). Vigilance and processing speed performance are also examined in these groups. This study mitigates the confound of developmental maturation by using an adult sample.

Attention Deficit/Hyperactivity Disorder

Attention Deficit/Hyperactivity Disorder (AD/HD) is a developmental neurobehavioural disorder characterized by a broad array of cognitive, neuropsychological, behavioural, and emotional indicators (American Psychiatric Association, 2000). The primary symptoms of this disorder throughout the lifespan
include hyperactivity, impulsivity, and inattentiveness (Barkley, 1998). The current diagnostic guidelines, as outlined in the Diagnostic and Statistical Manual (DSM-IV-TR; American Psychiatric Association, 2000), list three subtypes of AD/HD in children and adults: predominantly inattentive type, predominantly hyperactive/impulsive type, and a combined type which includes symptoms of inattention, hyperactivity, and impulsivity.

Approximately 50%-70% of children with AD/HD exhibit the primary symptoms of the disorder well into adulthood (Barkley, 1998). AD/HD affects between 2% and 12% of elementary school children and approximately 4% of adults (Sagvolden, Aase, Borga-Johansen, & Russell, 2005). Furthermore, it is estimated that AD/HD is prevalent in 2% to 4% of the postsecondary student population (DuPaul et al., 2001). Postsecondary students with AD/HD obtain a lower grade point average, are less likely to graduate, and demonstrate more significant levels of psychological distress and aggression than non-AD/HD students (Weyandt & DuPaul, 2006). In addition to academic and behavioural difficulties, approximately 30%-50% of individuals with AD/HD may have cognitive deficits, specifically in the area of EFs (Seidman, 2006). It is critical to examine the association of EFs deficits and AD/HD as Biederman et al. (2008) found that AD/HD adults with EFs deficits had significantly lower socioeconomic status, educational attainment, and occupational outcomes when compared to AD/HD adults without EFs deficits.

Barkley (1997) theorized that the AD/HD hyperactive/impulsive type and combined type are associated with proximal deficits in EFs. Support for this hypothesis is obtained from structural and functional neuroimaging research and through meta-analyses of EFs deficits in children with AD/HD hyperactive/impulsive type and combined type in
comparison to non-AD/HD children (Nigg, 2005). According to Nigg, Wilcutt, Doyle, and Sonuga-Barke (2005) EFs deficits are viable core cognitive impairments in children with the hyperactive/impulsive type and combined type of AD/HD. Barkley (1997) argued that the AD/HD predominantly inattentive type is associated with a different set of cognitive deficits which Lahey et al. (1998) characterized as sluggish cognitive tempo symptoms. AD/HD predominantly inattentive children with these symptoms exhibit vigilance and processing speed impairments due to slow information processing abilities and low levels of alertness (Barkley, DuPaul, & McMurray, 1990).

Most EF tests were conceptualized, developed, and normed for use with adults and results from these tests can be applied without reference to variables associated with brain maturation, a developmental process often implicated as a potential contributor to performance differences in AD/HD (Tannock, 1998). The use of the Test of Variables of Attention (TOVA; Greenberg, Kindschi, & Corman, 2000), a continuous performance test, has been recommended as an assessment tool for adults with AD/HD as it reliably discriminates inhibition and vigilance deficits in this group compared to non-AD/HD controls (Weyandt et al., 1998). The Wisconsin Card Sorting Task (Heaton, 1981) has long been considered in general neuropsychological literature to be one of the premier measures of set shifting in AD/HD adults (Seidman & Bruder, 2003). Hervey, Epstein, and Curry’s (2004) meta-analysis of memory deficits in AD/HD adults indicated that the Digit Span Backward test is sensitive to working memory deficits in adults with AD/HD.

According to Hervey et al. (2004) the effect size of a variety of continuous performance tests to discriminate between individuals with AD/HD and non-AD/HD controls was in the moderate to large range. However, the few studies utilizing the TOVA
with AD/HD adults have displayed mixed results. Ossmann and Mulligan (2003) found that AD/HD adults exhibited significant inhibition deficits on the TOVA in comparison to non-AD/HD adults. Conversely, Forbes (1998) found that an adult AD/HD group displayed significant vigilance deficits but not inhibition impairments on the TOVA compared to a control group without AD/HD. Despite its validity in discriminating children with AD/HD from normal controls (Barkley, Grodzinsky, & DuPaul, 1992; Romine, Lee, & Wolfe, 2004), the WCST has been reported to be ineffective in distinguishing adults with AD/HD from clinical reference groups or healthy controls (Gansler, Fucetola, Krengel, Stetson, Zimering, & Makary, 1998; Holdnack, Moberg, Arnold, Gur, & Gur, 1995; Weyandt et al., 1998). Mahone et al. (2002) reviewed the literature on WCST performance and identified a significant confound that contributes to reported nonsignificant findings. Criterion for inclusion in the AD/HD group (self or questionnaire referral versus diagnostic referral) appears to confound WCST performance in AD/HD adults with the latter referral method being associated with more effective discrimination. The empirical evidence for working memory deficits in adults with AD/HD is equivocal. In a meta-analysis examining working memory deficits, Hervey et al. (2004) found that Digit Span (Wechsler, 1994) performance in adults with AD/HD appears to be mildly impaired compared to non-AD/HD adults. Conversely, in a review of EFs in AD/HD adults, Pennington and Ozonoff (1996) concluded that there was no robust evidence of working memory impairments. The findings are likely because studies have not always controlled for potential confounding variables such as comorbid reading difficulties or language impairments. Several studies suggest that if these factors were
controlled, adults with AD/HD may not exhibit impairments on working memory tasks (Rucklidge & Tannock, 2002; Wilcutt et al., 2001)

Barkley (1997) theorized that the AD/HD primarily inattentive subtype, as opposed to the hyperactive/impulsive and combined subtypes, is associated with vigilance deficits. However, Huang-Pollock, Nigg, and Halperin (2006) found that both the inattentive and combined subtypes of children with AD/HD had vigilance system dysregulation deficits as detected by a continuous performance test. There is limited research regarding use of the TOVA to detect vigilance deficits in adults with AD/HD. Forbes (1998) found vigilance impairments in a group of AD/HD adults in comparison to a control sample using the TOVA. Impairments in processing speed are found in adults with AD/HD (Woods, Lovejoy, & Ball, 2002), and several studies have found that processing speed performance is one of the most discriminating predictors of inattention in children with AD/HD (Chhabildas, Pennington, & Wilcutt, 2001; Rucklidge & Tannock, 2002; Wilcutt, Doyle, Nigg, Faraone, & Pennington, 2005).

In summary, previous research supports deficits in EFs, vigilance, and processing speed in AD/HD children. However, the hypothesis that executive functions, vigilance, or processing speed deficits are core impairments in adults with AD/HD requires further analysis (Weyandt & DuPaul, 2006).

Dyslexia

Dyslexia, or specific reading disability, is characterized by significant difficulties in acquiring basic reading subskills such as word identification and phonological (letter-word) decoding in individuals with at least average intelligence and whose reading problems are not due to extraneous factors such as sensory acuity deficits, socioeconomic
disadvantage and like factors (Vellutino, Fletcher, Snowling, & Scanlon, 2004). Developmental dyslexia is among the most common of learning disabilities, with adult prevalence estimates ranging from 5% to 17.5% (Shaywitz, 1998; Stoet, Markey, & Lopez, 2007). Studies of dyslexia indicate that the major symptom pattern defining dyslexia (i.e., a basic deficit in word recognition) persists well into adulthood (Bruck, 1993; Hatcher, Snowling, & Griffiths, 2002). The academic ramifications of dyslexia from a postsecondary perspective include inaccurate and dysfluent word recognition and spelling skills, and poor reading comprehension abilities. Consequently, dyslexic postsecondary students employ immature and ineffective strategies for word recognition and spelling compared to age-matched controls (Bruck, 1993; Kirby, Silvestri, Allingham, Parrila, & LaFave, 2008).

Phonological awareness plays an important role in reading progress and achievement (Castles & Coltheart, 2004; Wagner & Torgesen, 1987). There is robust evidence that individuals with developmental dyslexia have phonological impairments (Pennington, Orden, Smith, Green, & Haith, 1990; Scarborough, 1990). Furthermore, the persistence of phonological deficits is evident in adults with dyslexia (Ramus et al., 2003; Shaywitz et al., 1999). The view that a phonological deficit is the sole cognitive impairment in developmental dyslexia is difficult to reconcile considering the numerous studies that find attention problems and dyslexia co-occur more frequently than explained by chance. It has been estimated that 15% to 40% of children with dyslexia also have AD/HD and that 25%-40% of children with AD/HD have dyslexia (Semrud-Clikeman et al., 1992; Wilcutt & Pennington, 2000). Therefore, the phenotypic expression of attention
deficits along with phonological processing impairments in dyslexia has led researchers
to examine potential EFs deficits within this clinical group.

Dyslexic children perform poorly on inhibition tasks, specifically continuous
performance tests (Losier, McGrath, & Klein, 1996; Tarnowski, Prinz, & Nay, 1986).
Taroyan, Nicolson, and Fawcett (2007) questioned whether dyslexic children would
display inhibition deficits on continuous performance tests in the absence of AD/HD
symptoms. Across studies related to performance on the WCST, a measure of cognitive
set shifting, dyslexic children tend to perform somewhat better than non-dyslexic
children. Small to medium effects have been found indicating that dyslexic children made
fewer perseveration errors (perseverative errors indicate an inability to flexibly shift
cognitive set) compared to non-dyslexic children (Helland & Asbjornsen, 2000; Reiter,
Tucha, & Lange, 2005).

Working memory is the most extensively studied aspect of executive functioning
in children with dyslexia (Reiter et al., 2005). A number of studies have shown auditory
working memory deficits in children with dyslexia compared to non-dyslexic children
(Chiappe, Hascher, & Siegel, 2000; Wilcutt et al., 2001). More specifically, Pickering and
Gathercole (2001) found dyslexic children to exhibit lower backwards digit span scores
than control samples. Compared to the numerous studies supporting auditory working
memory deficits in dyslexic children, those pertaining to visual or visual-spatial working
memory deficits have mixed results. Although there is some evidence in support of a
deficit in this domain for dyslexic children (Smith-Spark & Fisk, 2007; Swanson, 1992),
recent studies have failed to find significant differences (Jeffries & Everatt, 2004; Kibby,
dyslexic samples are defined narrowly, excluding broad language deficits, only specific auditory working memory deficits appear, and these continue into adulthood.

There are few studies of inhibition performance in adult dyslexics. Taroyan et al. (2007) found no significant differences in errors of commission (an index that gauges inhibition skills) when comparing a small sample of adolescents with dyslexia to a normal control group. Similarly, Weyandt et al. (1998) found no differences in inhibition performance as measured by the TOVA when comparing a sample of postsecondary students with developmental reading disorder to a control group without dyslexia. With respect to set shifting deficits in adult dyslexics, Weyandt et al. (1998) found that reading disordered students exhibited deficits in set shifting as evidenced by a higher perseverative error score on the WCST compared to a control group without dyslexia. However, the selection of reading disordered participants in this study was not rigorously controlled to exclude comorbid attention problems which could have contributed to the obtained results (Mahone et al., 2002). The use of dyslexic groups with comorbid attention problems or wider language difficulties could lead to more deficits being observed.

Numerous studies have demonstrated that individuals with dyslexia have problems with rapid naming of letters, objects, numbers, and colors (Kirby, Parrila, & Pfeiffer, 2003; Wolf & Bowers, 1999). Although the causal mechanism of rapid naming deficits in dyslexic groups has not been determined, a general processing speed impairment has been argued to contribute to rapid naming difficulties (Kail & Hail, 1994). Previous research has found that children with dyslexia have been found to display difficulty with processing speed tasks that are thought to be less dependent on linguistic
abilities, such as the Wechsler (1994) Coding and Symbol Search subtests (Kail & Hail, 1994; 1999; Catts, Gillespie, Leonard, Kail, & Miller, 2002). There were no previous studies found of vigilance performance in adult dyslexics

AD/HD with Comorbid Dyslexia

To thoroughly understand EFs, vigilance, and processing speed performance in AD/HD and dyslexia, groups with dyslexia-only, AD/HD-only, and AD/HD with comorbid dyslexia should be compared. Previous research comparing these groups is primarily etiologically driven and has found that core impairments associated with both AD/HD and dyslexia lead to the phenotypic cognitive expression of the comorbid group (Nahri & Ahonen, 1995; Wilcutt et al., 2001). Furthermore, the common etiology hypothesis (Wilcutt, Pennington, Olson, Chhabildas, & Huslander, 2005) suggests that since the same etiological influences contribute to most cases of AD/HD and dyslexia, the cognitive deficits of the comorbid group should essentially be the sum of deficits associated with both AD/HD and dyslexia alone.

The Current Study

The current study investigates EFs performance in adults with AD/HD, dyslexia, and AD/HD with comorbid dyslexia, using Pennington and Ozonoff’s (1996) theoretical framework of EFs. The cognitive domains of vigilance and processing speed that are associated with EFs are also examined.

This study aims to overcome several methodological limitations in previous studies. Clinical group inclusion for this study was based on diagnostic referrals from a psychologist or psychological associate rather than to self or questionnaire referrals and the maturation confound related to EFs tasks is mitigated through the use of adult clinical
groups. Furthermore, the comparison of cognitive performance among clinical groups, as opposed to solely with normal control participants, should provide more specificity of deficits associated with the individual clinical groups. Finally, EFs and associated cognitive measures with demonstrated construct validity are employed and these measures are used as covariates to each other, when necessary, to increase purity of measurement in statistical analyses.

I hypothesize that the AD/HD and comorbid groups will exhibit deficits in all EFs, processing speed, and vigilance (Forbes, 1998; Nigg, 2005; Ossmann & Mulligan, 2003; Shanahan et al., 2006). The second hypothesis is that the dyslexic group will display EFs deficits specific to auditory working memory and exhibit impairments in processing speed (Savage et al., 2007; Shanahan et al., 2006). Third, I hypothesize that the comorbid group’s cognitive deficits will be similar to the deficits found in AD/HD and dyslexia when considered separately (Wilcutt et al., 2005).

Method

Participants

The 73 participants in this study were undergraduate students recruited from Trent University, in Peterborough, Ontario and attending the 2006 summer, 2006 fall, or the 2007 winter academic sessions. There were 22 males and 51 females. Copies of the Research Ethics Board approval to commence testing are found in Appendices A and B and all students provided informed consent prior to testing.

The students with disabilities were registered with the Disability Services Office at Trent University and were recruited through a disability services list serve announcement asking for volunteers. Students with disabilities formed the following
groups: AD/HD, which included both the predominately inattentive type and the predominantly hyperactive/impulsive/combined type \((n = 23, 11\) of whom were male), dyslexic \((n = 19, 5\) of whom were male), and students with AD/HD and comorbid dyslexia (comorbid, \(n = 10, 4\) of whom were male). The mean chronological ages of the AD/HD, dyslexic, and comorbid groups were respectively, 23.3 years \((SD = 3.2)\), 21.9 years \((SD = 2.0)\), and 22.0 years \((SD = 2.6)\). The control group consisted of 21 student participants \((2\) of whom were male) who were recruited through posters placed throughout the university detailing the study and requesting volunteers. The mean chronological age of this group was 20.4 years \((SD = 3.2)\).

*Diagnostic Group Exclusionary Criteria*

Potential participants with a documented brain injury or sensory deficit (e.g., hearing and/or vision impairments) were excluded from the sample. Participants had to have a standard score of 85 or greater on an intellectual measure to be included in the study. Estimated intellectual ability was assessed through the composite score obtained from administration of the Vocabulary and Block Design tests (Sattler, 1992) of the Wechsler Adult Intelligence Scale–Third Edition (Wechsler, 1994).

*Diagnostic Criteria for Group Assignment*

Members of the AD/HD group had to have a current psychoeducational assessment and diagnosis of AD/HD provided by a psychologist or psychological associate. The psychoeducational assessment included a structured clinical interview based on DSM-IV-TR (2000) criteria for AD/HD and corroboration of *DSM-IV-TR* (2000) criteria with parent and teaching rating scales. Additionally, a standardized IQ test (primarily WAIS-Third Edition), tests of information processing, and a full battery of
achievement tests assessing all aspects of reading, writing, and math were administered. Only students with an affirmed DSM-IV-TR (2000) diagnosis (i.e., the presence of six or more symptoms in at least one of the two symptom groups of inattention or hyperactivity/impulsivity) were included in the AD/HD group. Inclusion in the dyslexic group required a diagnosis of dyslexia or specific reading disability by a psychologist or psychological associate as stated in a current psychoeducational assessment. Although the tests used by individual clinicians differed, the diagnosis of dyslexia or specific reading disability was guided by the Learning Disability Association of Canada’s (LDAC, 2002) discrepancy based definition. The LDAC definition states that impairment in one or more psychological processes (e.g., phonological processing) related to learning, in combination with otherwise average abilities essential for thinking and reasoning, and unexpectedly low academic achievement (e.g., in reading) are required for a diagnosis of a learning disability. The comorbid group was similarly diagnosed and consisted of students with an affirmed AD/HD diagnosis based on DSM-IV-TR (2000) criteria and a confirmed diagnosis of dyslexia or specific reading disability as stated on a psychoeducational assessment. For inclusion into the control group, students had to (a) exhibit no at-risk or high-risk scores on the College AD/HD Response Evaluation - Student Response Inventory (CARE-SRI; Glutting, Sheslow, & Adams, 2002) Factor and DSM-IV scales employing both gender and general norms, (b) score below the cut-off scores established by LeFly and Pennington (2000) on the Adult Reading History Questionnaire-Revised (ARHQ-R; Parrila, Corkett, Kirby, & Hein, 2003; see also Kirby et al., 2008) indicating that no significant reading difficulties were present, and (c) exhibit average or better scores in comparison to age normative data on the Test of Word
Reading Efficiency Phonemic Decoding and Sight Word subtests (Wagner, Torgesen, & Rashotte, 1996) and on the Rapid Naming subtest of the Comprehensive Test of Phonological Processing (Wagner, Torgesen, & Rashotte, 1999).

**Measures**

*CARE-SRI.* The College AD/HD Response Evaluation – Student Response Inventory (Glutting et al., 2002) is a 59 item self-rating scale designed to provide information relevant to the assessment of AD/HD at the university level. The CARE-SRI provides two different systems for interpreting results: factor scores and DSM-IV (diagnostic) scores. The factor scales are: Inattention, Hyperactivity, and Impulsivity. The diagnostic scales are the DSM-IV Inattention and the DSM-IV Hyperactivity/Impulsivity scales.

The CARE-SRI manual (Glutting et al., 2002) indicates that the alpha coefficients for the factor scales of Inattention, Hyperactivity, and Impulsivity are .82, .87, and .77, respectively. The alpha coefficients for the DSM-IV Inattention and Hyperactivity/Impulsivity scales are .63 and .65. For the current sample, the alpha coefficients for the factor scales of Inattention, Hyperactivity, and Impulsivity were .83, 83, and .80, respectively. The alpha coefficient for the current sample on the DSM-IV Inattention and Hyperactivity/Impulsivity scales were .73 and .82.

*ARHQ-R.* The Adult Reading History Questionnaire–Revised (Parrila et al., 2003) is based on the Adult Reading History Questionnaire (ARHQ) developed by Lefly and Pennington (2000). Respondents are asked about their reading and spelling ability, reading speed, attitudes toward school and reading, additional assistance they received, repeating grades or courses, effort required to succeed, and print exposure. These types of
questions are asked separately for elementary, secondary, and postsecondary education. For this study, only the postsecondary items were utilized. Scoring for this questionnaire is based on the proportion of the total points possible for the postsecondary items, with higher proportions indicating more symptoms of reading difficulty. Lefly and Pennington (2000) reported the alpha coefficient of the original ARHQ to be .94 and the test-retest reliability over a two year period to be .87. For the current sample, the alpha coefficient for the Postsecondary Basic Reading scale was .79. Refer to a copy of this questionnaire in Appendix C.

**TOVA.** The Test of Variables of Attention (Greenberg et al., 2000) is an individually administered computerized 23 minute fixed-interval visual continuous performance test designed to measure inhibition (i.e., a simple inhibition task employing a GO/NO-GO paradigm to reduce working memory effects) and endogenous vigilance (i.e., a simultaneous discrimination task to minimize working memory demands). One of two easily discriminated visual stimuli was randomly presented for 100 milliseconds every 2 seconds. The stimuli consisted of a larger coloured square containing a smaller square in either the top or bottom half of the larger square. The stimulus configuration in which the inner square is in the top half of the larger square is the designated target. Participants are instructed to press a switch every time they see this stimulus. The target-non-target ratio differs in the two halves of the TOVA. The target is presented on 22.5% of the trials during the first half (stimulus infrequent condition) and on 77.5% of the trials during the second half (stimulus frequent condition). The dependent measures of the TOVA are standard scores (based on TOVA age equivalent normative samples) of Inhibition and Vigilance in stimulus infrequent and stimulus frequent conditions.
Inhibition errors occur when the participant incorrectly responds to a non-target, and vigilance errors are displayed when the subject does not respond to the designated target. Test-retest reliability correlation coefficients for nondisabled children ($M = 8.31$ years) using a 90 minute time interval for response inhibition scores and vigilance scores were .78 and .80 respectively (Greenberg et al., 2000). I will refer to these variables as Inhibition (F), Inhibition (I), Vigilance (F), and Vigilance (I), where F indicates frequently occurring stimuli and I indicates infrequently occurring stimuli.

**WCST.** The Wisconsin Card Sorting Test – 64 Card Version (Kongs, Thompson, Iverson, & Heaton, 2000) is an abbreviated form of the standard 128 card version of the Wisconsin Card Sorting Test (WCST; Heaton, 1981). The WCST requires individuals to sort 64 cards to match either color (red, blue, yellow, or green), form (crosses, circles, triangles, or stars), or number of figures (one, two, three, or four) to target cards. The dependent measure of the WCST is the Perseverative Error score, which measures the inability to flexibly shift cognitive set (between color, form, and number). A higher Perseverative Error score is reflective of set shifting difficulties. The WCST has been found to be sensitive to set shifting differences between AD/HD children and control groups (Barkley et al., 1992). Ozonoff (1995) found test-retest coefficients greater than .90 in a study of children and adolescents with learning problems over an interval of approximately 2.5 years. We will refer to this score as WCST Errors.

The *Digit Span* subtest of the Wechsler Adult Intelligence Scale, Third Edition (WAIS-III; Wechsler, 1994) is composed of two independently administered tasks: Digit Span Forward and Digit Span Backward. In Digit Span Forward, the examinee is required to repeat a digit sequence in the same order as presented; this measures auditory short-
term memory. Digit Span Backward requires the examinee to repeat a digit sequence in
the reverse order; it assesses auditory working memory. The dependent measures for each
are the number sequences recalled correctly. Split-half reliability coefficients for Digit
Span (composite of Digit Span Forward and Backwards) are .91 and .90 respectively for
subjects 18-19 and 20-24 years of age (Wechsler, 1994).

The Auditory Digit Sequence subtest of the Swanson Cognitive Processing Test
(SCPT; Swanson, 1996) assesses the respondent’s auditory working memory. It examines
the ability to remember numerical information embedded in a short sentence. The
dependent measure is the number of digit sets correctly recalled (range of 0-9).
Coefficient alpha with the effects of age partialed out is .73 (Swanson, 1996).

The Visual Matrix subtest of the SCPT (Swanson, 1996) assesses the examinee’s
visual-spatial working memory. The examiner presents a series of dots in a matrix and
allows the examinee 5 seconds to study the matrix. After the examinee answers a process
question (i.e., “Are there any dots in the first column”), the examiner presents a blank
matrix (a grid with no dots) and asks the examinee to draw the dots in the correct boxes.
The items range in difficulty from a matrix of 4 squares with 2 dots to a matrix of 45
squares with 12 dots. The dependent measure is the number of matrices reproduced
correctly (range 0-11). Coefficient alpha with the effects of age partialed out is .73
(Swanson, 1996).

The Speed of Information Processing Test (Kirby, 2005) consists of two parts. In
each item of the simple processing task (10 items in total), the participant is shown a
target digit and asked to circle all examples of it within a series of digits. The dependent
measures are the Time needed to complete all 10 items, and Efficiency (calculated by
subtracting errors and omissions from correct responses and dividing this number by the total time). For the 10 items of the complex processing speed task, the participant is shown a four-to-six digit target and asked to circle all examples of it within a series of digit sequences of equal length. The dependent measures are again the Time needed to complete all 10 items, and Efficiency (calculated in the same way as in the Simple task). This test takes approximately two minutes to complete. Reliability coefficients could not be calculated because there is only one score per dependent variable (Time and Efficiency) for both simple and complex processing speed tasks. See Appendix D for a copy of this measure.

The *Phonemic Decoding Efficiency* subtest (Form A) of the Test of Word Reading Efficiency (Wagner, Torgesen, & Rashotte, 1996) measures the number of pronounceable nonwords that can be accurately decoded within 45 seconds. The dependent measure is the total number of nonwords correctly pronounced within 45 seconds. Alternate form reliability is .94 for individuals 18 to 24 years of age (Wagner et al., 1996).

The *Sight Word Efficiency* subtest (Form A) of the Test of Word Reading Efficiency (Wagner et al., 1996) assesses the number of printed familiar words that can be accurately identified within 45 seconds. The dependent measure is the total number of words correctly pronounced within 45 seconds. Alternate form reliability is .93 for individuals 18 to 24 years of age (Wagner et al., 1996).

The *Rapid Digit Naming* subtest of the Comprehensive Test of Phonological Processing (Wagner, Torgesen, & Rashotte, 1999) is a 72 item subtest that measures the speed with which an individual can name digits. The dependent measure is the total number of seconds taken to name all the digits on both stimulus sets. This test is a
measure of rapid automatized naming ability. Test-retest reliability (14 day interval) for the 18-24 age level is .90 (Wagner et al., 1999).

Procedure

The testing was completed in two sessions lasting approximately 75 minutes per session. The tests were administered in a quiet room removed from distractions and possible interruptions at Trent University. All students were asked to be off psychostimulant medication for at least 24 hours prior to testing as research indicates improved performance on EFs measures for AD/HD individuals taking psychostimulants (Kempton et al., 1999). The author of the study administered the questionnaires and psychometric measurements to the study participants.

Results

Data Treatment and Missing Values

All dependent measures were examined for accuracy of data, missing values, and fit between their distributions and the assumptions of analyses of variance and analyses of covariance. One participant from the control group was not available to take the TOVA, therefore missing values were replaced by regression. All dependent variables were examined for extreme values (i.e., scores > 2.5 standard deviations from the mean of each study group) as suggested by Tabachnick and Fidell (2007). The following dependent measures each displayed one outlier: Vigilance (I), Digit Span Forward, Simple Time, and Simple Speed. Inhibition (F). Vigilance (F) and Digit Span Backward each exhibited two outliers, and Inhibition (I) and WCST Errors each had three outliers. Outliers were transformed by assigning a raw score to the outlier that was one unit larger (or smaller) than the next most extreme score in the distribution (Tabachnik & Fidell, 2007). All
outcome measures were screened for violations of the normal distribution. For all dependent variables, the Shapiro-Wilkes and Kolmogorov-Smirnov Lillefors tests of normality were significant, indicating that the assumption of normality was not achieved.

**Statistical Analyses**

Because all dependent variables violated normality assumptions, Kruskal-Wallis and Mann-Whitney U tests were performed for all outcome measures in addition to parametric tests. However, because the Kruskal-Wallis and Mann-Whitney U tests produced comparable results to the parametric tests, the parametric results are reported here. Separate univariate analyses of variance and analyses of covariance (if required) were used for each dependent measure. Partial eta squared ($\eta_p^2$) is reported for all group comparisons to convey effect size for univariate analyses of variance and analyses of covariance. Partial eta squared has the following effect size conventions: small (.05), medium (.10), and large (.20) (Cohen, 1969).

**Descriptive Statistics**

ANOVAs and Tukey-Kramer post hoc comparisons pertaining to demographic and descriptive characteristics of the study participants are summarized in Table 6. Diagnostic groups did not differ on estimated full-scale IQ, $F (3, 69) = 1.03, p = .38, \eta_p^2 = .04$. Post hoc Tukey-Kramer comparisons indicated that the AD/HD group displayed a higher mean age in comparison to the control group ($p < .01$). The higher mean age of AD/HD study participants is consistent with previous research that indicates students with disabilities enter postsecondary education at an older age than their non-disabled peers (Foreman, Dempsey, Robinson, & Manning, 2001). To investigate the effect of age differences on performance, the sample was stratified into groups
representing one standard deviation below the mean age (under 19 years), within one standard deviation (20 to 24 years), and above one standard deviation of the mean age (25 years and older), and the performance of these groups on the EFs, vigilance, and processing speed measures was compared. Analyses of variance indicated that the three groups did not differ statistically. A Pearson chi-square test indicated that there was a significant difference in gender distribution across the groups, $X^2 (3, N=73) = 8.25, p = .04$. Pairwise comparisons indicated that the control group had a significantly greater female-to-male ratio than the AD/HD group, $t (42) = 2.93, p < .01$, and the comorbid group, $t (29) = 2.01, p \leq .05$. The higher participation rate of female compared to male students was unexpected. This result can be attributed in part to the greater number of females in the nondisabled student population at Trent University, and to the higher volunteer rate of females for psychological research in postsecondary institutions (Martin & Marcuse, 1958; Rosenthal, 1965). To examine the effect of gender, $t$-tests comparing the EFs, vigilance, and processing speed scores of males and females were computed and resulted in no statistically significant differences between the sexes. Because of these nonsignificant results, age and sex were not included in subsequent analyses.
Table 6.
Demographic Variables, IQ and Symptom Severity Information by Diagnostic Group

<table>
<thead>
<tr>
<th>Variable</th>
<th>Comorbid (n = 10)</th>
<th>AD/HD (n = 23)</th>
<th>Dyslexia (n = 19)</th>
<th>Normal (n = 21)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Age in Years</td>
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<td>2.62</td>
<td>23.26</td>
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<tr>
<td>Estimated FSIQ</td>
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<td>8.68</td>
<td>111.78</td>
<td>15.27</td>
</tr>
<tr>
<td>Sex Rates Female</td>
<td>60.0%</td>
<td>52.2%</td>
<td>73.7%</td>
<td>90.5%</td>
</tr>
<tr>
<td>Care-SRI DSM-IV Scales</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hyperactive-Impulsive</td>
<td>12.40</td>
<td>4.93</td>
<td>9.39</td>
<td>4.05</td>
</tr>
<tr>
<td>Inattention</td>
<td>11.90</td>
<td>3.28</td>
<td>11.26</td>
<td>3.36</td>
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<tr>
<td>Care-SRI Factor Scales</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hyperactivity</td>
<td>17.40</td>
<td>4.01</td>
<td>15.13</td>
<td>4.65</td>
</tr>
<tr>
<td>Impulsivity</td>
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<td>7.22</td>
<td>11.83</td>
<td>6.31</td>
</tr>
<tr>
<td>Inattention</td>
<td>28.60</td>
<td>5.56</td>
<td>26.74</td>
<td>6.40</td>
</tr>
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<td>ARHQ-R PSBR Ratio</td>
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<td>.14</td>
<td>.47</td>
<td>.14</td>
</tr>
<tr>
<td>TOWRE Phonemic Decoding</td>
<td>38.60</td>
<td>14.92</td>
<td>59.00</td>
<td>4.77</td>
</tr>
<tr>
<td>CTOPP Rapid Digit Naming</td>
<td>28.83</td>
<td>8.02</td>
<td>21.08</td>
<td>3.46</td>
</tr>
</tbody>
</table>

Note. ADHD = Attention Deficit/Hyperactivity Disorder; FSIQ = Full scale IQ; CARE-SRI = College ADHD Response Evaluation Student Response Inventory; ARHQ-R = Adult Reading History Questionnaire - Revised; PSBR= Post Secondary Basic Reading scale; TOWRE = Test of Word Reading Efficiency; CTOPP = Comprehensive Test of Phonological Processing; ηp² = partial eta squared; C = comorbid; A = AD/HD; D = dyslexia; N = normal.
Table 6 also provides a description of the diagnostic groups based on their self-reported symptoms of AD/HD on the CARE-SRI scales and of reading difficulties on the ARHQ-R Postsecondary Basic Reading scale. Higher means on the CARE-SRI and ARHQ-R scales are associated with greater symptoms and difficulties. Consistent with diagnostic grouping, the AD/HD and comorbid groups displayed significantly higher symptoms on all CARE-SRI scales compared to the dyslexic and control groups. The comorbid group did not differ statistically from the AD/HD group on the CARE-SRI scales, however, there was a trend for the comorbid group to have higher means. The dyslexic and comorbid groups reported more reading difficulties compared to the AD/HD and control groups on the ARHQ-R Postsecondary Basic Reading scale. The comorbid and dyslexic groups did not differ statistically on the ARHQ-R, however, there was a trend for the comorbid group to report more reading difficulties. To substantiate reading difficulties in the comorbid and dyslexic groups, a series of ANOVAs with Tukey-Kramer post hoc comparisons (summarized in Table 6) indicated that dyslexic and comorbid groups displayed significant deficits in comparison to the AD/HD and control groups on the TOWRE Phonetic Decoding Efficiency and TOWRE Sight Word Efficiency tests. Additionally, the dyslexic and comorbid groups were significantly slower on the Rapid Digit Naming Test compared to the AD/HD and control groups.

Two discriminant analyses were conducted to explore the ability of the CARE-SRI scales and the ARHQ-R Postsecondary Basic Reading scale to classify groups. In the first, classification by the ARHQ-R Postsecondary Basic Reading scale and the CARE-SRI DSM-IV Inattention and DSM-IV Hyperactivity/Impulsivity scales was carried out for the groups. Three discriminant functions were derived with a significant overall Wilks
lambda, Λ = .24, $X^2 (9, N = 73) = 97.79, p < .01$. Removal of the first discriminant function resulted in a significant Wilks Lambda, Λ = .64, $X^2 (4, N = 73) = 30.27, p < .01$, and with removal of the first and second discriminant functions, the Wilks Lambda remained significant, Λ = .88, $X^2 (1, N = 73) = 8.92, p < .01$. The structure matrix of correlation coefficients between predictors and discriminant functions indicated that the CARE-SRI DSM-IV Inattention scale demonstrated the strongest relationship with the first discriminant function ($r = .93$). The second discriminant function exhibited a high correlation ($r = .99$) with one predictor only: ARHQ–R Postsecondary Basic Reading scale. The CARE-SRI DSM-IV Hyperactivity/Impulsivity scale had the only strong correlation with the third discriminant function ($r = .76$). The group centroids indicated that the AD/HD group displayed its highest mean on the first discriminant function, while the dyslexic group exhibited its highest mean on the second discriminant function. Furthermore, the comorbid group recorded high means on all three discriminant functions. Utilizing the discriminant functions to predict clinical group membership resulted in 71.2% of the individuals in the sample being classified correctly. In order to take into account chance agreement, a kappa coefficient was computed and a value of .60 was obtained, a moderate value (Landis & Koch, 1977).

In the second discriminant analysis, classification by ARHQ-R Postsecondary Basic Reading scale and CARE-SRI factor-based Inattention, Hyperactivity, and Impulsivity scales was carried out. Again three discriminant functions were significant, Λ = .21, $X^2 (12, N = 73) = 104.86, p < .01$ for the first, Λ = .66, $X^2 (6, N = 73) = 28.19, p < .01$ for the second, and Λ = .91, $X^2 (2, N = 73) = 6.70, p = .04$ for the third. The inattention and hyperactivity scales correlated highly with the first discriminant function.
(r = .86 and .69 respectively), while the ARHQ-R Postsecondary Basic Reading scale demonstrated the strongest relationship with the second discriminant function (r = .99).

The impulsivity scale displayed the highest correlation with the third discriminant function (r = .78). The AD/HD group exhibited the highest mean on the first discriminant function, and the dyslexic group displayed the highest mean on the second discriminant function. Furthermore, the comorbid group recorded high means on all three discriminant functions. Predicting clinical group membership with the derived discriminant functions resulted in 68.5% of the individuals in the sample being classified correctly which resulted in a moderate kappa coefficient of .57 (Landis & Koch, 1977).

The results of the discriminant analyses indicate that both the AD/HD and comorbid groups exhibit self-reported inattention and hyperactivity characteristics; however, only the comorbid group displays significant impulsivity symptoms. The dyslexic and comorbid groups reported problematic reading histories but the dyslexic group did not report having attentional difficulties.

Correlations

Table 7 provides the correlation coefficients between the demographic (age and IQ) and other variables; Visual Matrix and Simple Processing Time are excluded as no significant correlations were observed for these measures. Regarding the demographic variables, IQ was significantly correlated with performance on one auditory working memory measure (Digit Span Backward) and with Digit Span Forward.
### Table 7.

*Correlations Between Demographic Variables and EFs, Vigilance, and Processing Speed*

<table>
<thead>
<tr>
<th></th>
<th>Age</th>
<th>IQ</th>
<th>Inhibition (F)</th>
<th>Inhibition (I)</th>
<th>WCST Errors</th>
<th>Auditory Digit Sequence</th>
<th>Digit Span Backward</th>
<th>Vigilance (F)</th>
<th>Vigilance (I)</th>
<th>Simple Processing Speed</th>
<th>Complex Processing Time</th>
<th>Complex Processing Speed</th>
<th>Digit Span Forward</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Inhibition (F)</td>
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<td>.09</td>
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<tr>
<td>Inhibition (I)</td>
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<td>.07</td>
<td>.41**</td>
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<tr>
<td>WCST Errors</td>
<td>.11</td>
<td>- .02</td>
<td>- .05</td>
<td>- .08</td>
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<td></td>
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<tr>
<td>Auditory Digit Sequence</td>
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<td>.17</td>
<td>.42**</td>
<td>.39**</td>
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<tr>
<td>Digit Span Backward</td>
<td>.19</td>
<td>.28*</td>
<td>.25*</td>
<td>.11</td>
<td>.12</td>
<td>.35**</td>
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<tr>
<td>Vigilance (F)</td>
<td>-.08</td>
<td>-.04</td>
<td>.53**</td>
<td>.54**</td>
<td>-.18</td>
<td>.20</td>
<td>.11</td>
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<tr>
<td>Vigilance (I)</td>
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<td>.04</td>
<td>.40**</td>
<td>.36**</td>
<td>-.07</td>
<td>.21</td>
<td>.10</td>
<td>.67**</td>
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<tr>
<td>Simple Processing Efficiency</td>
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<td>-.09</td>
<td>.09</td>
<td>.14</td>
<td>-.08</td>
<td>.18</td>
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<td>.04</td>
<td>.01</td>
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<tr>
<td>Complex Processing Time</td>
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<td>.15</td>
<td>-.21</td>
<td>-.25*</td>
<td>-.09</td>
<td>.37**</td>
<td>-.29*</td>
<td>-.11</td>
<td>-.11</td>
<td>-.67**</td>
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<td>.08</td>
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<td>.12</td>
<td>.67**</td>
<td>-.96**</td>
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</tr>
<tr>
<td>Digit Span Forward</td>
<td>.22</td>
<td>.29*</td>
<td>.31</td>
<td>.15</td>
<td>.01</td>
<td>.49**</td>
<td>.48**</td>
<td>.22</td>
<td>.17</td>
<td>.11</td>
<td>- .31**</td>
<td>.34**</td>
<td></td>
</tr>
</tbody>
</table>

*Note.* F. = stimulus frequent condition; I = stimulus infrequent condition; WCST = Wisconsin Card Sorting Test.

* *p < .05. **p < .01.
Regarding EFs measures, both conditions of Inhibition are significantly correlated to each other and to Auditory Digit Sequence and Vigilance (F and I). In addition to the above correlations, Inhibition (F) shared a unique significant correlation with Digit Span Backward while Inhibition (I) displayed a specific significant correlation with Complex Processing Time. Auditory Digit Sequence and Digit Span Backward were significantly correlated to each other and to Inhibition (F), Complex Processing Time, Complex Processing Efficiency, and Digit Span Forward. Furthermore, Digit Span Backward was uniquely correlated to IQ and Simple Processing Efficiency while Auditory Digit Sequence displayed a specific significant correlation with Inhibition (I). WCST Errors did not exhibit significant correlations to any of the dependent variables.

For the non-EFs dependent variables, both conditions of Vigilance were significantly correlated with Inhibition (F and I). Simple Processing Efficiency was significantly correlated with Digit Span Backward, Complex Processing Time, and Complex Processing Efficiency. Complex Processing Efficiency is significantly correlated to Complex Processing Time, both measures of auditory working memory, and Digit Span Forward. Complex Processing Time displayed similar significant correlations to that of Complex Processing Efficiency with the addition of one further significant correlation with Inhibition (I).

Covariates

Covariates were used in this study to provide purer measurements of cognitive processes, specifically executive functions, considering the many separate definitions of this term, and necessary due to the moderate correlations found between EFs (Miyake et al., 2000; Sergeant et al., 2002). Covariates were employed based on theoretical grounds,
to control for significant variability between covariate and dependent variable that have been reported in previous research, and on statistical significance as a correlate (Tabachnick & Fidell, 2007). We covaried the effects of IQ or EFs that were correlated significantly with EFs, except when two EFs measured the same process (i.e., one working memory measure from the other). The following variables were employed as covariates: IQ was used as a covariate for one measure of auditory working memory (Digit Span Backward) as found in Barkley, Edwards, Laneri, Fletcher, & Metevia (2001), measures of working memory (Auditory Digit Sequence and Digit Span Backward) and Inhibition (F) were covariates for each other (Luna, Garver, Urban, Lazar, & Sweeney, 2004; Ossmann & Mulligan, 2003). Based on extensive research reporting an association between auditory short-term memory and auditory working memory; auditory short-term memory (Digit Span Forward) was used as a covariate for both measures of working memory (Baddeley, 2003; Huizinga et al., 2006).

**Diagnostic Groups’ Performance on Executive Functions, Processing Speed, and Vigilance**

Means and standard deviations for all EFs are presented in Table 8, and those for vigilance and processing speed in Table 9. Each table shows the group effects (i.e., without covariates) with Bonferroni post hoc comparisons. Analyses of covariance (ANCOVA) results (with Bonferroni post hoc comparisons) are discussed in the text. Group effects pertaining to Inhibition (I), Visual Matrix (see Table 8), Simple Processing Efficiency, and Simple Processing Time (Table 9) were nonsignificant and are not discussed further. There were no errors on the simple processing speed task, and very few omissions.
Table 8.

*Group Means and ANOVAs for EFs Measures*

<table>
<thead>
<tr>
<th>Measures</th>
<th>Comorbid ((n = 10))</th>
<th>AD/HD  ((n = 23))</th>
<th>Dyslexia ((n = 19))</th>
<th>Normal ((n = 21))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Inhibition (F)</td>
<td>84.50</td>
<td>22.38</td>
<td>97.13</td>
<td>13.67</td>
</tr>
<tr>
<td></td>
<td>3.69</td>
<td>3.79</td>
<td>.14</td>
<td>.01</td>
</tr>
<tr>
<td>Inhibition (I)</td>
<td>101.30</td>
<td>5.50</td>
<td>100.74</td>
<td>13.17</td>
</tr>
<tr>
<td></td>
<td>3.69</td>
<td>.15</td>
<td>.01</td>
<td>.93</td>
</tr>
<tr>
<td>WCST Errors</td>
<td>5.00</td>
<td>1.49</td>
<td>5.87</td>
<td>2.56</td>
</tr>
<tr>
<td></td>
<td>3.69</td>
<td>.13</td>
<td>.02</td>
<td>A&gt;D</td>
</tr>
<tr>
<td>Auditory Digit</td>
<td>4.70</td>
<td>2.00</td>
<td>5.74</td>
<td>1.76</td>
</tr>
<tr>
<td></td>
<td>3.69</td>
<td>5.06</td>
<td>.18</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Sequence</td>
<td>Digit Span Backward</td>
<td>5.50</td>
<td>1.84</td>
<td>7.35</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.69</td>
<td>6.47</td>
<td>.22</td>
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<tr>
<td>Visual Matrix</td>
<td>9.40</td>
<td>1.35</td>
<td>9.17</td>
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</tr>
<tr>
<td></td>
<td>3.69</td>
<td>.07</td>
<td>.01</td>
<td>.98</td>
</tr>
</tbody>
</table>

*Note.* F = stimulus frequent condition; I = stimulus infrequent condition; WCST = Wisconsin Card Sorting Test; \(\eta_p^2\) = partial eta squared; C = comorbid; A = AD/HD; D = dyslexia; N = normal; n.s = non significant.
Table 9.

**Group Means and ANOVAs for Non-EFs Measures**

<table>
<thead>
<tr>
<th></th>
<th>Comorbid $(n = 10)$</th>
<th>AD/HD $(n = 23)$</th>
<th>Dyslexia $(n = 19)$</th>
<th>Normal $(n = 21)$</th>
<th>df</th>
<th>$F$</th>
<th>$\eta^2_p$</th>
<th>$P$</th>
<th>Contrasts</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Non-Executive Measures</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vigilance (F)</td>
<td>78.80 28.72</td>
<td>93.83 24.96</td>
<td>102.68 7.36</td>
<td>104.63 3.25</td>
<td>3,69</td>
<td>5.54</td>
<td>.19</td>
<td>&lt;.01</td>
<td>C&lt;D,N</td>
</tr>
<tr>
<td>Vigilance (I)</td>
<td>79.20 32.24</td>
<td>84.30 30.91</td>
<td>95.68 23.42</td>
<td>102.47 6.93</td>
<td>3,69</td>
<td>3.10</td>
<td>.12</td>
<td>.03</td>
<td>(C+A&lt;N)</td>
</tr>
<tr>
<td>Simple Processing Efficiency</td>
<td>1.06 .15</td>
<td>1.07 .17</td>
<td>1.06 .18</td>
<td>1.14 .18</td>
<td>3,69</td>
<td>1.01</td>
<td>.04</td>
<td>.39</td>
<td>n.s.</td>
</tr>
<tr>
<td>Complex Processing Time</td>
<td>50.10 12.31</td>
<td>46.76 9.84</td>
<td>54.35 14.65</td>
<td>42.48 7.65</td>
<td>3,69</td>
<td>4.01</td>
<td>.15</td>
<td>&lt;.01</td>
<td>D&gt;N</td>
</tr>
<tr>
<td>Complex Processing Efficiency</td>
<td>.52 .12</td>
<td>.560 .14</td>
<td>.49 .13</td>
<td>.590 .11</td>
<td>3,69</td>
<td>2.47</td>
<td>.10</td>
<td>.07</td>
<td>(D&lt;N)</td>
</tr>
<tr>
<td>Complex Processing Errors and Omissions</td>
<td>.25 .55</td>
<td>.09 .29</td>
<td>.11 .32</td>
<td>.62 .81</td>
<td>3,69</td>
<td>5.38</td>
<td>.19</td>
<td>&lt;.01</td>
<td>D,A&lt;N</td>
</tr>
</tbody>
</table>

*Note.* $F =$ stimulus frequent condition; $I =$ stimulus infrequent condition; $\eta^2_p =$ partial eta squared; $C =$ comorbid; $A =$ AD/HD; $D =$ dyslexia; $N =$ normal; n.s = non significant; parentheses denote significance levels between .05 and .10.
Executive Functions

Inhibition (F). The group effect was significant (Table 8) with post hoc analyses indicating that the comorbid group displayed poorer inhibition than the control ($p = .02$) and dyslexic ($p = .046$) groups. Covarying Auditory Digit Sequence, the group effect remained significant, $F(4, 68) = 3.01, p = .04, \eta_p^2 = .12$, and post hoc analyses indicated that the comorbid group exhibited worse response inhibition than the dyslexic group ($p = .03$). Similarly, with Digit Span Backward as a covariate, the group effect remained significant, $F(4, 68) = 3.55, p = .02, \eta_p^2 = .14$, with post hoc analyses indicating that the comorbid group exhibited poorer inhibition performance in comparison to the control ($p = .046$) and dyslexic ($p = .03$) groups.

WCST Errors. The group effect was significant (Table 8) with post hoc analyses indicating that the AD/HD group made more perseverative errors (indicative of less ability to flexibly shift cognitive sets) than the dyslexic group ($p = .02$) which displayed slightly better performance than the control group.

Auditory Digit Sequence. The group effect was significant (Table 8) with post hoc analyses indicating that the dyslexic and comorbid groups displayed poorer performance compared to the control group ($p < .01$ and $p = .03$ respectively). Covarying Inhibition (F), a significant group effect remained, $F(4, 68) = 4.22, p < .01, \eta_p^2 = .16$, and post hoc analyses indicated that the dyslexic group performed worse than the control group ($p < .01$). However, when controlling for the effect of auditory short term memory, the group effect was not significant, $F(4, 68) = 2.22, p = .09, \eta_p^2 = .09$.

Digit Span Backward. The group effect was significant (Table 8) with post hoc analyses indicating that the dyslexic group performed worse than the AD/HD and control
groups ($p \leq .01$ for each group). With Inhibition (F) as a covariate, the group effect remained significant, $F(4, 68) = 6.18, p<.01, \eta_p^2 = .21$. Post hoc analyses again indicated that the dyslexic group exhibited significantly lower performance than the AD/HD and control groups ($p < .01$ for each). Similarly, controlling for the effect of IQ, the group effect was significant, $F(4, 68) = 5.47, p = < .01, \eta_p^2 = .19$, with the same post hoc results. Controlling for Digit Span Forward resulted in a significant group effect, $F(4, 68) = 4.06, p < .01, \eta_p^2 = .15$, with post hoc analyses indicating that the dyslexic group performed worse than the AD/HD group ($p = < .01$).

**Summary of group performance on executive functions measures.** Of the six EFs measures, four showed group effects (Table 8). The groups with attention deficits (comorbid and AD/HD) tended to perform worse on the inhibition and set shifting measures, whereas those with reading deficits (dyslexic and comorbid) performed worse on the auditory working memory measures. The comorbid group performed particularly poorly on response inhibition (stimulus frequent condition).

**Non-Executive Functions**

**Vigilance (F).** The group effect was significant (see Table 9) and post hoc analyses revealed that the comorbid group exhibited lower standard scores (indicative of problematic vigilance abilities) in comparison to the dyslexic and control groups ($p < .01$ for each group).

**Vigilance (I).** The group effect was significant (Table 9). Although none of the original group comparisons was significant, post hoc analyses indicated that a combined AD/HD and comorbid group performed significantly worse than the control group ($p < .01$).
Complex Processing Speed Task. The group effect for Complex Processing Time was significant (Table 9) with post hoc analyses indicating that the dyslexic group displayed significantly longer processing times than the control group \((p < .01)\). Complex Processing Efficiency (Table 9) showed a trend for a group effect \((p < .07)\) however, this effect did not reach the conventional level (.05) of significance. Further analysis related to errors and omissions on the complex processing speed task indicated that the discrepancy between the time and efficiency effects was due to the clinical groups making fewer errors and omissions than the control group. A significant group effect was found on the score of errors and omissions (Table 9). The dyslexic and AD/HD groups made significantly fewer errors and omissions than the control group \((p < .01\) for each group).

Summary of group performance on non-executive functions measures. The comorbid group performed particularly poorly on the vigilance measures. The dyslexic group displayed a significantly longer Complex Processing Time than the control group (this pattern was not apparent on the simple processing speed task or on the Complex Processing Efficiency measure). However, along with the AD/HD group, the dyslexic group committed fewer errors and omissions than the control group on the complex processing speed task.

Discussion

The purpose of this study was to investigate EFs (i.e., response inhibition, set shifting, and working memory) in postsecondary students with AD/HD, dyslexia, and AD/HD with comorbid dyslexia. Associated cognitive domains of vigilance and processing speed were also examined. Three hypotheses were proposed.
The first hypothesis, that postsecondary students with AD/HD would perform poorly on EFs tasks and measures of vigilance and processing speed, was partially supported. The ADHD group displayed significantly more perseverative errors (reflective of set shifting deficits) on the WCST compared to the dyslexic group, which displayed better performance than the control group. Previous studies had reported that the WCST is ineffective in discriminating AD/HD adults from age matched clinical groups or healthy controls (Gansler et al., 1998; Holdnack et al., 1995; Weyandt et al., 1998); however, avoiding the confound of sample inclusion (use of diagnostic referrals as opposed to self or questionnaire based referrals; Mahone et al., 2002) may have contributed to the WCST results obtained in this study. This finding is consistent with previous research indicating that diagnostically referred AD/HD adults display WCST set shifting deficits in comparison to non-AD/HD adults (Seidman, Biederman, Faraone, Weber, & Ouellette, 1997). The AD/HD group (when combined with the ADHD comorbid group) also demonstrated vigilance impairments in the stimulus infrequent condition or the low response mode in which the target appears randomly and infrequently (Greenberg et al., 2000). This finding provides support for previous research reporting vigilance deficits in children with AD/HD (Barkley et al., 1990) and adds to the sparse research reporting vigilance deficits in adults with AD/HD (Forbes, 1998).

Notwithstanding deficits in set shifting and vigilance, there were no other significant performance deficits observed for the AD/HD group. Failure to detect inhibition deficits in the AD/HD group, which is considered a core impairment (Barkley, 1997; Ossmann & Mulligan, 2003), can be attributed to the attentional profile of this group. Discriminant function analyses of the CARE-SRI indicated that the AD/HD group
self-reported more inattention and hyperactivity symptoms than impulsivity symptoms. Efficient inhibitory processes are considered principal mechanisms contributing to impulse control (Brown, Manuck, Flory, & Hariri, 2006); therefore, the absence of inhibition deficits could be the result of this group not experiencing significant impulsivity. An alternative explanation for the lack of AD/HD cognitive performance deficits involves the inconsistency with which deficits of EFs, processing speed, and vigilance are experienced in an adult AD/HD sample. Seidman (2006) found that only 30%-50% of individuals with AD/HD can be considered neuropsychologically abnormal.

The lack of performance deficits displayed by this group may be attributed to the utilization of compensatory strategies to aid cognitive processing. AD/HD postsecondary students in comparison to lower achieving AD/HD peers have been found to employ more self-regulatory coping strategies to deal with their symptoms (Faigel, 1995; Hallowell & Ratey, 1994; Nadeau, 1994). Although the prefrontal cortex (PFC) is implicated as the site of AD/HD impairments (Broyd, et al., 2005), it also possesses the capacity for compensation of behaviour and goals due to its anatomical connections to practically all sensory and subcortical structures (Miller, 2000). Fassbender and Schweitzer (2006) found that adults with AD/HD compensate for PFC deficits by activating a more diffuse, wider system of brain regions to perform cognitive tasks compared to non-AD/HD adults.

The second hypothesis, that students with dyslexia would display EFs deficits in auditory working memory and exhibit processing speed impairments, was supported. Adult dyslexics exhibited specific auditory working memory performance deficits even when controlling for IQ, inhibition, and short-term memory. Previous research with
dyslexic groups has found both auditory and visual working memory impairments (Swanson, 1992); however, the use of a postsecondary dyslexic group without broad language deficits in this study may have allowed the finding of specific auditory working memory deficits (Savage et al., 2007). Contrary to studies of dyslexic children that have reported inhibition deficits on continuous performance tests (Losier et al., 1996; Tarnowski, et al., 1986), the present findings are in agreement with the preponderance of adult dyslexic literature (Taroyan et al., 2007; Weyandt et al., 1998) that found no inhibition impairments on continuous performance tests. The use of an adult dyslexic sample to mitigate developmental confounds (Huizinga et al., 2006), use of dyslexics without comorbid attention difficulties (Taroyan et al., 2007), and controlling for working memory (three potential confounds found in studies of dyslexic children) may have contributed to the lack of significant differences. With respect to set shifting, the findings are consistent with the literature (Romine et al., 2004) that indicates that dyslexic groups do not experience performance deficits on set shifting tasks. The inclusion of a dyslexic sample without comorbid attention problems may have contributed to the obtained results. Weyandt et al. (1998) found set shifting deficits in reading disabled postsecondary students, but did not control for comorbid attention problems.

Research with dyslexic individuals has reported deficits in processing speed (Kail & Hail, 1994, 1999; Catts et al., 2002; Wilcutt et al., 2005). This study is consistent, as the dyslexic group exhibited complex processing time deficits and a trend for poorer complex processing efficiency when compared to the control sample. Further analysis of errors and omissions on this task indicates that the dyslexic group made fewer errors and omissions on this task than control participants. The dyslexic group is likely employing a
compensatory speed-accuracy tradeoff (Gros-Glenn, Jallad, Novoa, Helgren-Lempesis, & Lubs, 1990); processing speed time is sacrificed to focus resources towards making fewer errors. This result supports previous research indicating that dyslexic individuals display similar task accuracy compared to non-dyslexic controls on visual tasks, but exhibit a general slowing of response speed (Stoet et al., 2007). Additionally, the compensatory speed-accuracy tradeoff exhibited in this study also substantiates research reporting that dyslexic postsecondary students tend to utilize deep learning strategies such as time management techniques to compensate for their cognitive deficits (Kirby et al., 2008).

The third hypothesis, that the comorbid group’s cognitive deficits would consist of the sum of deficits found in AD/HD and dyslexia alone, was supported. In comparison to the deficits exhibited by the AD/HD (i.e., in set shifting and vigilance) and dyslexic (i.e., auditory working memory and processing speed) groups alone, the comorbid group exhibited statistically similar levels of cognitive performance. Therefore, the results of this study provide support for the common etiology hypothesis (Wilcutt et al., 2005) as an explanation for cognitive deficits manifested by the comorbid group. Further analysis of the comorbid group’s cognitive performance also indicates performance weaknesses in stimulus frequent conditions as opposed to stimulus infrequent conditions. This result could be attributed to the attentional composition of the comorbid group which includes greater self-reported impulsivity symptoms. According to Greenberg et al. (2000), the stimulus frequent condition is a high response demand mode which requires more impulse control. Consequently, individuals with greater impulsivity deficits are more likely to display inhibition and vigilance errors (Greenberg et al., 2000) in stimulus frequent conditions as exhibited by the comorbid group in this study (see Tables 3 and 4).
Conclusion

Cognitive performance of the groups with attention difficulties (AD/HD and comorbid groups) indicates deficits in EFs and in vigilance. This result indicates that dispersed regions of the prefrontal cortex (PFC) associated with inhibition and set shifting (Aron et al., 2004; Rushworth et al., 2004), and midbrain areas such as the locus coeruleus that underlie vigilance processing (Posner & Raichle, 1994) are likely anatomical sites of AD/HD cognitive deficits. This finding provides support for general EFs impairments and endogenous vigilance deficits in AD/HD as posited by Swanson et al. (1998).

Analysis of the groups with reading impairments (dyslexic and comorbid groups) on EFs performance indicates that only auditory working memory deficits are evident (Savage et al., 2007). Therefore, it cannot be concluded that dyslexic adults exhibit extensive EFs impairments. Rather, the findings indicate a localized EF deficit related to language processing and storage. In addition to performance deficits in auditory working memory, the dyslexic group also displayed general processing speed impairments. These findings substantiate Wolf and Bowers’ (1999) position that response time deficits are characteristic of dyslexics.

Future Directions and Limitations

Compensatory strategies that are used by AD/HD and dyslexic groups in response to cognitively challenging tasks merit further examination. Learning strategies research and neuroimaging studies have indicated that adult AD/HD individuals utilize phylogenetically older, more basic or automatic processes of the brain to compensate for prefrontal cognitive impairments (Fassbender & Schweitzer, 2006). For example, AD/HD
groups have been found to use visual-spatial compensatory strategies instead of verbally mediated strategies (Fassbender & Schweitzer, 2006). Postsecondary dyslexics compensate for their reading deficits by employing deep learning approaches and associated strategies (Kirby et al., 2008). Previous research has indicated that the impact of dyslexia on reading can be modified by compensatory strategies such as use of semantic knowledge (Snowling, Bishop, & Stothard, 2000), use of context (Nation & Snowling, 1998), and visual strategies (Campbell & Butterworth, 1985). Future studies investigating the cognitive etiology associated with AD/HD and dyslexia would be more effective delineating the deficits associated with these disabilities by minimizing the use of the abovementioned compensatory strategies in cognitive task completion.

Research is also needed to examine the phonological/linguistic performance of a comorbid group in comparison to AD/HD and dyslexic groups. Although the results in this study indicate common EFs, vigilance, and processing speed etiology in the comorbid group when compared to AD/HD and dyslexic groups, the same might not be evident with phonological/linguistic measures. For example, Rucklidge and Tannock (2002) found significant impairment in the comorbid group on rapid naming tasks compared to a dyslexic group. Furthermore, Purvis and Tannock (1997) found that the comorbid group is less impaired on language measures than the dyslexic group and pointed to the possibility that dyslexia in the comorbid group might be caused by a different combination of deficits and their interaction.

Although the findings from this study contribute to further specifying EFs and related non-EFs deficits associated with AD/HD, dyslexia, and AD/HD with comorbid dyslexia, there were a number of limitations. First, the primary investigator was not blind
to group assignment when collecting questionnaire and cognitive data. This presents a potential threat to the internal validity of the study. Second, the small sample size may have limited the study’s ability to detect smaller effects that might be expected in adults who have partially compensated for their cognitive deficits. A further limitation was the gender distribution of the study groups which included more female than male participants, especially in the control cohort. Although statistical analyses indicated that gender effects did not affect the findings, generalizability of the findings across sexes must be interpreted cautiously. Lastly, given the broad and weakly defined character of EFs (Sergeant et al., 2002), there may be other aspects of EFs not measured here that would better discriminate the clinical groups. Despite these limitations, the results from this study indicate that with more stringent AD/HD and dyslexic participant selection, the specific cognitive etiology associated with these disorders can be further delineated.
CHAPTER 5: GENERAL DISCUSSION

The overall objective of this dissertation was to investigate attention, cognitive executive functions (EFs), vigilance, and processing speed performance in three groups of postsecondary students, those with Attention Deficit/Hyperactivity Disorder (AD/HD), dyslexia, and AD/HD with comorbid dyslexia. Cognitive task performance for these groups was examined and contrasted based on Posner and Raichle’s (1994) model of attention networks in Chapter 3 and Pennington and Ozonoff’s (1996) conceptualization of EFs in Chapter 4. Although attention and EFs deficits are reported in children with AD/HD and dyslexia (Barkley, 1998; Barkley et al., 1990; Chiappe et al., 2000; Reiter et al., 2005), these deficits are difficult to detect in high functioning adults who may have partially compensated for their cognitive deficits. The current studies were designed to reduce methodological confounds associated with past AD/HD and dyslexia cognitive research (e.g., developmental/maturational factors, sample inclusion, and task validity confounds) and to determine whether tasks associated with theoretical models of attention and EFs display the necessary sensitivity to delineate cognitive deficits in adults. Additionally, this investigation was initiated to better inform clinicians and educators about attention and EFs performance in adults with these disorders to assist with more effective identification/assessment and educational interventions.

Posner and Raichle (1994) posited that there are multiple attention networks, each responsible for different aspects of attention. This comprehensive theoretical account of attention identifies three constituent attention networks: the alerting network which underlies arousal and sustained attention, the orienting network which contributes to
selective and focused attention, and the executive network that regulates divided attention. This model of attention was employed in Chapter 3 because it contains sufficient breadth to examine the varying attentional deficits associated with AD/HD and the integral role that attention networks play in word reading, a core deficit in dyslexia (Shaywitz, Morris, & Shaywitz, 2008).

Although the construct of EFs is subject to many different definitions, the seminal work of Pennington and Ozonoff (1996), who conceptualized EFs as primarily composed of inhibition, set shifting, and working memory components, was utilized in Chapter 4. The use of this model is critical to the examination of EFs because inhibition, set shifting, and working memory differentially predict performance on most EF tasks (Miyake et al., 2000). Research has indicated EFs impairments are related to both AD/HD and dyslexia, therefore Pennington and Ozonoff’s (1996) model of three primary components of EFs should provide sufficient coverage of this construct for examination in these disability groups and in an AD/HD with comorbid dyslexia group (Barkley, 1997; Helland & Asbjornsen, 2000; Reiter et al., 2005).

The attention and EFs theoretical models used in this dissertation with the inclusion of related vigilance and processing speed components provide a comprehensive overall framework for the evaluation of higher order cognitive processes in these disability groups. Posner and Raichle’s attention networks with the addition of tonic (i.e., vigilance) attention processes form the cognitive foundation necessary for EFs to develop and mature. Additionally, processing speed allows the integration of attention and EFs processes to maximize cognitive efficiency. Therefore, this cognitive framework allows
examination of both distal (attention and vigilance) and proximal (EFs and processing speed) cognitive processes in AD/HD, dyslexia, and AD/HD with comorbid dyslexia.

The discussion of the findings is presented in five sections. Addressing the limitations of past AD/HD and dyslexia research which has included developmental/maturational, sample inclusion, and task impurity/validity confounds, the first section summarizes the present findings on attention, EFs, vigilance, and processing speed deficits in the three groups. The second section integrates the study findings into an overall cognitive framework and compares these findings with current cognitive etiological research of these disorders in children (due to the preponderance of studies compared to adults) as well as adults. The third section discusses the implications of the findings for research related to identification/assessment of these disabilities, compensation for cognitive deficits, and the effects of the identified deficits on educational interventions. The limitations of this study are presented in the fourth section followed by the conclusion in the final section.

Summary of the Findings

Attention Deficit Hyperactivity Disorder

In Chapter 3, it was hypothesized that the AD/HD group would display performance deficits on alerting and executive attention tasks, and in Chapter 4, that they would exhibit deficits in EFs (i.e., inhibition, set shifting, and working memory performance impairments), vigilance, and processing speed. The results indicated that they did not demonstrate deficits on any of the attention tasks, but did display performance deficits on set shifting and vigilance. The failure in the current studies to detect additional performance deficits, similar to those found in studies of children, was
attributed to having reduced maturational/developmental and construct validity
confound, the behavioural composition of the group (i.e., preponderance of inattentive
symptoms), the ability of AD/HD adults to compensate for cognitive deficits, and the
inconsistency with which cognitive deficits are evident in AD/HD adults.

Attention and EFs tasks are primarily conceptualized, developed, and normed for
adults; consequently the performance of AD/HD children on these tasks is subject to
maturational/developmental confounds (Tannock, 1998). The use of AD/HD adults in the
current studies attenuated these confounds, thus the broader range of attention and EFs
performance deficits found in research with AD/HD children was not evident in the
present findings. The research design for the current studies also incorporated covariates
for analyses and used measures with demonstrated construct validity which may have
further reduced the extent of attention and EFs deficits in the AD/HD participants.

In Chapter 4, the failure to detect an inhibition deficit, which is considered a core
EF impairment in AD/HD (Barkley, 1997; Ossmann & Mulligan, 2003), may have been a
result of the composition of this group. Discriminant function analyses demonstrated that
the AD/HD group was composed of adults who reported more inattentive than impulsive
symptoms and this may explain why no difficulties with impulse control were found.
Previous research has reported that AD/HD postsecondary students compensate more
effectively for their cognitive deficits than their lower-achieving AD/HD peers (Faigel,
1995; Hallowell & Ratety, 1994; Nadeau, 1994); consequently, cognitive deficits are
more difficult to detect in postsecondary students with AD/HD (Kooij et al., 2010).
Fassbender and Schweitzer (2006) found that higher levels of general intelligence and the
use of visual and visual-spatial cognitive processes allow AD/HD adults to circumvent
cognitive deficits associated with prefrontal cognitive impairments. The AD/HD group in the current studies had general intelligence in the high average range of ability (i.e. mean full-scale intelligence quotient of 111.8) and they demonstrated visual-spatial processing skills that were equivalent to those of the control students. Thus, these compensatory attributes may have contributed to the lack of cognitive performance deficits demonstrated in the present study. Lastly, Seidman (2006) found that cognitive abnormality is not evident in all AD/HD adults. Despite consistent findings of AD/HD behavioural symptoms (i.e., inattention and hyperactive/impulsive traits), cognitive impairments are displayed in only 30%-50% of AD/HD adults.

**Dyslexia**

Previous research had reported orienting and executive attention impairments in dyslexic children and adults (Buckholz Aimola-Davies, 2007; Facoetti & Molteni, 2001). Accordingly, the hypothesis pertaining to the attention performance for dyslexic adults followed from these findings. The results displayed in Chapter 3 did not support this hypothesis. The hypothesis listed in Chapter 4 which predicted specific EFs deficits related to auditory working memory and processing speed impairments was supported. A crucial confound in previous studies examining dyslexic etiology concerned sample inclusion criteria: individuals with comorbid attention problems or broadly based language deficits were frequently included in research instead of participants with dyslexia only (Ramus et al., 2003; Wimmer et al., 1999). For the present study, the use of diagnostically referred dyslexic participants screened to exclude comorbid attention and broad language deficits minimized sample inclusion confounds. This may have contributed to this group’s more successful performance on attention tasks, and restricted
EFs findings to a specific impairment in auditory working memory (as had been suggested by Savage et al., 2007). Similar to previous processing speed research (Stoet et al., 2007; Stodley & Stein, 2006), the dyslexic group demonstrated significantly longer response times to a complex processing speed task. They also appeared to be employing a compensatory speed-accuracy trade-off, as found by Gross-Glenn et al. (1990), whereby response time was sacrificed in the interest of making fewer errors.

**AD/HD with Comorbid Dyslexia**

The examination of performance on attention tasks for the comorbid group in Chapter 3, although exploratory, was consistent with the hypothesis and findings from Chapter 4 related to EFs, vigilance, and processing speed: the comorbid group’s deficits were equivalent to the sum of the impairments found in AD/HD (i.e., set shifting and vigilance) and dyslexia (i.e., auditory working memory and complex processing speed response times). Discriminant function analyses did indicate however that this group displayed greater self-reported impulsivity than the AD/HD group. This may be the cause of their specific performance deficits on tasks measuring impulse control (i.e., executive attention and inhibition measures). Although this result appears contrary to the common etiology theory, Wilcutt and Pennington (2000) argued that the influence of different AD/HD subtypes in these types of cognitive comparisons is an explanation for these inconsistencies. Comorbid and AD/HD-only groups who exhibit different AD/HD subtypes contribute to heterogeneity of cognitive deficits (Wilcutt & Pennington, 2000); in the current studies the comorbid group displayed greater impulsive symptoms compared to the AD/HD-only group while the AD/HD-only group exhibited more inattentive characteristics than the comorbid group. Greater impulsivity rather than
inattentive symptoms in comorbid postsecondary students may be more than just a sampling artifact as previous AD/HD research with postsecondary students has indicated that symptoms of inattention as opposed to impulsivity are more significantly associated with lower GPAs, less use of study strategies, and poorer academic adjustment (DuPaul, Weyandt, O’Dell, & Varejas, 2009). Therefore, if the pattern of dyslexia combined with impulsivity characteristics is more frequent in comorbid postsecondary students, this subset of students would be less likely to experience the aforementioned academic and adjustment difficulties than comorbid students with primarily inattentive characteristics and dyslexia.

Integration of Findings with Previous Research

The study groups with attention deficits (i.e., AD/HD and comorbid groups) exhibited both energetic (vigilance) and executive attention impairments. They also displayed EFs deficits related to inhibition (comorbid group) and set shifting. These findings support previous research which found that AD/HD is best conceptualized as a disorder with multiple routes of cognitive etiology: deficits within phylogenetically older energetic and attention processes (i.e., vigilance and executive attention) and later evolving EFs, specifically inhibitory and set shifting abilities (see Sergeant et al., 2002, cognitive energetic model of AD/HD).

In comparison to the diffuse cognitive deficits exhibited by the groups with attention deficits, the groups with reading impairments (i.e., dyslexic and comorbid groups) demonstrated more localized cognitive etiology related to language processing. In addition to phonological processing deficits (on the TOWRE Phonemic Decoding subtest), they displayed a specific EF deficit in auditory working memory and a
processing speed response time deficit. The results for this group support previous meta-analysis findings by Swanson and Hsieh (2009) who reported the prevalence of auditory working memory deficits in dyslexic adults even when controlling for phonological processing performance. These findings also display some similarities to Wolf and Bowers’ (1999) double deficit hypothesis of dyslexia which states that this disorder is composed of both phonological awareness deficits and naming speed impairments. In the present study phonological difficulties were demonstrated in TOWRE Phonemic Decoding, and naming speed impairment was represented as slow performance in complex processing speed (one of the interpretations of naming speed deficits is that they are due to slow general processing speed, usually measured with complex tasks; see Kail, Hall, & Caskey, 1999).

This study’s findings for the comorbid group are consistent with the preponderance of comorbidity research with children which has found that the common etiology hypothesis (Wilcutt et al., 2005) best describes this group. This hypothesis postulates that cognitive impairments in the comorbid group should essentially be equivalent to the sum of the deficits associated with AD/HD and dyslexia when considered individually.

Implications for Further Research

Because the findings from the current study indicate that the cognitive etiology associated with the AD/HD and comorbid dyslexia group best represents the additive effect of deficits found in AD/HD and dyslexia, the discussion of future research will centre on AD/HD and dyslexia only.
Identification/Assessment

The current findings which indicate that AD/HD (i.e., AD/HD and comorbid groups) is associated with energetic (vigilance), attention (executive attention) and EFs (inhibition in the comorbid group and set shifting) cognitive deficits have potential ramifications for the assessment of AD/HD in adults. These results indicate that no single cognitive test possesses sufficient predictive validity or specificity to discriminate cognitive deficits exclusive to AD/HD. Rather, the findings suggest that incorporating a broad array of energetic, attention, and EFs measures for an assessment would be most sensitive in determining the cognitive deficits associated with AD/HD. Future research should test the discriminant validity of tasks associated with varying theoretical models of attention and/or EFs (e.g. Barkley’s, 1997, EFs model) to more effectively specify cognitive etiology associated with AD/HD. A further avenue of research would be to examine the longitudinal course of cognitive deficits found in AD/HD. Although, there is a waning of behavioral symptoms of AD/HD over time (Faraone, Biederman, & Mick, 2006) there is a dearth of studies examining the trajectory of cognitive deficits from childhood to adulthood. Fischer, Barkley, Smallish, and Fletcher (2005) and Beiderman et al. (2009) found that cognitive deficits found in children with AD/HD persist into adulthood. However, the phenotypic expression of this persistence is influenced by several variables: AD/HD sample inclusion criteria (e.g., presence of comorbidities) and source of participant referral (self-referred and questionnaire-referred vs. diagnostic referrals). Future studies investigating the longitudinal trajectory of AD/HD cognitive functions employing more rigourous sampling would assist researchers in identifying the changes in the cognitive expression of AD/HD from childhood to adulthood.
When dyslexia is assessed, measures related to phonological and orthographic processing and naming speed are often employed to diagnose its source (Castles & Colheart, 1993; Shaywitz et al., 2008). The findings from the current studies indicate that the assessment protocol for dyslexia (in adults) should also incorporate measures of EFs (i.e., auditory working memory) measures. Although response time deficits were evident on the complex processing speed task, this type of measure is not considered a core diagnostic task in this discussion because complex processing speed is significantly influenced by auditory working memory (e.g., Chiaravallotti, Christodoulu, Demaree, & DeLuca, 2003); this is also shown by the significant correlation between these two cognitive constructs in Chapter 4. Therefore, the remainder of this section on the identification of dyslexia will focus solely on auditory working memory processes.

Despite findings of specific EF deficits in auditory working memory associated with dyslexia, further detailed analyses of this result would be of benefit. Future research with adults who have dyslexia should delineate whether working memory deficits are domain specific (i.e., auditory only; Vasic et al., 2008; Brosnan et al., 2002) or domain general (i.e., auditory and visual-spatial working memory deficits; Smith-Spark et al., 2003; Swanson, 1999). The present findings indicate that the dyslexic group displayed no significant visual-spatial working memory deficits on one type of visual-spatial working memory task: a delayed response measure. Future studies are needed to determine if visual-spatial working memory deficits are evident in dyslexia employing a hierarchy of tasks that vary in their executive control demands (e.g., ranging from delayed response tasks to more resource-intensive tasks requiring strategic self-monitoring of visual-spatial information; for a review of these tasks see Luciana, Conklin, Hooper, and Yarger, 2005).
Additionally, once the modality of working memory deficits is more clearly established, further research is needed to examine the source of working memory deficits: are working memory deficits due to endogenous impairments, or are working memory deficits evident because of bottlenecks in cognitive domains associated with dyslexia such as phonological or orthographic processes which demand more working memory involvement leading to reductions in memory capacity? Future research is needed comparing subtypes of deep and surface dyslexia (exhibiting poor phonological and orthographic processing respectively; Castles and Coltheart, 1993). This research may indicate that working memory deficits vary depending on the subtype of dyslexia. Research needs to delineate whether core phonological or orthographic processing deficits lead to reductions in working memory capacity in deep and surface dyslexics. Other research is needed to examine dyslexic adults with poor reading comprehension (associated with working memory deficits; Oakhill, Cain, & Bryant, 2003) on tasks with increasing working memory demands to determine if intrinsic working memory impairments are evident irrespective of other cognitive processes.

A further issue related to identification of dyslexia is the frequent comorbidity of this disorder with AD/HD. Research delineating the cognitive etiology associated with dyslexia (particularly research showing broad attention and EFs deficits) often fails to control for the contribution of attention deficits on cognitive performance. Future studies with adults and children are needed to replicate the findings of cognitive deficits in dyslexia employing cohorts screened to exclude attention deficits.

*Compensation for Cognitive Deficits*
The groups with AD/HD in the current studies displayed high average intellectual ability and more proficient visual-spatial working memory abilities in comparison to auditory working memory skills; these are two cognitive attributes that could be used to compensate for areas of relative weakness. Kooji et al. (2010) reported that individuals with AD/HD and higher levels of general intellectual ability displayed more effective compensatory strategies to circumvent their cognitive weaknesses than those with lower intellectual ability. Future research comparing groups of AD/HD adults varying in general intellectual ability is needed to distinguish the compensatory strategies utilized. Longitudinal studies are needed to provide more fine-grained analysis of the developmental trajectory of compensatory strategy use according to level of intellectual ability. Further inquiry is required to determine the emergence of strategies ranging from less complex strategies such as repetition to those incorporating EFs such as organizational, associational, and elaboration strategies across the school years (Borkowski & Burke, 1996). Research is also needed to clarify from a developmental perspective how these two groups of AD/HD students choose compensatory strategies in relation to academic tasks: do specific types of tasks or processing demands of tasks trigger the use of specific strategies? Analysis of the differences in how they adapt or revise strategies also requires delineation.

Regarding the modality of compensatory strategy use, Fassbender and Schweitzer (2006) found that on tasks requiring higher cognitive functioning, AD/HD adults as opposed to normal controls displayed greater activation in brain regions associated with visual and visual-spatial processing. Schirduan, Case, and Faryniary (2002) found that more than 50% of their participants with AD/HD reported visual and visual-spatial
strengths on learning styles questionnaires. A potential methodology for examining AD/HD visual or visual-spatial compensatory strategies would be the use of dynamic assessments such as the Swanson Cognitive Processing Test (SCPT: Swanson, 1996) in which strategy selection and efficiency are indexed in response to challenging cognitive tasks.

The findings from the current studies indicate that participants with dyslexia displayed higher order cognitive strengths (i.e., in attention, inhibition, set shifting, and visual spatial working memory) while exhibiting a specific auditory working memory deficit. The current results are consistent with those of Shaywitz et al. (2008) who found that dyslexic adults compensate for their cognitive deficits with EFs and visual and visual-spatial memory processing strengths. Future research could capitalize on attention and EFs strengths displayed in dyslexic adults and analyze compensation through think-aloud protocols or other methods that would make explicit compensatory processes utilized in reading tasks. Also, future research could further quantify compensatory strategies through the use of dynamic assessments indexing strategy selection on reading tasks and utilizing neuroimaging techniques to delineate the specific anatomical correlates of compensatory reading mechanisms.

Educational Interventions

Participants with AD/HD in the current studies exhibited impairments in executive attention and EFs which have been found to contribute to the development of self-regulation skills (Garon et al., 2008). They also displayed deficits in vigilance which helps to regulate concentration. Reaser, Prevatt, Petscher, and Proctor (2007) similarly found that AD/HD postsecondary students reported difficulties on the Learning and
Study Skills Inventory (LASSI; Weinstein & Palmer, 2002) related to scales measuring the ability to self-regulate, manage time, and sustain concentration. Accordingly, future research would benefit from the development and evaluation of methods to improve EFs performance, for example, examination of the efficacy of executive functions coaches in assisting AD/HD postsecondary students to improve academic self-regulation and concentration. EFs coaches are increasingly being utilized to assist AD/HD students in postsecondary settings and provide support for the development of skills, strategies, and beliefs to manage self-regulatory challenges (Parker & Boutelle, 2009).

Participants with dyslexia in the current studies exhibited intact attention and EFs abilities while displaying specific language working memory deficits. These cognitive findings are similar to research on study approaches and learning strategies of dyslexic postsecondary students (Kirby et al., 2008) which found that, although these students tend to have a deep approach to learning (perhaps associated with proficient EFs skills), they continue to struggle with selecting main ideas in text which could be attributed in part to deficits in auditory working memory ability. Consequently, future research should examine the use of metacognitive learning strategies to address memory difficulties associated with text comprehension (for a review see Swanson, 2001). More specifically, further examination of the use of metacognitive strategies that engage EFs strengths in dyslexics such as inhibition and set shifting abilities are needed to examine if these strategies facilitate both on-line processing of text (e.g., the RAP strategy (Schumaker, Denton, & Deschler, 1984), in which individuals read text while inhibiting overlearned text comprehension strategies and shifting cognitive set to a strategy that involves answering questions and paraphrasing) and consolidation of text information to long
term memory (e.g., inhibition of habitual memory strategies while shifting cognitive set to the use of mnemonic strategies to remember and retrieve information; Allsop, Minskoff, & Bolt, 2005).

Limitations

The findings were limited by the small sample size resulting in less statistical power to detect cognitive deficits in high functioning adults employing compensatory strategies. In particular, the sample size limitation may have hindered detecting the small effect size of working memory and processing deficits commonly found in research with AD/HD adults (Hervey et al., 2004; Shanahan et al., 2006) and orienting and executive attention impairments that have been reported in research with dyslexic adults (Bucholz & Aimola-Davies, 2007). An additional limitation associated with this study involved the principal investigator being aware of group assignment when collecting questionnaire and cognitive data. This creates a potential threat to the internal validity of the study. A further limitation was the gender distribution of the study groups which included more female than male participants, especially in the control cohort. Although statistical analyses indicated that gender effects did not affect the findings, generalizability of the findings across sexes must be interpreted cautiously.

A specific limitation pertaining to the Chapter 3 study was the restriction of the construct of attention to solely visual attentional processes and conceptualizing attention as depicted within one theoretical framework: Posner and Raichle’s (1994) attention network model. Although this is a limiting factor, Posner and Raichle’s model of attention has been substantiated through numerous neuropsychological and neuroimaging studies and is considered one of the most accepted models of attention in cognitive
research (Raz, 2004). A limitation pertaining to the Chapter 4 study was the broad and weakly defined concept of EFs. EFs are integral to the attainment of future goals and as such incorporate a number of cognitive processes to facilitate this action. Unfortunately, the complexity of this construct has contributed to a proliferation of definitions; for example, Sergeant et al. (2002) found 33 separate definitions in the research literature. Despite this limitation, EFs components used in this study have been found to predict performance on most EFs tasks (Miyake et al., 2000) thus mitigating construct validity concerns.

Conclusion

There is a dearth of studies investigating the cognitive performance of adults with AD/HD (Weyandt & DuPaul, 2006). Of the available studies, few have found differences in cognitive performance between AD/HD and non-AD/HD adults (DuPaul et al., 2009). The current studies demonstrate that by addressing the methodological limitations associated with past AD/HD research (i.e., sample inclusion and task validity confounds), cognitive performance deficits are evident in this cohort. The present studies also demonstrate that through the use of comprehensive theoretical models of attention and EFs that AD/HD represents a disorder with multiple routes of cognitive etiology involving energetic (i.e., vigilance), attention, and EFs processes. This finding assists in the conceptualization of AD/HD as a disorder with both top-down (e.g., EFs) and bottom-up (e.g., energetic and attention processes) cognitive deficits (Sergeant, Guerts, Hujibregts, & Oosterlaan, 2003) as opposed to a disorder solely with top-down deficits as reported in the majority of the AD/HD research literature (e.g., Barkley, 1998).
Similar to AD/HD research, there are limited studies investigating cognitive etiology in dyslexic adults. The extant literature has reported a wide range of attention and EFs deficits for both children and adults with dyslexia (Bucholz & Aimola-Davies, 2007; Faceotti & Molteni, 2001; Taronowski et al., 1986; Weyandt et al., 1998). In the current studies however, rigorous sample inclusion criteria, including diagnostic referrals and exclusion of participants with comorbid attention deficits, may have allowed us to reach the more precise conclusion that the attention and EFs etiology associated with dyslexia in adults is primarily linguistically based, specifically EFs impairments in auditory working memory.

Literature searches related to the cognitive etiology of adults with AD/HD and comorbid dyslexia have indicated no relevant studies. The present findings, in accordance with the results from studies with children, indicate that attention and EFs deficits associated with the comorbid condition are equivalent to the sum of the deficits found in AD/HD and dyslexia when considered individually (i.e., the common etiology hypothesis of deficits; Wilcutt et al., 2005). This finding represents the first step in testing the validity of the common etiology hypothesis in adults with AD/HD and comorbid dyslexia. Additionally, research employing adult comorbid and AD/HD-only cohorts matched on AD/HD subtypes is required to further validate this hypothesis.
REFERENCES


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Lintermann, I., & Weyandt, L. (2001). Divided attention skills in college students with ADHD: Is it advantageous to have ADHD. *The ADHD Report, 9*, 1-10.


APPENDIX A

January 22, 2006

Robert J. Silvestri
PhD Student
Faculty of Education
Queen's University

GREB Ref # GEDUC-256-06
Title: “A Comparison of Executive Functions in Adults with the Inattentive Subtype of AD/HD to the AD/HD Combined Subtype and Dyslexia”

Dear Mr. Silvestri:

The General Research Ethics Board (GREB) has given expedited approval to your proposal entitled “A Comparison of Executive Functions in Adults with the Inattentive Subtype of AD/HD to the AD/HD Combined Subtype and Dyslexia”. In accordance with the Tri-Council Guidelines (article D.1.6) and Senate Terms of Reference (article G), your project has been approved for one year. At the end of each year, GREB will ask if your project has been completed and if not, what changes have occurred or will occur in the next year.

You are reminded of your obligation to advise the GREB, with a copy to your unit REB, of any adverse event(s) that occur during this approval period (form available on our webpage www.queensu.ca/vpr/greb/adviforms.htm#Adverse ). An adverse event includes, but is not limited to, a complaint, a change or unexpected event that alters the level of risk for the researcher or participants or situation that requires a substantial change in approach to a participant(s). You are also advised that any adverse events must be reported to the GREB within 48 hours.

You are also reminded that all changes that might affect human participants must be approved by the GREB. Examples of required approvals are changes in study procedures or implementations of new aspects into the study procedures that affect human subjects. These changes must be sent to Linda Frid at the Office of Research Services or fridl@queensu.ca prior to implementation. Ms. Frid will seek the approval of the GREB reviewer(s) who originally assessed your application.

On behalf of the General Research Ethics Board, I wish you continued success in your research.

Yours sincerely,

Lee Fabrińak
Assoc. Professor and Member
General Research Ethics Board

cc: Drs. K. Smithson & D. Klinger, Co-Chairs E-REB
Dr. John Kirby, Faculty Supervisor
Heather Cross

Office of Research Services
Queens University
Kingston, Ontario, Canada K7L 3N6
Tel 613-533-6081
Fax 613-533-6086
oers@queensu.ca
www.queensu.ca/vpr/

Preparing Leaders and Citizens for a Global Society

191
January, 2007

Robert Silvestri
Graduate Student
Faculty of Education
Queen’s University

GREB ref. # GEDUC-256-06
Title: “A comparison of executive functions in adults with the AD/HD inattentive subtype to the AD/HD combined subtype and dyslexia”

Dear Robert Silvestri:

The General Research Ethics Board (GREB) has reviewed and approved your request for renewal of ethics approval for the above-named study. This renewal is valid for one year from Jan. 22, 2007. Prior to the next renewal date you will be sent a reminder memo and form to reapply.

You are reminded of your obligation to advise the GREB, with a copy to the E-REB, of any adverse event(s) that occur during this approval period (details available on our webpage www.queensu.ca/vpr/arch/ethics.html#Adverse). An adverse event includes, but is not limited to, a complaint, a change or unexpected event that alters the level of risk for the researcher or participants or situation that requires a substantial change in approach to a participant(s). You are also advised that any adverse events must be reported to the GREB within 48 hours.

You are also reminded that all changes that might affect human participants must be approved by the GREB. Examples of required approvals are: changes in study procedures or implementations of new aspects into the study procedures that affect human subjects. These changes must be sent to Linda Frid at the Office of Research Services or fridl@post.queensu.ca prior to implementation. Ms. Frid will seek the approval of the GREB reviewer(s) who originally assessed your application.

On behalf of the General Research Ethics Board, I wish you continued success in your research.

Yours sincerely,

Joan Stevenson, Ph.D.
Professor and Chair
General Research Ethics Board

JS/If

cc: Heather Cross

think Research
think Queen's
APPENDIX C

Research ID: _______________________

Adult Reading History Questionnaire

1. Male ____  Female ____

2. Age ______

3. Spoken language of preference ____________________________

4. Written language of preference ____________________________

5. You prefer to use your: 
   Right hand ____  Left hand ____  Ambidextrous ____

6. You have normal or corrected-to-normal vision  Yes____  No ____

7. Number of years of schooling (from elementary school to present) ________________

8. To the best of your knowledge, did your parents ever report that either of them had a problem with reading or spelling?
   Yes ____  No ____  Not Sure ____

   If yes, please give details: ______________________________________

9. To the best of your knowledge did your brother(s) and/or sister(s) ever have a problem with reading or spelling?
   Yes ____  No ____  Not Sure ____

   If yes, please give details: ______________________________________

10. To the best of your knowledge, have any other members of your family (e.g., aunt, uncle, grandparents) ever had difficulties with reading?
    Yes ____  No ____  Not Sure ____
**ELEMENTARY SCHOOL**

Please circle the number of the response that most nearly describes your attitude or experience for each of the following questions or statements. If you think your response would be between numbers, place an "X" where you think it should be.

11. When you were in elementary school, which of the following most nearly describes your parents' attitude towards education?

<table>
<thead>
<tr>
<th>Education was important</th>
<th>Education was not important</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

12. Which of the following most nearly describes your attitude toward school when you were in elementary school:

<table>
<thead>
<tr>
<th>Loved school; Favourite activity</th>
<th>Hated school; tried to get out of going</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

13. How much difficulty did you have learning to read in elementary school?

<table>
<thead>
<tr>
<th>None</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>A great deal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

14. How much extra help did you need when learning to read in elementary school?

<table>
<thead>
<tr>
<th>No help</th>
<th>Help from:</th>
<th>Teachers/ parents</th>
<th>Tutors or special class 1 year</th>
<th>Tutors or special class 2 or more years</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

15. Did you ever reverse the order of letters or numbers when you were a child?

<table>
<thead>
<tr>
<th>No</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>A great deal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

16. Did you have difficulty learning letter and/or colour names when you were a child?

<table>
<thead>
<tr>
<th>No</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>A great deal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

17. How would you compare your reading skill to that of others in your elementary classes?

<table>
<thead>
<tr>
<th>Above average</th>
<th>Average</th>
<th>Below average</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>4</td>
</tr>
</tbody>
</table>
18. All students struggle from time to time in elementary school. In comparison to your classmates, how much did you struggle to complete your work?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>Less than most</th>
<th>About the same</th>
<th>More than most</th>
<th>Much more than most</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

19. Which of the following most nearly describes your attitude toward reading as a child?

<table>
<thead>
<tr>
<th>Very positive</th>
<th>Very negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

20. When you were in elementary school, how much reading did you do for pleasure?

<table>
<thead>
<tr>
<th>A great deal</th>
<th>Some</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

21. How would you compare your reading speed in elementary school with that of your classmates?

<table>
<thead>
<tr>
<th>Above average</th>
<th>Average</th>
<th>Below average</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

22. How much difficulty did you have learning to spell in elementary school?

<table>
<thead>
<tr>
<th>None</th>
<th>Some</th>
<th>A great deal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

23. Did your parents ever consider having you repeat any grades in elementary school due to academic failure (not illness)?

<table>
<thead>
<tr>
<th>No</th>
<th>Talked about it but didn’t do it</th>
<th>Repeated 1 grade</th>
<th>Repeated 2 grades</th>
<th>Repeated more than 2 grades</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

24. When you were in elementary school, how many books did you read for pleasure each year?

<table>
<thead>
<tr>
<th>More than 10</th>
<th>6-10</th>
<th>2-5</th>
<th>1-2</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

25. How many comic books did you read for pleasure each year?

<table>
<thead>
<tr>
<th>More than 10</th>
<th>6-10</th>
<th>2-5</th>
<th>1-2</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>
SECONDARY SCHOOL

26. When you were in secondary school, which of the following most nearly describes your parents' attitude towards education?

<table>
<thead>
<tr>
<th>Education was important</th>
<th>Education was not important</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

27. Which of the following most nearly describes your attitude toward school when you were in secondary school:

<table>
<thead>
<tr>
<th>Enjoyed school</th>
<th>Hated school</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

28. How much difficulty did you have with reading in secondary school?

<table>
<thead>
<tr>
<th>None</th>
<th>A great deal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

29. Did you receive extra help in secondary school?

<table>
<thead>
<tr>
<th>No help</th>
<th>Help from:</th>
<th>Teachers/</th>
<th>Tutors or</th>
<th>Tutors or</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Friends</td>
<td>parents</td>
<td>special</td>
<td>special</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>class 1</td>
<td>class 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>year</td>
<td>or more</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>years</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

30. How would you compare your reading skill to that of others in your secondary classes?

<table>
<thead>
<tr>
<th>Above average</th>
<th>Average</th>
<th>Below average</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

31. All students struggle from time to time in secondary school. In comparison to your classmates, how much did you struggle to complete your work?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>Less than most</th>
<th>About the same</th>
<th>More than most</th>
<th>Much more than most</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

32. Did you experience difficulty in your high school English classes?

<table>
<thead>
<tr>
<th>No; enjoyed and did well</th>
<th>Some</th>
<th>A great deal; did poorly</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

34. During secondary school what was your attitude toward reading?

<table>
<thead>
<tr>
<th>Very positive</th>
<th>Very negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>
35. When you were in secondary school, how much reading did you do for pleasure?

<table>
<thead>
<tr>
<th>A great deal</th>
<th>Some</th>
<th>Average</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

36. How would you compare your reading speed in secondary school with that of your classmates?

<table>
<thead>
<tr>
<th>Above average</th>
<th>Average</th>
<th>Below average</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

37. How much difficulty did you have with spelling in secondary school?

<table>
<thead>
<tr>
<th>None</th>
<th>Some</th>
<th>A great deal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

38. Did you or your parents ever consider having you repeat any courses in secondary school due to academic failure (not illness)?

<table>
<thead>
<tr>
<th>No</th>
<th>Talked about it but didn't do it</th>
<th>Repeated 1 course</th>
<th>Repeated 2 or more course</th>
<th>Dropped out</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

39. Did you have difficulty remembering complex verbal instructions in secondary school?

<table>
<thead>
<tr>
<th>No</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>A great deal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

40. When you were in secondary school, how many books did you read for pleasure each year?

<table>
<thead>
<tr>
<th>More than 10</th>
<th>6-10</th>
<th>2-5</th>
<th>1-2</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

41. How many comic books did you read for pleasure each year?

<table>
<thead>
<tr>
<th>More than 10</th>
<th>6-10</th>
<th>2-5</th>
<th>1-2</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

42. How many magazines did you read for pleasure each month?

<table>
<thead>
<tr>
<th>More than 10</th>
<th>6-10</th>
<th>2-5</th>
<th>1-2</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

43. Did you read daily (Monday-Friday) newspapers when you were in secondary school?

<table>
<thead>
<tr>
<th>Every day</th>
<th>1-4 times a week</th>
<th>Once in a while</th>
<th>Rarely</th>
<th>Never</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>
44. Did you read a newspaper on Saturday?

<table>
<thead>
<tr>
<th>Completely every Saturday</th>
<th>Scan every week</th>
<th>Once in a while</th>
<th>Rarely</th>
<th>Never</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

45. Did you read a newspaper on Sunday?

<table>
<thead>
<tr>
<th>Completely every Sunday</th>
<th>Scan every week</th>
<th>Once in a while</th>
<th>Rarely</th>
<th>Never</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

CURRENT STATUS

46. Which of the following most nearly describes your parents' attitude towards postsecondary education?

<table>
<thead>
<tr>
<th>Education is important</th>
<th>Education is not important</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

47. Which of the following most nearly describes your attitude towards postsecondary education?

<table>
<thead>
<tr>
<th>Enjoy school</th>
<th>Hate school</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

48. How much difficulty do you currently have with reading?

<table>
<thead>
<tr>
<th>None</th>
<th>A great deal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

49. Have you received extra help during your postsecondary education?

<table>
<thead>
<tr>
<th>No help</th>
<th>Help from: Friends</th>
<th>Parents</th>
<th>Professor(s)</th>
<th>Tutor(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

50. How would you compare your reading skill to that of others in your postsecondary classes?

<table>
<thead>
<tr>
<th>Above average</th>
<th>Average</th>
<th>Below average</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

51. All students struggle from time to time at the postsecondary level. In comparison to your classmates, how much do you struggle to complete your work?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>Less than most</th>
<th>About the same</th>
<th>More than most</th>
<th>Much more than most</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>
52. Have you experienced difficulty in any of your postsecondary English classes?

<table>
<thead>
<tr>
<th>Not at all</th>
<th>Some</th>
<th>A great deal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

53. What is your current attitude toward reading?

<table>
<thead>
<tr>
<th>Very positive</th>
<th>Very negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

54. How much reading do you do for pleasure?

<table>
<thead>
<tr>
<th>A great deal</th>
<th>Some</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

55. How would you compare your current reading speed with that of others with the same age and education?

<table>
<thead>
<tr>
<th>Above average</th>
<th>Average</th>
<th>Below average</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

56. How much reading do you do in conjunction with your studies?

<table>
<thead>
<tr>
<th>Over 40 hours a week</th>
<th>30-40 hours a week</th>
<th>20-30 hours a week</th>
<th>10-20 hours a week</th>
<th>Less than 10 a week</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

57. How would you compare your current spelling to that of others of the same age and education?

<table>
<thead>
<tr>
<th>Above average</th>
<th>Average</th>
<th>Below average</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

58. Have you ever repeated any courses at the postsecondary level due to academic failure (not illness)?

<table>
<thead>
<tr>
<th>No</th>
<th>Repeated 1-2</th>
<th>Repeated 3-4</th>
<th>Dropped a course</th>
<th>Placed on academic probation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

59. Do you ever have difficulty remembering people’s names or names of places?

<table>
<thead>
<tr>
<th>No</th>
<th></th>
<th>A great deal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

60. Do you have difficulty remembering addresses, phone numbers, or dates?

<table>
<thead>
<tr>
<th>No</th>
<th></th>
<th>A great deal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>
61. Do you have difficulty remembering complex verbal instructions?
   No 0 1 2 3 A great deal 4

62. Do you currently reverse the order of letters or numbers when you read or write?
   No 0 1 2 3 A great deal 4

63. How many books do you read for pleasure each year?
   More than 10 6-10 2-5 1-2 None 0 1 2 3 4

64. How many magazines do you read for pleasure each month?
   5 or more 3-4 regularly 1-2 regularly 1-2 irregularly None 0 1 2 3 4

65. Do you read daily (Monday-Friday) newspapers?
   Every day 0 1 Once a week 2 Once in a while 3 Rarely 4 Never

66. Do you read a newspaper on Saturday?
   Completely every Saturday 0 1 Scan every week 2 Once in a while 3 Rarely 4 Never

67. Do you read a newspaper on Sunday?
   Completely every Sunday 0 1 Scan every week 2 Once in a while 3 Rarely 4 Never
APPENDIX D

Instructions

In this test I am going to see how fast you can find some numbers. There is going to be a number on the left (point), and I want you to circle all the numbers that are the same as that one on the same line.

Example. Try this example. See the number on the left (point)? Circle all the numbers on that line that are the same as the one on the left. (After first line is done) Now try the second line – try to be as fast as you can.

\[
\begin{array}{cccccccc}
7 & 2 & 3 & 7 & 2 & 7 & 6 & 9 & 5 & 7 & 2 \\
2 & 7 & 2 & 8 & 7 & 1 & 2 & 4 & 7 & 4 & 2 \\
\end{array}
\]

On the next page, there are going to be more of these. I want you to do as many as you can in 30 seconds. Don’t worry if you don’t finish – there are more than anyone can do!

Remind to circle ALL the numbers that are the same (not just one per line). If a mistake is made, tell him/her to cross the circle out (no erasing).
Speed of Processing Test 1

<table>
<thead>
<tr>
<th>9</th>
<th>9 1 3 9 6 5 2 9 7 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>3 5 5 1 8 5 2 4 6 5</td>
</tr>
<tr>
<td>2</td>
<td>6 9 3 7 2 1 8 4 2 5</td>
</tr>
<tr>
<td>8</td>
<td>8 2 1 8 6 4 3 5 9 8</td>
</tr>
<tr>
<td>3</td>
<td>1 3 4 8 2 5 3 6 8 9</td>
</tr>
<tr>
<td>1</td>
<td>4 5 1 1 6 3 2 1 9 7</td>
</tr>
<tr>
<td>7</td>
<td>7 3 4 6 7 8 5 1 7 2</td>
</tr>
<tr>
<td>4</td>
<td>5 4 9 2 4 6 3 1 4</td>
</tr>
<tr>
<td>0</td>
<td>7 2 5 0 1 3 0 4 0 6</td>
</tr>
<tr>
<td>6</td>
<td>2 6 8 3 4 6 5 6 9 1</td>
</tr>
</tbody>
</table>
Speed of Processing Instructions 2

On the next page, I’m going to ask you to do it again, but this time the numbers will be bigger, so you will have to look carefully.

Try this example:

<table>
<thead>
<tr>
<th>6921</th>
<th>6912</th>
<th>6921</th>
<th>9621</th>
<th>2169</th>
<th>6921</th>
<th>6927</th>
</tr>
</thead>
<tbody>
<tr>
<td>8113</td>
<td>8113</td>
<td>8114</td>
<td>8113</td>
<td>6116</td>
<td>6113</td>
<td>8113</td>
</tr>
</tbody>
</table>

'This time I am going to give you ONE MINUTE to see how many you can do!'
### Speed of Processing Test 2

<table>
<thead>
<tr>
<th>1739</th>
<th>1718</th>
<th>1739</th>
<th>5739</th>
<th>6418</th>
<th>1739</th>
<th>5939</th>
</tr>
</thead>
<tbody>
<tr>
<td>5917</td>
<td>5917</td>
<td>5939</td>
<td>5918</td>
<td>5917</td>
<td>6417</td>
<td>5917</td>
</tr>
<tr>
<td>2271</td>
<td>2218</td>
<td>5971</td>
<td>2271</td>
<td>2271</td>
<td>2279</td>
<td>2271</td>
</tr>
<tr>
<td>6418</td>
<td>6418</td>
<td>6419</td>
<td>6418</td>
<td>1718</td>
<td>6418</td>
<td>6417</td>
</tr>
<tr>
<td>77172</td>
<td>77975</td>
<td>77172</td>
<td>21972</td>
<td>47166</td>
<td>49176</td>
<td>77172</td>
</tr>
<tr>
<td>21975</td>
<td>77172</td>
<td>21966</td>
<td>21975</td>
<td>71972</td>
<td>21975</td>
<td>49976</td>
</tr>
<tr>
<td>49966</td>
<td>29966</td>
<td>49966</td>
<td>77172</td>
<td>49975</td>
<td>77172</td>
<td>49966</td>
</tr>
<tr>
<td>37741</td>
<td>37741</td>
<td>37172</td>
<td>47166</td>
<td>37741</td>
<td>37741</td>
<td>77171</td>
</tr>
<tr>
<td>845921</td>
<td>587878</td>
<td>845921</td>
<td>219721</td>
<td>587878</td>
<td>845418</td>
<td>845921</td>
</tr>
<tr>
<td>587878</td>
<td>585921</td>
<td>219778</td>
<td>587878</td>
<td>845871</td>
<td>587878</td>
<td>587878</td>
</tr>
</tbody>
</table>