DISSERTATION

THE RELATIONSHIP OF SELF-REGULATION AND ACADEMIC ACHIEVEMENT IN COLLEGE STUDENTS WITH AND WITHOUT ATTENTION-DEFICIT/HYPERACTIVITY DISORDER: A BRAIN-BEHAVIOR PERSPECTIVE

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In partial fulfillment of the requirements
For the Degree of Doctor of Philosophy
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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY WEN-PIN CHANG ENTITLED THE RELATIONSHIP OF SELF-REGULATION AND ACADEMIC ACHIEVEMENT IN COLLEGE STUDENTS WITH AND WITHOUT ATTENTION-DEFICIT/ HYPERACTIVITY DISORDER: A BRAIN-BEHAVIOR PERSPECTIVE BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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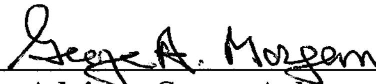

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ABSTRACT OF DISSERTATION

THE RELATIONSHIP OF SELF-REGULATION AND ACADEMIC ACHIEVEMENT IN COLLEGE STUDENTS WITH AND WITHOUT ATTENTION-DEFICIT/HYPERACTIVITY DISORDER: A BRAIN-BEHAVIOR PERSPECTIVE

The main purpose of this dissertation is to investigate the relationships among three constructs: (a) the underlying executive processes of self-regulation, (b) self-regulation behaviors, and (c) academic achievement in college students with and without ADHD.

Thirty-two adult college students (16 males and 16 females) between the age of 18 and 30 years (mean = 23.68 ± 3.65) who reported no known disorders participated in this study. Thirty-six adult college students (18 males and 18 females) between the age of 18 and 30 years (mean = 23.69 ± 3.73) who had been diagnosed with ADHD also participated in this study. All participants had an estimated IQ above 96 measured by the Wechsler Abbreviated Scale of Intelligence (WASI). They also filled out the Conners Adult ADHD Rating Scale (CAARS) and the Adult Self-Report (ASR) to confirm their current ADHD symptoms and other comorbid problems. The participants performed three event-related potential (ERP) tasks; i.e., the Posner cue attention task, visual letter flanker task, and go/no-go task during electroencephalogram (EEG) recordings. They also filled out several self-repot questionnaires; i.e., the Adult Temperament Questionnaire (ATQ), Behavioral Rating Inventory of Executive Function – Adult Version (BRIEF-A), Self-Regulation Scale (SRS), and Motivated Strategies for Learning

Questionnaire (MSLQ). The participants were also given the Woodcock Johnson III – Tests of Achievement Form C/Brief Battery (WJ III Brief Battery).

The results revealed that (a) for control students, the ERP components accounted for 36.6% of the variance of the letter-word identification score, 37.4% of the variance of the spelling score, 63.9% of the variance of the calculation score and 59.6% of the variance of the academic skill score, and (b) for students with ADHD, the ERP components accounted for 38.3% of the variance of the spelling score, and 31% of the variance of the academic skill score.

In conclusion, the results of this study supported that there is a relationship between self-regulation and academic achievement in college students with and without ADHD. The ERP components, representative of the executive processes of self-regulation, accounted for a significant amount of the variance in performance on academic achievement tests.

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CHAPTER ONE: INTRODUCTION

Statement of the Research Problem

Self-regulation, the ability to control and regulate one's behaviors, has recently become a growing interest in many areas of psychology including social, personality, developmental, organizational, clinical, educational, and health (Pintrich, 2000a). In educational psychology, one major focus of self-regulation research is to examine the construct of self-regulation in attention-deficit hyperactivity disorder (ADHD; Schunk & Zimmerman, 2003). For several years, ADHD has been conceptualized as difficulties in attention, hyperactivity, poor impulse control, and behavioral management problems (American Psychiatric Association, 1994; 2000); however, a current perspective of ADHD is that individuals with ADHD demonstrate a broader syndrome of deficient executive function resulting in impaired self-regulation of behaviors (e.g., Barkley, 1997a, 1998, 2004; Brown, 2006; Sergeant, Guerts, & Oosterlaan, 2002; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005).

Given the recent emphasis on the role of self-regulation in ADHD, some research has investigated the underlying executive processes (e.g., inhibition, attention, and performance monitoring) related to self-regulation in ADHD. For instance, a recent review described studies using functional magnetic resonance imaging (fMRI) and event-related potential (ERP) investigating response inhibition and inhibitory control in ADHD (Aron and Poldrack, 2005). The summative results reported in this review indicate that individuals with ADHD often fail to stop an ongoing response showing a lack of

inhibitory control (see Aron & Poldrack, 2005, for review). In terms of attention, Alvarez and Freides (2004) reviewed studies using a behavioral measure, Ponser's covert orienting of attention paradigm, to examine attention in ADHD. They concluded that individuals with ADHD demonstrate overall slowing of reaction time (RT) which indicates they may be under-aroused by some stimuli, which slows their response. This overall slowing of RT also helps to differentiate individuals with ADHD from the controls (see Alvarez & Freides, 2004, for review). For error/performance monitoring, three electrophysiological studies revealed that individuals with ADHD have reduced amplitudes (i.e., voltage of the brain electrical activity) of components related to error monitoring compared to the controls (i.e., Liotti, Pliszka, Perez, Kothmann, & Woldorff, 2005; Wiersema, van der Meere, Antrop, & Roeyers, 2006; Wiersema, van der Meere, & Roeyers, 2005). Of interest to this research, smaller brain responses or smaller amplitudes generally relate to less behavioral control, attention, and monitoring. One behavioral study, using a stop-signal task, reported that individuals with ADHD make more errors in relation to their control peers (Schachar et al., 2004). Collectively these studies demonstrated, using neurophysiological and behavioral measures, that individuals with ADHD have deficits in inhibition, attention, and performance monitoring which are all related to the construct of self-regulation.

The difficulties or poor performance in school for individuals with ADHD may relate to or result from deficient self-regulation. When they engage in academic or school activities requiring self-regulation, such as maintaining on-task behaviors, following instructions, and planning goal-directed actions, their poor performance is enormously evident (Harris, Reid, & Graham, 2004). Difficulties with being able to continue to

participate in activities that require persistence may also result in lower average marks, more failed grades, more expulsions, increased dropout rates, and a lower rate of college undergraduate completion (Ingersoll, 1988; Johnston, 2002).

Self-regulation has been studied in individuals with ADHD by educational psychologists, and cognitive neuroscientists have looked at executive functions in individuals with ADHD. However, there have not been any studies that have looked at the relationship between self-regulation and executive functions, and the impact of the interaction of these two constructs on academic performance. Therefore, this dissertation examines self-regulation and executive functions in adults with ADHD and relates the interaction of these two constructs to academic achievement.

Purpose and Significance of the Study

Around 50% of children with attention-deficit/hyperactivity disorder (ADHD) do not grow out the behavioral symptoms (e.g., inattention, hyperactivity-impulsivity) into adulthood (Barkley, Fischer, Smallish, & Fletcher, 2002; Wender, Wolf, & Wasserstein, 2001). ADHD is now recognized as a chronic condition that will persist over the life span in persons diagnosed with ADHD (National Institute of Health, 1998). Therefore, there is a growing importance to investigate adults with ADHD. One major focus of research in adults with ADHD is self-regulation. "Self-regulation refers to the ability to monitor and modulate cognition, emotion, and behavior, to accomplish one's goal and/or adapt to the cognitive and social demands of specific situations" (Berger, Kofman, Livneh & Henik, 2007, p. 257). However, it is not yet determined how executive processes of self-regulation and behavioral performance of self-regulation affect learning in adults with ADHD. Therefore, the purpose of this dissertation is to investigate the relationship

between three constructs: (a) the underlying executive processes of self-regulation (i.e., inhibition, attention, and monitoring), (b) self-regulation behavior (e.g., If I am distracted from an activity, I don't have any problem coming back to the topic quickly), and (c) academic achievement in college students with and without ADHD. Specifically, this study is to investigate how the brain processes of self-regulation and self-regulation behavior could impact academic achievement in college students with and without ADHD. If there is a significant relationship between self-regulation and academic achievement, it will indicate the need for further studies to address the intervention regimen using self-regulation strategies to enhance academic performance and learning in students with ADHD.

Research Questions/Hypothesis

1. Are there any differences between adult students with and without ADHD in the areas of the executive processes of self-regulation (i.e., inhibition, attentional control, and performance monitoring), self-regulatory behaviors, and academic achievement?

   Hypothesis 1: Students with ADHD will display reduced inhibitory ability as measured during the go/no-go ERP paradigm when compared to students without disabilities, specifically:

   a. The ERP components in the go/no-go paradigm (e.g., frontal N2, No-Go P3) will be smaller in students with ADHD than control students.

   b. The behavior of inhibitory control/response inhibition (e.g., mean RT, SD of Mean RT) will be slower in students with ADHD than control students.

   Hypothesis 2: Students with ADHD will display reduced error monitoring ability as compared to students without disabilities, specifically:

a. The ERP components of the error monitoring paradigm (e.g., ERN, Pe) will be smaller in students with ADHD than control students.

b. The behavior of error monitoring (e.g., post-error slowing) will be slower in control students than students with ADHD.

Hypothesis 3: Students with ADHD will display reduced attentional control ability as measured during the Posner cue attention task when compared to students without disabilities, specifically:

a. The target-P1, -N1, and -P3 to three cue conditions (valid, invalid, and no) in the Posner cue attention task will be smaller in students with ADHD than control students.

b. The contingent negative variation (CNV)/readiness potential (RP) to two cue conditions (valid vs. invalid) in the Posner cue attention task will be smaller in students with ADHD than control students.

c. The cue-P3 to two cue conditions (valid vs. invalid) in the Posner cue attention task will be smaller in students with ADHD than control students.

d. On the Posner cue attention task, the reaction time to three cue conditions (valid, invalid, and no) will be slower in students with ADHD than control students.

Hypothesis 4: Students with ADHD will display deficient behavioral manifestations of regulation as compared to students without disabilities, specifically:

a. The scores on the Adult Temperament Questionnaire, Behavioral Rating Inventory of Executive Function – Adult Version, Self-Regulation Scale, and Motivated Strategies for Learning Questionnaire will be lower in students with ADHD than control students.

b. The scores on the Behavioral Rating Inventory of Executive Function – Adult Version will be higher in students with ADHD than control students.

Hypothesis 5: Students with ADHD will display poor academic performance as compared to students without disabilities, specifically:

The standard scores of letter-word identification (reading), spelling, and mathematic calculation on the academic achievement test will be lower in students with ADHD than control students.

2. Are there any interrelationships between the inhibition, attentional control, and performance monitoring?

   Hypothesis: A relationship will be found between the executive processes of self-regulation and behavioral regulation in students with and without ADHD. The magnitude of relationship will be different from students with and without ADHD.

3. Can the executive processes and self-regulatory behaviors predict or account for the variance of academic achievement in adult students with and without ADHD?

   Hypothesis: The executive processes of self-regulation and behavioral regulation will account for a significant amount of variance in academic performance in students with and without ADHD.

4. Which ERP components and self-reported self regulatory behaviors best discriminate or classify students with and without ADHD?

   Hypothesis: Some ERP components and self-reported self regulatory behaviors will be able to discriminate or classify students with and without ADHD.

Definitions of Terms

Cognitive neuroscience is the scientific study of the neural mechanisms underlying cognition and a branch of neuroscience. Cognitive neuroscience overlaps with cognitive psychology, and focuses on the neural substrates of mental processes and their behavioral manifestations.

Self-regulation refers to the ability to monitor and modulate cognition, emotion, and behavior to accomplish one's goal and/or adapt to the cognitive and social demands of specific situations (Berger et al., 2007, p. 257).

Electroencephalogram (EEG) is a test that measures and records the electrical activity of the brain. It is commonly used to evaluate the type and location of seizure activity in the brain. It also is used to evaluate people who are having problems associated with brain function. EEG is also a common research technique used to evaluate brain processing.

Event-related potential (*ERP*) refers to the voltage changes in the electrical activity of the brain (i.e., continuous EEG) which is time-locked to an 'event' such as a sensory or cognitive stimulus (Polich, 1993). It provides good temporal resolution of the electrical activity changes in brain processing on the order of a few milliseconds (Otten & Rugg, 2005).

Executive processes of self-regulation refers to the underlying brain processes that play an important role in both executive functions and self-regulation. These brain processes include inhibition/inhibitory control, attention/attentional control and error/performance monitoring.

Error-related negativity (ERN) has been related to error monitoring and is a negative deflection peaking approximately 40 – 120 ms after an erroneous response at the fronto-central site of EEG recording.

Error positivity (Pe) is a subsequent component following the ERN, which is a more parietal positive deflection within 200 – 500 ms, and has been related to the evaluation of an error.

Target-P1 is a positive deflection peaking within 60 – 150 ms after a target presentation in the Posner cue attention task and is associated with attentional orienting.

Target-N1 is a negative deflection peaking within 70 – 170 ms after a target presentation in the Posner cue attention task and is associated with visual discrimination.

No-go N2 is a negative deflection peaking within 150 – 350 ms after the presentation of a no-go stimulus in the go/no-go task and is associated with response inhibition or inhibition control.

Target-P3 is a positive deflection peaking within 260 – 440 ms after a target presentation in the Posner cue attention task and is associated with target identification.

Contingent negative variation (CNV) is a slow negative deflection brainwave that occurs in the time period between a warning and an imperative stimulus, and is considered to be both an expectancy and preparatory aspect of sustained attention.

Readiness potential (RP) is an electrophysiological component, which is associated with an event reflecting anticipation and preparation of a motor response.

Behavioral regulation (Karoly, 1993) implies modulation of behavioral manifestation of self-regulation via deliberate or automated use of specific mechanisms (e.g., attention) and supportive meta-skills (e.g., the capacity to learn vicariously).

Executive attention is the ability to allocate attention in a way consistent with self-established goals and plans (Richards, 2005).

Metacognition encompasses people's awareness of required skills, strategies, and resources for effective task performance, as well as their knowledge of how to regulate their behaviors for successful task completion (Boekaerts, Pintrich, & Zeidner, 2000).

Academic achievement refers to the achievement by individuals of objectives related to various types of knowledge and skills. These objectives are socially established based on the age, prior learning, and capacity of individuals with regard to education, socialization, and qualification.

Valid cue refers to both target and cue stimuli that appear on the same location on the computer monitor in the Posner cued-attention task (Posner & Cohen, 1984).

Invalid cue refers to both target and cue stimuli that appear on different locations on the computer monitor in the Posner cued-attention task (Posner & Cohen, 1984).

Latency jitter refers to the variability in the time occurrence of the ERP signal or the latency of an ERP component varying from trial to trial (Otten & Rugg, 2005; Spencer, 2005).

Post-error slowing refers to the adjustment or slowing down the speed of response immediately following the commission of an error in order to sustain an adequate level of accuracy (Jones, Rothbart, Posner, 2003).

Delimitation of the Study

This dissertation will confine itself to data collection related to electrophysiological measures of self-regulation processes, behavioral manifestations of self-regulation, and academic performance in adult college students with and without ADHD. This

dissertation will be restricted to self-regulation issues in adults with ADHD and also delimited to adult college students at Colorado State University. The population studied may be primarily Caucasians and native English speakers. This delimitation will limit the generalization of the findings to this type of participants.

Limitations of the Study

Given the nature of computer tasks used in the electrophysiological recording, the processes of self-regulation examined in these tasks may not represent the real-world situation, which means that the electrophysiological recording could have low ecological validity. There may be large individual differences within the groups in both electrophysiological and behavioral measures; therefore, this dissertation might fail to demonstrate group differences. Also, the sample studied in this dissertation may not represent the population of adults with ADHD across the country, which may limit the generalization of the findings.

Assumptions of the Study

It is assumed that electrophysiological measures would be more sensitive, reliable and valid than behavioral measures and self-report because electrophysiological measures can directly examine how the human brain functions over time whereas behavioral measures and self-report indirectly examine how the brain influences behaviors. It is necessary to assume that the participants will be honest in their self-reports and when performing tasks on the behavioral measures.

Researcher's Perspectives

I worked as a clinical occupational therapy (OT) practitioner for two years in Taiwan before coming to the US for graduate school. I have been working at an

electroencephalogram (EEG) lab for the past five years. I am interested in understanding how the human brain responds to and processes different stimuli or information. Examining how the human brain processes information helps researchers and practitioners recognize brain-behavior relationships. By understanding the interactions between brain and behavior, researchers and practitions can begin to discern what brain malfunction leads to what types of dysfunctional behaviors. Also researchers and practitioners can begin to examine if behavioral interventions, such as occupational therapy lead to changes in brain processing. Therefore, my goals in graduate school have been to: (a) learn to conduct research using EEG techniques and (b) participate in conducting several research projects in the EEG lab. For my master's thesis, I studied how children with disabilities respond to auditory stimuli. Since completing my master's thesis, I have expanded my own research interests to include exploration of how human brain deals with more complex information and how complex brain processing relates to behavioral performance (e.g., cognitive functions related to the prefrontal cortex). The events instrumental in broadening my interests include: (a) the discovery of the dynamic inter-relationship of several auditory ERP paradigms in my master's thesis research and (b) the opportunity to participate in lab seminars and learn about how human brain processes more complex events (e.g., thinking tasks).

With the advent of technological innovations, new neuroimaging techniques have been developed to investigate brain activity and the relationship of brain functions and human behaviors. EEG and ERP, real-time measures of brain activation and electrical activity from the scalp, may be an ideal neuroimaging technique offering a variety of

professions new strategies for studying simple and complex information processing performance.

As an OT, I am concerned about people's daily life functions in different contexts. Investigating how people deal with simple and complex information might help me to understand how their brain functions support aspects of their daily life activities. For instance, in the education setting students need to maintain an optimal academic performance in order to succeed and graduate. It is possible that successful academic performance may be influenced by brain processes. By studying brain processing, I may discover new ways of explaining every day function and dysfunction, as it relates to academic performance, for example.

In order to make sure that students with ADHD were comfortable with the testing environment and relaxed as much as possible during data collection, I provided more breaks and encouragement for college students with ADHD relative to control students. This adaptation was based on my previous clinical and research experiences and could have affected the data collection procedure and result interpretation. This adaptation helped to get reliable data from students with ADHD; however, they may perform better than they would have without this adaptation. This probably had a minor influence on the findings of this dissertation. With respect to interpretation of the results, I assumed that students with ADHD are different from control students in several aspects of self-regulation. Therefore, I may have over interpreted the findings or may have overlooked some significant information revealed from the results. However, previous research training helped me accept and understand the results even if the findings were not as expected.

CHAPTER TWO: REVIEW OF THE LITERATURE

This literature review will focus on two primary topics that relate to the constructs of this dissertation project. First, I will examine the body of literature with respect to self-regulation. Specifically, the review will include an overview, a discussion of the theory or perspectives related to self-regulation, the relationship between self-regulation and executive function, brain processes involved in self-regulation, and functional implications of self-regulation. Second, I will review the literature related to attention-deficit/hyperactivity disorder (ADHD), with specific emphasis on ADHD in adults. Related to ADHD, I will examine the body of literature with respect to the behavioral model of ADHD, diagnostic considerations of ADHD in adults, and biological, psychological and functional aspects of adults with ADHD. In this review, different neuropsychological or behavioral measures and electrophysiological measures that have been used to study self-regulation and ADHD will be discussed. Reviewing both behavioral and electrophysiological measures is important because recent advancement in these techniques have made it possible to investigate the constructs related to this dissertation project with more accuracy.

Self-Regulation

Overview of Self-Regulation

Self-regulation has a profound impact on people's everyday life. The failure of self-regulation could result in nearly every major personal and social problem (Vohs & Baumeister, 2004). Therefore, there has been a growing interest in the area of self-

regulation research. However, researchers have differentially defined self-regulation or developed distinct but related constructs; thus, a clear understanding of what self-regulation involves is lacking. For example, Carver (2004) and Carver and Scheier (2000) have employed an idea of "behavior is goal-directed and feedback-controlled" to understand how the role of affect in self-regulation influences human actions. They pursue the idea that, in the context of regulatory goals, affect could serve as a signal to inform how a person is doing at achieving his or her goals. In contrast, Zimmerman (2000) has employed the social cognitive perspective to explain self-regulation. From this perspective, self-regulation is a triadic interaction between person, behavior, and environment. Behavioral self-regulation involves self-observing and strategically adjusting performance processes, whereas environmental self-regulation refers to observing and adjusting environmental conditions. Personal or covert self-regulation involves monitoring and adjusting cognitive and affective states. The research on personality and self-regulation also adopts the social cognitive perspective (Matthews, Schwean, Campbell, Saklofske, & Mohamed, 2000). The main premise being that personality traits may be influenced by self-regulation.

Besides social cognitive perspectives and personality theory, several constructs, such as temperament, effortful control, and executive function (including inhibition) are important aspects of self-regulation. For instance, Rothbart and her colleagues (2004) have investigated the relationship of self-regulation and individual differences in temperament (Rothbart, Ellis, & Posner, 2004). Using a questionnaire measure, they have identified the construct of effortful control to relate temperament and behavioral regulation. Effortful control is defined as the ability to inhibit a dominant response to

perform a subdominant response, and it also plays a major role in planning and controlling attention and related behavior. Barkley (1997a) has focused on self-regulatory processes in his model explaining the behavioral symptoms of attention deficit/hyperactivity disorder (ADHD). Barkley proposed that the primary deficit is behavioral inhibition with a secondary deficit in executive function which results in the symptoms of ADHD (Barkley, 1997a; 2006). He indicated that inhibition could be a prerequisite to self-regulation; if people respond impulsively to an event they could not direct their actions toward themselves (Barkley, 2004). He also believes that executive function can serve to control people's behaviors (i.e., inhibition) in order to regulate themselves in the envronment or the specific context (Barkley, 2001).

There are many more models or theories explaining self-regulation. However, the important aspect of self-regulation related to this dissertation project is that self-regulation is considered an adaptive and goal-directed process that requires the inhibition of a dominant response to perform a subdominant response resulting in the execution of appropriate behaviors. Self-regulation also requires the coordination and modulation of affective and cognitive processes. This dissertation will focus on the relation of executive function and self-regulation from the cognitive neuroscience perspective.

Self-Regulation and Executive Function

Similar to self-regulation, executive function is also difficult to define precisely. Sergeant and his colleagues (2002) note that there are "33 definitions of executive function" (Sergeant, Geurts, & Oosterlaan, 2002, p.3). For instance, executive function could be broadly defined as the ability to regulate behaviors within the context and to maintain a response set (Nigg et al., 2005), or could refer to the maintenance of behaviors

on a goal set over time and the complex organization of behaviors (see Nigg, 2005, for review). Executive function has also been operationalized as several components of cognitive control, such as detecting a mismatch from expectations, interrupting a response, shifting a response, conflict detection, sustaining working memory, inhibition of competing response, and regulation of response via alertness or allocation of effort (Nigg, 2005). Nevertheless, most researchers would agree that executive function is self-regulatory function incorporating the ability to inhibit, shift set, plan, organize, problem solve, and maintain set for future goals (Sergeant et al., 2002). Executive function is also distinct from other mental functions such as perception or memory.

Although there are different ways to describe self-regulation and executive function, both are considered "meta" constructs, which mean that these processes are very complex. Aspects of both terms overlap, yet they can also refer to independent constructs (Borkowski & Burke, 1996). For instance, executive function is more cognitive-orientated and heavily task dependent and hence may have greater measurement accuracy, while self-regulation depends on goal orientation and is related to motivation and may be more difficult to measure (Borkowski & Burke, 1996). However, as an example of the overlap in the use of the terms, Barkley (1996) has stated that executive functions can be viewed as goal-directed and future-oriented processes that are "deployed in the service of self-regulation" (p.318). Executive functions are also a general form of self-directed actions that humans use in self-regulation (Barkley, 2004). For the purpose of this dissertation, I will not make a distinction between these two terms since the cognitive aspects of these two constructs are interdependent. I will rather be

referring to the *executive processes of self-regulation* based on the cognitive neuroscience perspective.

Cognitive Neuroscience Perspectives of Self-Regulation

Self-regulation is a fundamental human capacity to regulate and control thoughts and behavior (Banfield, Wyland, Macrae, Münte, & Heatherton, 2004). It is a process that people use efforts to alter their own inner states or responses in order to regulate their thoughts, emotions, impulses or appetites, and task performances (Vohs & Baumeister, 2004). Self-regulation is considered as the higher order (i.e., executive) control of lower order processes responsible for the planning and execution of behavior from the cognitive neuroscience perspective (Banfield et al., 2004). The executive processes involved in self-regulation, include inhibition/inhibitory control, attention/attentional control, and error/performance monitoring. The following discussion, however, will mainly focus on the executive processes of self-regulation with respect to each process, the brain structures, and the neuropsychological and event-related potential (ERP) measures for each.

Executive Processes of Self-Regulation

Inhibition/inhibitory control. Inhibition is the ability to inhibit inappropriate action, and it includes (a) inhibition of prepotent responses, that is, responses that are or have been previously associated with reinforcement, (b) stopping of ongoing responses (which allows for a delay in the decision to continue responding), and (c) interference controls, that is, protecting responses from disruption by competing responses or events (Barkley, 1997a). The inability to inhibit may be problematic to regulate thoughts and behavior.

For example, when people try to lose weight and are on a diet, they may experience failure if they had difficulty inhibiting thoughts of food.

Some neuroimaging studies have investigated the underlying neural mechanism of internal inhibition of thoughts and behavior. When the participants are asked to suppress a particular thought, regulate all thoughts, or think freely, the ACC shows greater activation under the condition of suppressing a particular thought. These studies suggest that the ACC is functionally related to inhibition (Banfield et al., 2004).

Several neuropsychological or behavioral tests have been designed to measure inhibition. For instance, the Stroop Color-Word test is a measure of interference control, which produces a conflict between processes of automatic and novel response (Brocki & Bohlin, 2004). The participants are first presented with the word card, followed by the color naming card, and then the color-word card. With color-word card, participants need to ignore the verbal content and name the color in which the words are printed. There are also several versions of computerized Stroop-like tests that are used to measure inhibition. The Go/No-Go task with stop signal can be used to measure both inhibition of a prepotent response and stopping of an ongoing response. The participants are asked to press a button to half of the randomly distributed stimuli (go), whereas motor responses are suppressed to the other half of stimuli (no-go). To increase the inhibitory demand of the task, some studies manipulate the proportion of go trials or present a no-go signal at varying time intervals after the go stimulus. The behavioral efficiency of inhibition is measured by the number of omissions and the false alarm rate (Rueda et al., 2005).

Recent advances in the electrophysiological technique also allow researchers to understand processes of inhibition. For example, the frontal-central N2 (defined below), a

negative component of ERP produced in the go/no-go paradigm with and without a stop signal, is an electrophysiological indictor of inhibition. This N2 component, a negative deflection (the "N" in the label of the component) occurring at the peak latency of 200-400 milliseconds (the "2" in the component label shortened from 200) after stimulus onset, reflects the effective inhibition of responses to no-go stimuli (e.g., Ciesielski, Harris, & Cofer, 2004; Jonkman, Lansbergen, & Stauder, 2003). The amplitude of the N2 inhibition response can change based on the task complexity. When participants have less time to respond, the N2 amplitude is increased (Jodo & Kayama, 1992).

Attention/attentional control. "The construct of attention as studied in neuropsychology is multidimensional and can refer to alertness, arousal, selectivity or focus-execution, encoding, sustain attention, distractibility, or span of apprehension, among others" (Barkley, 2006, p. 78). The construct of attention also refers to attentional switching, selective attention, and sustained attention (Banfield et al., 2004).

Recent studies have found that attention is involved in the top-down (goal-directed) selection and the initiation of actions (Corbetta & Shulman, 2002). These processes seem related to behavioral manifestations of self-regulation (Banfield et al., 2004). Another attentional component contributing to self-regulation is the executive control of attention, or executive attention (Rueda, Posner, & Rothbart, 2005). The neural anatomical correlates of executive attention involve in the anterior cingulate cortex (ACC), lateral ventral prefrontal cortex, and basal ganglion (Rueda et al., 2005). Some attentional processes also involve the anterior part of the dorsolateral prefrontal cortex (DLPFC) (Banfield et al., 2004). In general, attention is a key process in cognitive and behavioral regulation and also seems to be involved in inhibition (Banfield et al., 2004).

Several behavioral measures can be used to investigate the attentional processes. For instance, the computerized Continuous Performance Test (CPT) is a measure of the vigilance maintenance to simple stimuli over a prolonged period of time (Brocki & Bohlin, 2004). The Broki & Bohlin CPT task has five different stimuli including a square with an X, a square with a short vertical line in the middle, a square with a long vertical line in the middle, a square with a diagonal to the right, and a square with a diagonal to the left. The participants are asked to press a response key as quickly as possible every time a cue stimulus (a square with an X) is immediately followed by a target stimulus (a square with a vertical line). The Attentional Network Test (ANT) evaluates three different attentional systems (i.e., altering, orienting, and executive attention) within a single 30 minute testing session (Fan, McCandliss, Sommer, Raz, & Posner, 2002). The ANT task consists of a row of five horizontal black lines with arrowheads pointing leftward or rightward against a gray background. The target stimulus is a leftward or rightward arrowhead at the center. There are congruent, incongruent, and neutral conditions in this test. The participants are asked to make a response based on the condition, pressing one button for a "pointing left" response and another button for a response of "pointing right".

In terms of electrophysiological measures, several ERP components relate to the attentional processes. For example, the contingent negative variation (CNV) is thought to reflect an index of cortical arousal during orienting and attention (Tecce, 1972). The CNV can be elicited by a go/no-go task that the participant is cued as to whether or not the second stimulus requires a response. A large negative potential is observed in the interval between the warning and the imperative stimuli when a response is required

(Davies, Segalowitz, Dywan, & Pailing, 2001). Another indictor of the attentional process is the P300. It is a late cognitive ERP component, generated in response to a target detection task that occurs about 300 ms after the warning stimuli, reflecting attentional operations during the information processing (Coull, 1998).

Error/performance monitoring. Performance monitoring or error monitoring, which includes both error detection and error correction, is the control mechanism related to the executive processes of self-regulation (Rueda et al., 2005). People with the ability to detect and correct an error, adjust or slow down their speed of response immediately following the commission of an error to sustain an adequate level of accuracy (Fernandez-Duque, Baird, & Posner, 2000; Rueda et al., 2005). The error monitoring system informs us of our cognitive abilities and the task difficulty. It also contributes to our coherent and successful behaviors by providing feedback about performance.

In recent years, studies have found that the ACC is related to the error monitoring system under task conditions conducive to error (e.g., Carter, Braver, Barch, Botvinick, Noll, & Cohen, 1998). The ACC activation is partly due to error detection and also associated with increased task difficulty because task difficulty is accompanied by a greater chance of errors. The ACC seems to be a critical brain structure involved in the executive processes of self-regulation.

Recent studies have shown that the Eriksen letter flanker task is a good behavioral measure to understand the process of error or performance monitoring (e.g., Luu, Tucker, Derryberry, Reed, & Poulsen, 2003). In this task, a central target stimulus is surrounded by either the same (congruent) or the opposite (incongruent) stimulus (flanker). The incongruent flankers produce larger reaction times and decreased response accuracy as

compared to the congruent ones. The error-related negativity (ERN), an electrophysiological component generated from the flanker task, has been associated with acknowledged errors or incorrect responses (e.g., Gehring, Gross, Coles, Meyer, & Donchin, 1993; Davies, Segalowitz, & Gavin, 2004; Luu et al., 2003). When the EEG or ERP is time-locked to the behavioral response, a negative deflection immediately following the response is displayed and this deflection or ERP component is called the ERN. The ERN is the most common electrophysiological indicator to study error or performance monitoring.

In summary, the focus here was to highlight what cognitive or executive processes are the most relevant to self-regulation under the cognitive neuroscience framework. It is clear that the self-regulation process is complicated, and the exploration of this process may help us understand the underlying neural mechanisms of self-regulation as well as the behavioral manifestations of self-regulation (Banfield et al., 2004).

Functional Implications of Self-Regulation

The practical application of self-regulation has been studied in several areas, such as physical health or health behaviors, psychopathology, academic achievement, learning and developmental disorders.

Physical Health

Health maintenance has become a critical issue in recent years. Several risk factors, such as smoking, unhealthy diet, and excessive body weight can increase the likelihood of having cardiovascular diseases, cancers, and other chronic diseases (Maes & Gebhardt, 2000). A current health behavior model has incorporated the concept of self-regulation to promote health behaviors. In this model, self-regulation is viewed as a person's attempt

to control his or her own behaviors over time and across contexts to achieve self-chosen goals (Maes & Gebhardt, 2000). People need to first modify their personal goal into target health behaviors while changing unhealthy behaviors. They need to recognize the emotional and health costs and benefits of changing their behavior as well as their personal capacities and environmental sources of change. Treatments or therapies based on self-regulatory principles have been developed for use with various health problems, such as hypertension, asthma, diabetes, and chronic pain and have been effective with patients with coronary heart disease (see Endler & Kocovski, 2000, for a summary). However, self-regulation is just one aspect of healthy behaviors, other factors, such as age and gender may also impact health behaviors.

Psychopathology

Failure to demonstrate self-regulation may relate to some psychological disorders (Endler & Kocovski, 2000; Vohs & Baumeister, 2004). Among psychological disorders, addictive behaviors, social anxiety, and depression are the most relevant to self-regulation (Endler & Kocovski, 2000). Addictive behaviors range from excessive gambling to life-threatening disorders, such as bulimia. Alcohol addiction also relates to difficulty in self-regulatory functioning (Hull & Slone, 2004). Many causes of failure in self-regulation of those addictive behaviors have been identified as a lack of or reduction in behavioral monitoring, inefficient coping, and difficulty in focusing attention on the task at hand.

Anxiety, a psychological disorder demonstrating self-regulation failure, has a state and a trait component. State anxiety is a transitional and emotional condition, whereas trait anxiety is relatively stable. When people have not behaved in a manner consistent

with their original goals, their social anxiety rises. Socially anxious individuals may not be able to monitor and appraise themselves in the self-regulatory process, which may contribute to their anxiety.

Similar to social anxiety, some individuals may experience depression attributed to various aspects of the self-regulation of behavior (Endler & Kocovski, 2000). In the self-regulatory processes, unrealistically personal goal attainment, cognitive distortions, and low rates of positive reinforcement are commonly seen in people with depression. Therefore, treatments or therapies focusing on changing these self-regulatory processes may be beneficial for some depressed people.

Academic Achievement

Research of self-regulation related to academic achievement or learning has been reported in recent literature. Self-regulation in learning is the process that students activate and sustain cognition, behavior, and affect toward attaining their goals (Schunk & Zimmerman, 1998). It is also an active and constructive process that learners set learning goals, and the goals and the contextual features of the environment guide and constrain how learners monitor, regulate, and control their cognition, motivation, and behavior (Pintrich, 2000b).

Today several theoretical perspectives guide the research of self-regulation in learning (e.g., Boekaerts et al., 2000; Zimmerman & Schunk, 2001) and have addressed various facets of self-regulation in learning. This line of research has also identified that students with better self-regulatory skills tend to be more academically motivated and demonstrate better learning (Pintrich, 2003). Pintrich (2000b) has developed a model of

goal orientation to investigate how learners can monitor, regulate, and control their cognition, motivation, and behavior in order to achieve their academic goals.

There are four phases in this model of goal orientation. During phase 1, the learners or students plan and set goals, and activate their perceptions and knowledge about the task and context. In phase 2, the students use their metacognition of different aspects of the self and task or context to monitor processes of learning. In phase 3, the students make an effort to control and regulate different aspects of the self or task and context. Phase 4 represents various kinds of reactions and reflections on the self and the task or context (Pintrich, 2000b). This model attempts to illustrate how different self-regulatory processes occur in learning

Several behavioral questionnaires can be used to study self-regulation in learning. For instance, there are the Motivated Strategies for Learning Questionnaire (MSLQ; Pintrich, Smith, Garcia, & McKeachie 1991), the Self-Regulated Learning Interview Scale (SRLIS; Zimmerman & Martinez-Pons, 1988), the Metacognitive Awareness Inventory (MAI; Schraw & Dennison, 1994), and the Learning Strategy Survey (LSS; Kardash & Amlund, 1991).

Developmental Disorders

Recent work has focused on the relationship of self-regulation and developmental disorders. Among developmental disorders, ADHD is commonly studied in relation to self-regulation (e.g., Barkley, 2004). People with ADHD have difficulty in regulating their attention and behaviors. This difficulty might be related to a lack of internalization of the ability to self-regulate their behaviors (Barkley, 2006). Barkley (2004) states that understanding the relationship between ADHD and the disrupted developmental

processes of self-regulation is very important. The following section of the literature review discusses more about ADHD, adults with ADHD, and some issues related to executive function and self-regulation in adults with ADHD.

Attention-Deficit/Hyperactivity Disorder

Overview of Attention-Deficit/Hyperactivity Disorder

Attention-deficit/hyperactivity disorder (ADHD) is one type of childhood behavioral disorder, which is a highly prevalent and is a heterogeneous disorder (Biederman, 2005). It has been estimated that ADHD affects 5-10% or 8-12% of children worldwide (Faraone, Sergeant, Gillberg, & Biederman, 2003), resulting in inattention, poor impulse control, hyperactivity, and behavioral management problems. According to the American Psychiatric Association (1994; 2000), ADHD has been categorized as predominantly inattention or predominantly hyperactivity-impulsivity. The inattention type of ADHD is behaviorally manifested as distractibility (Biederman, 2005) and deficits are seen on tasks requiring sustained attention (Aman, Robert, & Pennington, 1998). While the hyperactivity or hyperactivity-impulsivity type of ADHD is behaviorally expressed as fidgeting, inordinate talking, and disturbance (Biederman, 2005). Currently, there are at least five models explaining ADHD, including the delay aversion model, the behavioral inhibition/activation model, Barkley's behavioral inhibition model, the executive function model, and the cognitive-energetic model (Sergeant, Geurts, Huijbregts, Scheres, & Oosterlaan, 2003). For the purpose of this dissertation, I will only review Barkley's behavioral inhibition model because it is most related to executive function and self-regulation.

Barkley's Behavioral Inhibition Model of ADHD

Barkley (1997a) has formulated a behavioral inhibition model to understand the complex cognitive and behavioral problems characterizing children with ADHD as well as relevant normal development. Behavioral inhibition includes inhibition of prepotent responses, stopping of ongoing responses, and interference control. Barkley believes that ADHD involves deficits in these three aspects of behavioral inhibition.

In this behavioral inhibition model, Barkley posited three executive function components related to and interacted with behavioral inhibition. These components include: (a) working memory, (b) self-regulation of affect, motivation, and arousal, and (c) reconstitution. Working memory comprises two primary components: verbal working memory – internalization of speech, and nonverbal working memory. The self-regulatory part of the executive system emphasizes emotions which are regulated by self-directed and executive actions. This component also includes the self-generation of motivational and arousal states to maintain and to complete goal-directed behavior. Reconstitution refers to "flexibility. It involves analyzing and synthesizing information which means the ability to separate units of behavioral sequences and to recombine them into new sequences of behavior. Barkley (1997a) believes that behavioral inhibition and these executive function components share a common purpose. That purpose is to internalize or to make certain self-directed behaviors, so as to anticipate and prepare for the future.

Barkley also tries to illustrate the relation between self-regulatory behaviors and executive function. He defines self-regulatory behaviors as ones that serve to change the likelihood of a later rather than an immediate outcome and are future-directed, whereas

executive function refers to an individualized, internalized and specific class of self-directed actions that serve for self-regulation toward the future (Barkley, 1997b; 2006).

In terms of the relation between self-regulation, behavioral inhibition, and executive function, Barkley (2006) suggested that self-regulation is linked to behavioral inhibition, and he explained how executive function is related to both self-regulation and behavioral inhibition. These three constructs are essential for understanding ADHD in his model. Persons with ADHD disrupt their inhibitory control and execution of executive function, and thus they have difficulty controlling the goal-directed motor behavior which is internally represented and generated. "The inhibitory deficit in ADHD delays and disrupts the internationalization of behavior that forms the executive functions, and thereby has an adverse impact on the self-regulation they afford to the individual" (Barkley, 2006, p. 318).

Adults with ADHD

Although ADHD has traditionally been considered as a childhood disorder, it has been recently recognized as a lifelong disorder (see Weiss & Murray, 2003 for review). Several studies have suggested that the majority of children and adolescents diagnosed with ADHD demonstrate symptoms into adulthood, that their behavioral symptoms change over time, and that ADHD in adults is indeed a valid disorder (see Weyandt & DuPaul, 2006 for review). The following discussion will focus on the diagnostic considerations and prevalence of ADHD in adults, academic function in adults/college students with ADHD, and neuropsychological/executive function and self-regulation in adults with ADHD.

Diagnostic Considerations and Prevalence of ADHD in Adults

Based on parents' reports, up to approximately 50% of children diagnosed with ADHD do not outgrow their problems (Barkley et al., 2002; Wender et al., 2001). To date, there is no large scale epidemiological study investigating the prevalence of ADHD in adults; however, a conservative estimate of the prevalence of ADHD in adults is about 2% (Weiss & Murray, 2003). In comparison, the prevalence of ADHD in school-age children is about 5-10% (Scahill & Schwab-Stone, 2000).

The process for diagnosing ADHD in adults involves several steps, including documenting the current and past ADHD symptoms, establishing that the symptoms result in functional impairment at home, work, and school, obtaining a developmental and psychiatric history, and performing a physical examination to rule out medical causes of the symptoms (Weiss & Murray, 2003). There are two well-developed measures, the *Brown Attention-Deficit Disorder Scales (BADDS)* and the *Conners Adult ADHD Rating Scale (CAARS)* used with adults. They both have strong psychometric properties, appropriate sensitivity and specificity, and are commonly used to rate ADHD symptoms in the diagnostic process.

The BADDS is designed to obtain information about the frequency of difficulties with the cognitive and behavioral consequences of ADHD (Brown, 1996). It evaluates difficulties in organizing and activating oneself for work, sustaining attention and concentration, sustaining energy and effort, managing affective interference, and utilizing working memory and accessing recall. The scales are developed as a screening instrument to determine whether an individual would benefit from a more thorough

diagnostic review. Additionally, the scales can be a tool to track response to treatment once the ADHD diagnosis has been established (Brown, 1996).

The CAARS was created to obtain information on how accurately descriptions of behavior reflecting ADHD apply, and it has utility in discriminating between adults with current ADHD and adults without clinical concerns. The CAARS has a 42-item version and a 26-item version and evaluates inattention, hyperactivity, impulsivity/emotional liability, and problems with self-concept. Conners, Erhardt, and Sparrow (1999) established reliability with adults and normed the CAARS on a large sample. Both the BADDS and the CAARS can help determine how the symptoms affect a person's life by means of cluster scores and factors scores respectively.

In addition to rating scales, tests of intelligence, academic achievement, and neuropsychological functions are commonly used in the assessment of ADHD in adults. Tests of intelligence, such as the Wechsler Adult Intelligence Scale (WAIS; Wechsler, 1997), have shown that adults with ADHD score lower than adults without ADHD on the WAIS; however, the difference (effect size) is small and may not be clinically meaningful. Nevertheless, the WAIS will provide clinicians some information (Bridgett & Walker, 2006). Tests of academic achievement, such as the Woodcock-Johnson Tests of Achievement (Mather & Woodcock, 2001), help determine whether adults with ADHD exhibit problems and or have significant disturbances in their educational functioning. Tests of neuropsychological functions, especially executive function, help detect whether the symptoms of ADHD in adults are due to disturbances in executive function (Nigg et al., 2005). There are diverse tests measuring executive functions, such as Stroop Color-Word Test, Wisconsin Card Sorting Test, Trail Making Test, Stop Task,

and Tower of London. A thorough evaluation and clinical interview in the diagnostic process may also help determine whether or not an adult with ADHD has comorbid conditions. Adults with ADHD have lifetime prevalence rates of comorbid anxiety disorders in about 50%. Mood disorders, antisocial disorders, and alcohol/drug dependency also demonstrate substantial prevalence rates in adults with ADHD (Biederman, 2005).

Psychiatric Comorbidity in Adult with ADHD

Recent clinical and population-based studies have found that up to 89% of all adults with ADHD suffer from three most prevalent comorbid disorders, including affective disorders, substance use disorders, and eating disorders during their life time (Biederman et al., 2006; Fayyad et al., 2007; Kessler et al., 2006; Sobanski et al., 2007). Adults with ADHD-combined (i.e., exhibit both inattention and hyperactivity-impulsivity symptoms) have suffered more from substance use disorders than adults with predominantly inattentive type (Sobanski et al., 2008). Moreover, longitudinal and cross-sectional studies indicate that there is an increasing co-occurrence of antisocial personal disorders and ADHD. Up to 23% of young adults with ADHD present with comorbid antisocial personal disorders (Manuzza, Klein, Bessler, Malloy, & La Padula, 1993; Weiss, Hechtman, Milroy, & Perlman, 1985).

Underlying Brain Structure and Neural Substrate in Adults with ADHD

ADHD has currently been hypothesized to involve structural and functional brain abnormalities in the frontal-striatal circuitry (e.g., Casey et al. 1997; Durston 2003; Faraone 2004). The frontal-striatal circuitry represents the high level of executive control as well as behavioral inhibition and decision making. Areas of abnormalities in children

with ADHD include significantly smaller volumes in the prefrontal cortex, caudate, splenium of the corpus callosum, cerebellum, and overall cerebral volume. However, this hypothesis has not been fully tested in adults with ADHD yet. Recent efforts have started to investigate this hypothesis. Seidman and his colleagues (2006) have used magnetic resonance imaging (MRI) scans to investigate 24 adults with ADHD and 18 healthy controls comparable on age, socioeconomic status, sex, handedness, education, IQ, and achievement test performance (Seidman et al., 2006). They found that ADHD adults had significantly smaller overall cortical gray matter, prefrontal and anterior cingulate cortex volumes. They concluded that ADHD adults have volume differences in brain regions in areas involved in attention and executive control.

Castellanos et al. (2008) have tested another hypothesis to see whether adults with ADHD have abnormalities in functional connectivity between frontal foci involved in cognitive control and the non-goal-directed processes network. They used resting-state blood oxygen level-dependent functional MRI scan to examine the functional connectivity hypothesis in 20 adults with ADHD and 20 age- and sex-matched healthy volunteers. Their results indicated that ADHD adults have deficient functional connectivity between the anterior cingulate and precuneus/posterior cingulate cortex regions, and between precuneus and ventromedial prefrontal cortex. They suggest that the connection linking dorsal anterior cingulate to posterior cingulate and precuneus should be considered as a candidate locus of dysfunction in adults with ADHD.

Medication in Adults with ADHD

Aron and his colleagues (2003) have examined the effect of methylphenidate (MPH) on response inhibition using a stop-signal task in 13 adults with ADHD and 13

healthy, unmedicated, age- and IQ-matched control subjects (Aron, Dowson, Sahakian, & Robbins, 2003). They tested adults with ADHD on 2 separate days in a double-blind design while taking and while not taking a standard dose of 30 mg MPH. Also, a placebo (lactose) was administrated 75 minutes before the start of testing. The results found that unmedicated adults with ADHD have significantly slower stop-signal reaction time relative to healthy controls, and the deficit in slower reaction time is significantly ameliorated by MPH. Boonstra and colleagues (2005) had also found similar results in a group of adults with childhood-onset ADHD with the maximum MPH dose 1 mg/kg/day (Boonstra, Kooij, Oosterlaan, Sergeant, & Buitelaar, 2005). Moreover, Spencer and his colleagues (2005) conducted a large randomized clinical trial study to examine the effect of MPH in 146 adults with ADHD (Spencer et al., 2005). They used a randomized, 6-week placebo-controlled and parallel design with daily dose of 1.1 mg/kg/day MPH. The result showed that MPH decreased ADHD symptoms more as compared to placebo (76% vs. 19%) independent of socioeconomic status, gender, and lifetime history of psychiatric comorbidity. They concluded that MPH was effective in the treatment of adults with ADHD using a robust dose of 1.1 mg/kg/day.

Modafinil is a novel cognitive enhancer and has a clinical profile similar to a traditional stimulant such as MPH. Modafinil possibly improves inhibitory control. Turner and colleagues (2004) have examined the effect of modafinil on 20 adults with ADHD who had a mean age of 28 ± 9 years (Turner, Clark, Dowson, Robbins, & Sahakian, 2004). These ADHD participants received a single 200 mg dose of modafinil and were studied in a double-blind, randomized, placebo-controlled crossover design. The results indicated that modafinil enhances the performance on tests of short-term

memory span, visual memory, spatial planning, and stop-signal motor inhibition. The results also showed that increased accuracy is accompanied by slowed response tendency. This speed-accuracy trade-off may indicate that modafinil helps ADHD participants reflect on problems coupled with impulsive responding.

Müller and colleagues (2007) compared 30 adults with ADHD under stable psychopharmacological treatment and 27 healthy controls matched for age, gender, and IQ on 10 tests measuring attention, memory, executive function, and fine motor control (Müller et al., 2007). The results found that adults with ADHD have lower performance in verbal and visual memory, speed of visuomotor search, set shifting, and divided attention as compared to controls. There were no differences between the two groups in response inhibition and simple response speed. Under medication, adults with ADHD still show lowered cognitive performance related to memory and attention with high mental load.

Academic Function in Adults/College Students with ADHD

With regard to academic functioning in adults/college students with ADHD, students with ADHD tend to have lower grade point averages (GPAs) and more academic problems than their non-ADHD peers. College students with ADHD are also more likely to be on academic probation and are less likely to graduate from colleges and attend graduate and professional schools than their non-ADHD peers (see Weyandt & DuPaul, 2006, for review). Moreover, vulnerability is seen in the first two years of college with notable difficulty in transitioning from secondary to postsecondary settings (Mannuzza, et al., 1993). The academic failure may be due to impaired organizational skills, deficient study skills, deficient executive function, and other cognitive deficits. However, Sparks,

Javorsky, and Philips (2004) reported that college students with ADHD are not always at risk for academic problems. They found that the mean GPA for students with ADHD is 2.7, ranging from 2.0 to 3.6, compared to the typical graduating senior whose mean GPA is 2.9. Nevertheless, most students with ADHD are still at an increased risk for academic underachievement and lower GPAs.

Neuropsychological/Executive Function and Self-Regulation in Adults with ADHD

Neuropsychological, executive function and self-regulation in ADHD have been mostly studied in children. However, investigation of these functions in ADHD has recently emerged in adults (Hervey, Epstein, & Curry, 2004). The tests of neuropsychological functions are important tools to quantify the attentional and/or cognitive deficits of ADHD in adults compared to normal adults (Schoechlin & Engel, 2005). Schoechlin and Engel (2005) categorized neuropsychological functions into 10 functional domains, including verbal ability, figural problem solving, abstract problem solving, executive function, fluency, simple attention, sustained attention, focused attention, verbal memory, and figural memory in their meta-analytic study in adults with ADHD. In general, they found that adults with ADHD display small to moderate deficits in their neuropsychological functions compared to controls. They also found that focused attention, sustained attention, and verbal memory discriminate best between adults with ADHD and controls. Another meta-analytic study examining different neuropsychological tests revealed that adults with ADHD express notable deficits in attention, behavioral inhibition, and memory across multiple domains of functioning, whereas normal performance is demonstrated in simple reaction time tasks (Hervey, Epstein, & Curry, 2004). These two meta-analytic studies indicate that adults with

ADHD express some core deficits of neuropsychological functions; however, the results should be interpreted cautiously because the published studies included in the meta-analytic studies may be confounded by some factors, such as the existence of diagnostic subgroups and comorbidity.

The investigation of executive function in adults with ADHD is critical to determine whether executive function deficits can be detected in adults with ADHD and how the deficits may relate to the course of ADHD over development (Nigg et al., 2005). In a study included 105 adults with ADHD and 90 controls aged 18-37, Nigg et al (2005) found that adults with ADHD have poorer performance than the controls on several executive function measures. The symptoms of inattention-disorganization were associated with executive function while statistically controlling for the symptoms of hyperactivity-impulsivity. Bekker et al. (2005) used stop-signal and stop-change tasks to measure inhibitory control/response inhibition (one component of executive function) in 24 adults with ADHD combined subtype and 24 controls. They found that adults with ADHD have the prolonged stop-signal reaction time and a higher proportion of errors and suggested that there is evidence of for a critical role of deficient inhibitory control in adults with ADHD. Bekker et al. (2005) proposed that response inhibition deficits seem to be more pronounced in adults with ADHD than in children with ADHD. However, their findings are in contrast with clinical studies revealing that symptoms of inattention may still exist in adults with ADHD while symptoms of hyperactivity and impulsivity decline in adults with ADHD (Nigg et al., 2005). The inconsistent finding related to symptomotology of ADHD between Nigg et al. (2005) and Bekker et al. (2005) might

reflect conceptualization differences between types of studies and executive function measures.

Malloy-Diniz and colleaques (2007) studied a sample of 50 adults with ADHD and 51 healthy control adults and found that adults with ADHD made more significant omission and commission errors than control adults in the Continuous Performance Task (CPT-II). They suggested that adults with ADHD exhibited impairment in impulse control, which required inhibiting a prepotent motor response (Malloy-Diniz, Fuentes, Lette, Correa, & Bechara, 2007).

Faraone et al. (2006) used several neuropsychological tests as external validators to address the validity of the DSM-IV age at onset and symptom threshold criteria in four groups of adults between the ages of 18 and 55. These four groups consisted of: (a) 127 full ADHD adults met all DSM-IV criteria for childhood-onset ADHD, (b) 79 late-onset ADHD adults met all criteria except the age at onset criteria, (c) 41 subthreshold ADHD adults did not meet full symptom criteria, and (d) 123 non-ADHD adults did not meet any of the above criteria. Their results indicated that late-onset and full ADHD adults had similar patterns of neuropsychological dysfunction. Subthreshold ADHD adults showed few neuropsychological differences (i.e., Wisconsin Card Sorting Test and oral arithmetic) with non-ADHD adults. They suggest that the DSM-IV age at onset criteria may be too demanding.

Stavro and colleagues (2007) have examined the relations of adaptive impairment to ADHD symptom and to deficits in executive function (EF) in 105 ADHD adults and 90 normal adults between ages 18 and 37 (Stavro, Ettenhofer, & Nigg, 2007). Participants completed a battery of EF measures (i.e., Trail Making Test, Stroop Color-Word Test,

Wisconsin Card Sorting Test, Stop Task, Tower of London, and Full Scale IQ) as well as assessments of adaptive functioning (i.e., Young Adult Self-Report, Global Assessment of Functioning, and Self-reported ADHD symptom impairment). They found weaker EF was associated with poorer adaptive functioning. However, when current inattentive and hyperactive-impulsive ADHD symptoms were included in the structural model analysis, EF no longer predicted adaptive functioning. Furthermore, inattentive symptoms accounted for more variance in adaptive functioning than hyperactive-impulsive symptoms (67.2% vs. 3.6%). The results also found that childhood ADHD inattentive symptoms were related to EF or adaptive impairment. They suggest that in adults with ADHD, inattentive symptoms may be the primary contributor to key aspects of poorer adaptive functioning and may be the behavioral path through EF deficits leading to adaptive impairment.

Biederman, Petty, et al. (2006) have studied adults between the ages of 18 and 55 who did ($N = 213$) and did not ($N = 145$) meet DSM-IV criteria for ADHD. They have used the Stroop Color-Word Test, Wisconsin Card Sorting Test, Rey-Osterrieth Complex, Auditory Continuance Performance Test, California Verbal Learning Test, Oral Arithmetic, and Digit Span Test to define having deficits in executive function as having at least two of above mentioned measures with scores 1.5 standard deviations below those of matched comparison subjects. The results indicated that more adults with ADHD have executive function deficits than comparison subjects. Executive function deficits are associated with lower academic achievement independent of ADHD status. Subjects with ADHD who had executive function deficits had a significantly lower socioeconomic status and a significant functional morbidity beyond the diagnosis of

ADHD alone. They suggest that psychometrically defined executive function deficits may help identify a subgroup of adults with ADHD at high risk for occupational and academic underachievement.

In terms of self-regulation, there are a limited number of studies with regard to ADHD in adults. For instance, Wiersema and colleagues (2006) used the ERP technique to investigate regulation (Wiersema et al., 2006). They recorded the brain activity of 19 male adults with ADHD and 19 healthy controls during administration of a go/no-go task that incorporated the stressor presentation rate of stimuli. The results revealed that males with ADHD behaviorally responded slower than control males in the slower condition, which had longer inter-stimulus intervals between stimuli and was accompanied by smaller parietal P3, suggesting less effort allocation. With respect to inhibitory control/response inhibition measures (errors of commission and the N2 effect), there were no group differences. They concluded that problems with state regulation seem to persist in male adults with ADHD based on the behavioral data and the smaller parietal P3. Roderiguez and Baylis (2007) have used two different go/no-go tasks to investigate attention and impulse control in 16 control adults, 16 adults with ADHD-inattentive type, 16 adults with ADHD-hyperactivity/impulsivity type, and 16 adults with ADHD-combined type. These participants are undergraduate students with the ages between 18 and 24. They found that control adults consistently exhibited higher P3 amplitude than all the ADHD groups at the frontal site, which indicated that adults with ADHD symptoms might have deficits in the anterior attentional system. Behaviorally, the ADHD-inattentive and ADHD-hyperactivity/impulsivity groups have more difficulty with the

go/no-go task, which demands attention, while the ADHD-combined group responds more liberally to the go/no-go task, which demands inhibition.

MacLaren and colleagues (2007) have used a visual stop signal task to investigate the inhibition of predominant responses in 20 control adults and 20 adults with ADHD with the ages between 17 and 30 (MacLaren, Taukulis, & Best, 2007). They found that the control group had a larger amplitude in the N2/P3 complex evoked by stop signals. Based on their results, they suggest that people with ADHD have symptoms that persist into young adulthood.

McPherson and Salamat (2004) have used an auditory continuous performance task to investigate the attentional process in 20 normal adults and 11 adults aged between 17 to 25 years with ADHD. They found that ADHD participants have longer latencies and smaller amplitudes in both P3a and P3b components than the control group. They also found that ADHD participants show a greater separation between the P3a and P3b. They suggest that ADHD participants have a processing lag.

Summary

I have reviewed several aspects of self-regulation and ADHD in this chapter. The main aspects in this review include: theories of self-regulation, brain processes involved in self-regulation, the behavioral model of ADHD, the diagnosis of adults with ADHD, and different neuropsychological or behavioral measures and electrophysiological measures that have been used to study self-regulation and ADHD. It is clear that self-regulation is a complex construct. It is considered as an adaptive and goal-directed process, which requires the coordination and modulation of different brain processes. Due to deficient brain processes, individuals with ADHD have difficulty regulating their

behaviors. Problems with self-regulation may decrease an individual's capacity to engage in daily life activities, including performance in school.

CHAPTER THREE: METHODOLOGY

Participants

Forty adult college students who had not been diagnosed with any neurological or psychiatric disorders based on their self-report on the demographic questionnaire (see Appendix B) participated in this study. These adults without known disorders consisted of 20 males and 20 females between 18 and 30 years of age (mean = 23.68 ± 3.37). In addition, 37 adult college students between the age of 18 and 30 years (mean = 23.69 ± 3.73) who had been diagnosed with ADHD participated in this study. These adults with ADHD consisted of 19 males and 18 females. These 77 participants were recruited from Colorado State University and contacted: (a) through email and flyer advertisements, (b) through an existing adult pool in the Human Development Lab, (c) by personal contacts, and (d) through the Resources for Disabled Students (RDS) office.

Results from the Conners Adult ADHD Rating Scale (CAARS) and the Adult Self-Report (ASR; Achenbach & Rescorla, 2003) revealed that four adults who originally reported no disorders (3 males and 1 female) were excluded because they scored within the clinical range of symptoms for ADHD based on the CAARS. Another four adults who originally reported no disorders were also excluded (1 male and 1 female scored within the clinical range for an avoidant personality problem; 1 female for clinical level scores for anxiety disorder; and 1 female scored within the clinical range for both avoidant personality problem and ADHD). The exclusion criteria for these four participants were based on the ASR. The CAARS was used to determine the behavioral

symptoms of ADHD, and the ASR provided an estimate of comorbid anxiety/depression, substance use, antisocial personality disorder, and ADHD as well. In the ADHD group, participants had self-reported diagnoses of ADHD, but 17 participants did not have current ADHD symptoms based on their CAARS or ASR reports. Also, there were several comorbid problems or disorders within the ADHD group, and one ADHD male was excluded because of having Klinefelter Syndrome, which is a genetic disorder. Table 3.1 presents detailed information about the 36 ADHD participants.

Table 3.1. Time of ADHD Diagnosis, Comorbid Problems and Current Status, and Medication in ADHD Participants

Participant	Comorbid problems and current status	medication	Time of ADHD diagnosis
H101 Male	ADHD; no ADHD symptom at the time of study	Adderall	Adulthood
H102 Female	Depression & ADHD; no depression & ADHD symptoms at the time of study	MPH	Adolescence
H103 Male	Learning problem, depression & ADHD; no depression & ADHD symptoms at the time of study	None	Adolescence
H104 Female	Depression & ADHD; had anxiety, ADHD & antisocial personality problems at the time of study	Adderall	Adolescence
H105 Female	Depression & ADHD; no depression & ADHD symptom at the time of study	Concerta, Luvax, Chlonidine, Ritalin	Childhood
H106 Male	ADHD; no ADHD symptom at the time of study	Adderall	Adolescence
H107 Male	ADHD; has ADHD symptom at the time of study	Deaedaine	Childhood
H108 Female	Depression & ADHD; had depression, anxiety & ADHD problems at the time of study	Serzona Adderall	Childhood
H109 Female	Learning problem & ADHD; no ADHD symptom at the time of study	Ritalin	Childhood

H110	Female	ADHD; had ADHD symptom at the time of study	None	Adulthood
H111	Male	Depression, sensory processing difficulty& ADHD; had depression, ADHD, avoidant & antisocial personality problems at the time of study	Zoloft	Adolescence
H112	Male	ADHD; had ADHD symptom at the time of study	Adderall	Adulthood
H113	Female	ADHD; no ADHD symptom at the time of study	Adderall XR	Adolescence
H114	Female	Learning problem & ADHD; had ADHD symptom currently at the time of study	Concerta	Adulthood
H115	Female	Reading disability, learning problem, speech problem & ADHD; no ADHD symptom at the time of study	Adderall	Adulthood
H116	Female	ADHD; no ADHD symptom at the time of study	Lamictal Adderall	Childhood
H117	Male	ADHD; had ADHD symptom, avoidant personality problems at the time of study	Adderall XR	Adulthood
H118	Male	Reading disability, learning problem, depression & ADHD; had ADHD symptom, but not depression at the time of study	None	Adolescence
H119	Female	ADHD; had ADHD symptom at the time of study	Adderall	Adulthood
H120	Female	Reading disability, learning problem, depression & ADHD; had depression, ADHD, avoidant & antisocial personality problems at the time of study	None	Adulthood
H121	Female	ADHD; no ADHD symptom at the time of study	Ritalin	Childhood
H122	Male	Depression & ADHD; had depression, anxiety, ADHD, avoidant & antisocial personality problems at the time of study	Concerta Paxil	Adulthood
H123	Female	Learning problem, depression & ADHD; no ADHD symptom, but had anxiety problem at the time of study	Lamictal (depression)	Adulthood
H124	Male	ADHD; no ADHD symptom at the time of study	None	Adolescence

H125	Female	Depression & ADHD; had ADHD symptom at the time of study	Adderall	Adolescence
H126	Male	Learning problem, sensory processing difficulty& ADHD; no ADHD symptom at the time of study	None	Adulthood
H127	Female	Reading disability, learning problem, & ADHD; had ADHD symptom at the time of study	Adderall	Adolescence
H128	Female	Reading disability, learning problem, & ADHD; no ADHD symptom at the time of study	None	Childhood
H129	Male	ADHD; had ADHD symptom at the time of study	None	Childhood
H130	Male	Depression & ADHD; no depression symptom but had ADHD symptom at the time of study	None	Adolescence
H131	Male	Depression & ADHD; had depression, ADHD, & antisocial personality problems at the time of study	Lamictal Provigil Effexor	Adulthood
H132	Male	ADHD; had ADHD symptom at the time of study	Stratera	Childhood
H133	Male	ADHD; no ADHD symptom at the time of study	Adderall	Childhood
H134	Male	Reading disability, learning problem, depression & ADHD; had ADHD & anxiety problem at the time of study	Adderall PRN	Adulthood
H135	Male	Depression/anxiety & ADHD; no ADHD & depression/anxiety at the time of study	Lexapro Vyvanse	Adulthood
H136	Female	ADHD; no ADHD symptom at the time of study	Adderall	Adolescence

All final participants included in this study had normal estimated Wechsler Abbreviated Scale of Intelligence (WASI) intelligent quotient (IQ) higher than 96. All participants were native English speakers. Written informed consent (see Appendix A) was obtained from all participants at the beginning of the study. The procedures used in this study were approved by the Human Research Committee (IRB) of the Colorado State

University. Table 3.2 presents comparisons between the two groups in years of education, IQ scores, CAARS subscale T-scores. The two groups did not differ from each other in years of education. The ADHD group had lower IQ than the control group. The ADHD group had significant higher T-scores in each subscale of the CAARS than the control group.

Table 3.2 Comparisons of Two Groups in Years of Education, IQ scores, CAARS Subscale T-scores.

	Control Group (N = 32)	ADHD Group (N = 36)	*t*	*P*
Years of education	16.27 (2.24)	16.14 (2.52)	0.218	n.s.
IQ	117.31 (6.80)	113.22 (7.87)	2.279	.026
CAARS				
Inattention/memory problem	46.97 (7.40)	57.64 (13.59)	4.080	< .0001
Hyperactivity restlessness	46.28 (9.19)	53.58 (10.49)	3.035	.003
Impulsivity/emotional liability	42.97 (7.52)	50.17 (11.77)	3.036	.004
Self-Concept problems	44.38 (8.16)	51.19 (11.11)	2.853	.006
DSM inattention	49.09 (8.00)	67.42 (14.92)	6.407	< .0001
DSM hyperactivity – impulsivity	45.09 (8.83)	56.06 (14.17)	3.872	< .0001
DSM ADHD total	47.06 (8.90)	64.36 (15.42)	5.743	< .0001
ADHD index	44.38 (7.91)	55.78 (10.61)	4.972	< .0001

Note. Means and standard deviations (in the parenthesis) were presented in the table. Degrees of freedom (*df*) = 66; *p*-value = two-tailed.

Table 3.3 presents comparisons between the two groups in ASR subscale T-scores. The ADHD group had significant lower T-scores in education and mean adaptive scales than the control group. Lower T-scores reflect maladaptive behaviors. The ADHD group had significantly higher T-scores than the control group in several comorbid problems, such as depression, anxiety, and personality problems. Higher T-scores reflect more symptoms of the comrbid disorders.

Table 3.3. Comparison between Two Groups in ASR Subscale T-scores.

	Control Group (N = 32)	ADHD Group (N = 36)	*t*	*P*
ASR adaptive functioning Scale				
Friends	52.13 (6.08)	47.58 (7.95)	2.620	.011
Family	47. 22 (9.33)	45.86 (8.60)	0.624	n.s.
Job	48.84 (6.74)	44.56 (6.95)	2.378	.021
Education	50.66 (9.18)	41.17 (10.73)	3.871	< .0001
Mean adaptive	50.08 (4.45)	44.99 (5.63)	4.097	< .0001
Substance use scale				
Tobacco	50.16 (0.88)	51.03 (2.40)	2.032	.048
Alcohol	55.38 (6.62)	60.81 (10.08)	2.651	.010
Drugs	54.09 (9.78)	55.19 (8.92)	0.485	n.s.
Mean substance use	53.21 (4.76)	55.86 (6.16)	1.969	n.s.
ASR syndromes scale				
Anxious/depressed	53.38 (4.80)	59.86 (11.40)	3.116	.003
Withdrawn	52.75 (3.85)	57.75 (10.23)	2.724	.009
Somatic complaints	52.72 (4.73)	56.58 (7.67)	2.529	.014
Thought problems	54.72 (6.52)	60.97 (8.93)	3.323	.001
Attention problems	55.03 (4.13)	64.64 (9.63)	5.447	< .0001
Aggressive behavior	52.34 (3.69)	57.03 (8.40)	3.031	.004
Rule-breaking behavior	53.53 (4.36)	58.83 (9.54)	3.001	.004
Intrusive	55.25 (6.05)	57.31 (7.63)	1.220	n.s.
Internalizing	47.69 (9.04)	56.92 (12.67)	3.419	.001
Externalizing	49.28 (8.21)	56.53 (11.32)	2.988	.004
ASR DSM-oriented scales				
Depressive problems	52.22 (3.42)	59.63 (10.07)	4.002	< .0001
Anxiety problems	52.66 (4.85)	57.17 (9.17)	2.574	.013
Somatic problems	52.94 (5.23)	54.97 (6.75)	1.377	n.s.
Avoidant personality problems	53.25 (3.55)	58.17 (9.77)	2.818	.007
Attention deficit/ hyperactivity problems	54.75 (4.93)	66.58 (11.74)	5.525	< .0001
Antisocial personality problems	53.47 (5.17)	57.76 (8.48)	2.553	.013

Note: Means and standard deviations (in the parenthesis) were presented in the table. Degrees of freedom (*df*) = 66; except *df* for job = 56 because 10 participants did not have a job; *df* for education = 65 because one participant did not fill out education related questions; *p*-value = two-tailed.

Procedure

Electroencephalogram (EEG)/Event-Related Poential (ERP) Recording

In the EEG recording room, procedures were explained and an electrode-cap was placed on the participant's head. The participants were tested in a relaxed position in an attempt to decrease tightening of muscles that may cause artifacts. Prior to the EEG recording, they were provided a short training period on how to reduce artifacts that can be produced by eye blinks and muscle activity. The baseline continuous EEG was recorded for about 2 minutes. After instructions were given and prior to the initiation of each of the 3 main ERP tasks, the participants performed a short period of practice for each ERP task. Once the participants confirmed that they understood the instructions, the respective ERP task was administered. The ERP tasks were presented in the following order: the Posner cued attention task, first half of go/no-go task, first half of visual letter flanker task, second half of go/no-go task, and second half of visual letter flanker task.

Behavioral Measures Testing

After EEG recording, the participants were given intelligence and academic achievement measures in a quiet testing room. Procedures and instructions were given to participants before testing. Participants confirmed that they understood the instructions prior to the administration of the tests. Other behavioral questionnaires were filled out after the intelligence and academic achievement measures.

ERP Tasks

All ERP tasks were designed using the E-Prime software (Psychological Software Tools, Pittsburgh, PA), a psychological and/or physiological experiment generator.

Posner Cue Attention Task

In this task, participants were asked to detect and respond to a visual target stimulus (a red star) presented for 400 ms at 5° to the left or the right of a central fixation point. Eighty percent of targets were preceded by a peripheral cue delivered 500 ms before target onset. The cue, consisting of a yellow, brightened rectangle, appeared at 5° from the center of the screen, on the left or on the right visual field with equal probability, and remained on the screen until the disappearance of the target. Three cue-target combinations were intermingled randomly within each experimental run. In the "valid cue" condition (60% of trials), the cue correctly indicated the position of the upcoming target which appeared inside the cue rectangle. In the "invalid cue" condition (20% of trials), the cue appeared on the field opposite to the subsequent target. Finally, in the "no cue" condition (20% of trials), the target appeared without any preceding cue. For each of these three conditions, left and right targets were equiprobable, and the random intertrial interval from cue to cue was 1900 – 3400 milliseconds (ms). The presentation of stimuli was in a pseudorandom order. This task is summarized in Figure 3.1.

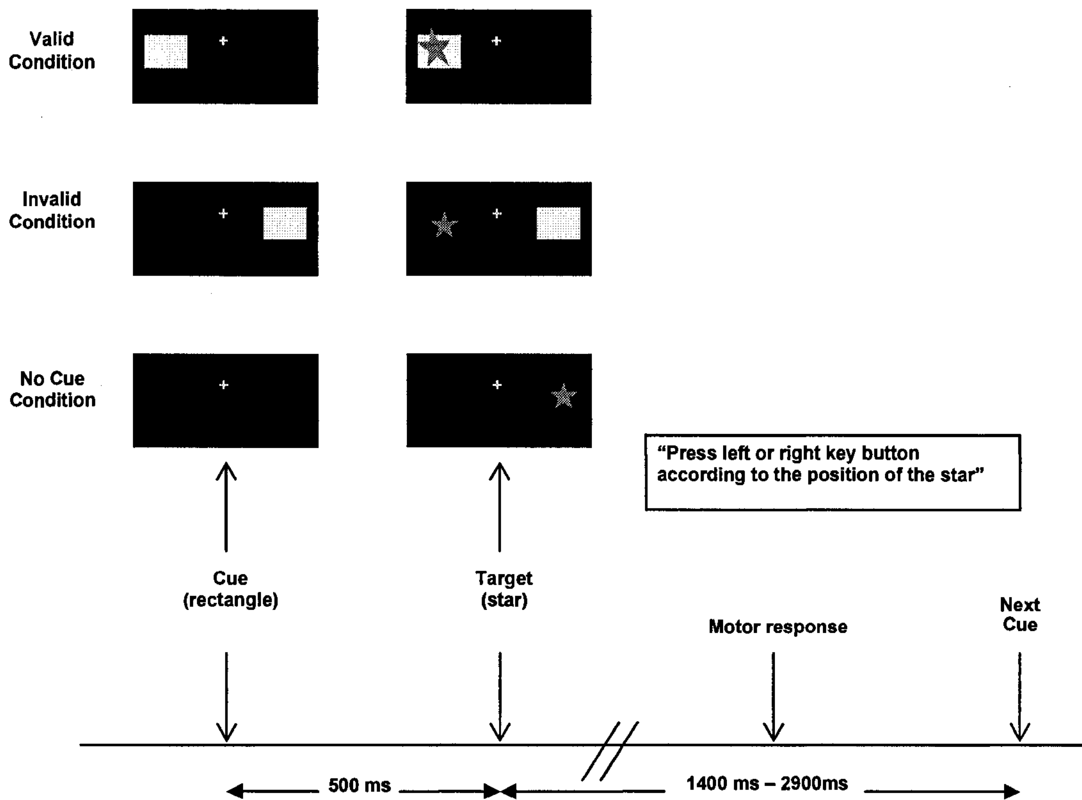

Figure 3.1. Schematic presentation of the Posner cue attention task.

Participants were asked to fix their eyes on the central fixation (a blue Cross) and to stay as quiet as possible. Each participant was requested to signal the detection of each target by pressing as quickly as possible the left or right buttons of the computer mouse with the right index finger or middle finger, respectively, corresponding to the side of target. Both accuracy and speed were emphasized in the instructions, and the participants were encouraged to try to make less than three errors. This task was 160 trials in total, which included 32 invalid, 32 no cue, and 96 valid cue trials. This task lasted around 7 minutes. Overt behavioral measures included reaction time (RT) to each target presentation, anticipation errors (i.e., the response occurred before the target presentation), and orientation errors (i.e., the side of response did not correspond to the target side). The behavioral "validity effect" was the difference between the reaction times (RT) of correct

responses of the "invalid" and "valid" conditions. This task was designed to measure ERP components related to attention.

Go/No-go Task

In this task, there were black letters A, B, C, D, E, F, G, H and X randomly presented against a gray background. Each letter appeared on the computer screen for 250 ms with a random inter-stimulus interval (ISI) between 750 ms and 1250 ms. The presentation of letters was in a pseudorandom order The procedure is summarized graphically in Figure 3.2. The participants were told to remember the letter "X" and to withhold their response when this letter (the no-go stimulus) appeared on the screen (20% of the trials). The participants were required to press a response key with their right index finger when letters other than "X" (the go stimulus) appeared on the screen (80% of the trials). They were instructed to do this as quickly and accurately as possible. There were a total of 400 trials (Wiersema et al., 2006). This task was divided into 2 parts so each part included 200 trials and each took about 4 minutes. Overt performance measures in this task included mean RT of go trials, standard deviation of mean RT (SDRT) of go trials, percentage of trials with an error of commission (EOC), and percentage of trials with an error of omission (EOO). This task was designed to measure the ERP components related to inhibition/inhibitory control.

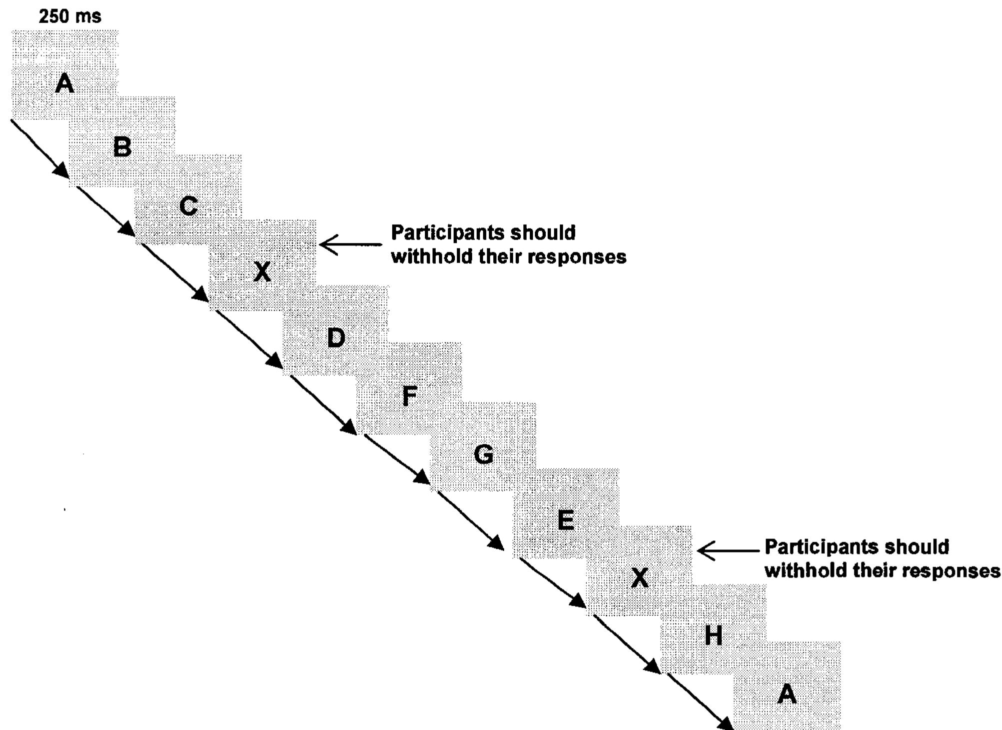

Figure 3.2. Schematic presentation of the modified go/no-go task.

Visual Letter Flanker Task

Each participant performed a visual flanker task (Eriksen & Eriksen, 1974), which contained a five-letter array through computer-generated displays. In this task, there were two congruent arrays, HHHHH AND SSSSS (80 trials each) and two incongruent arrays, SSHSS and HHSHH (160 trials each). Each array appeared on the computer screen for 250 ms with an adjusted inter-stimulus interval (ISI; at least 800 ms) between arrays. The presentation of arrays was in a pseudorandom order. The procedure is summarized graphically in Figure 3.3. The participants were asked to press a response key pad corresponding to the center letter, either an S or an H. This task consisted of a total of 480 trials presented in two series of 240 trials (Davies et al., 2004). Overt performance

measures in this task included mean RT for both correct and incorrect responses, SDRT for both correct and incorrect responses, post-error RT, and percentage of trials with an error of commission (EOC). This task was designed to measure the construct of error/performance monitoring.

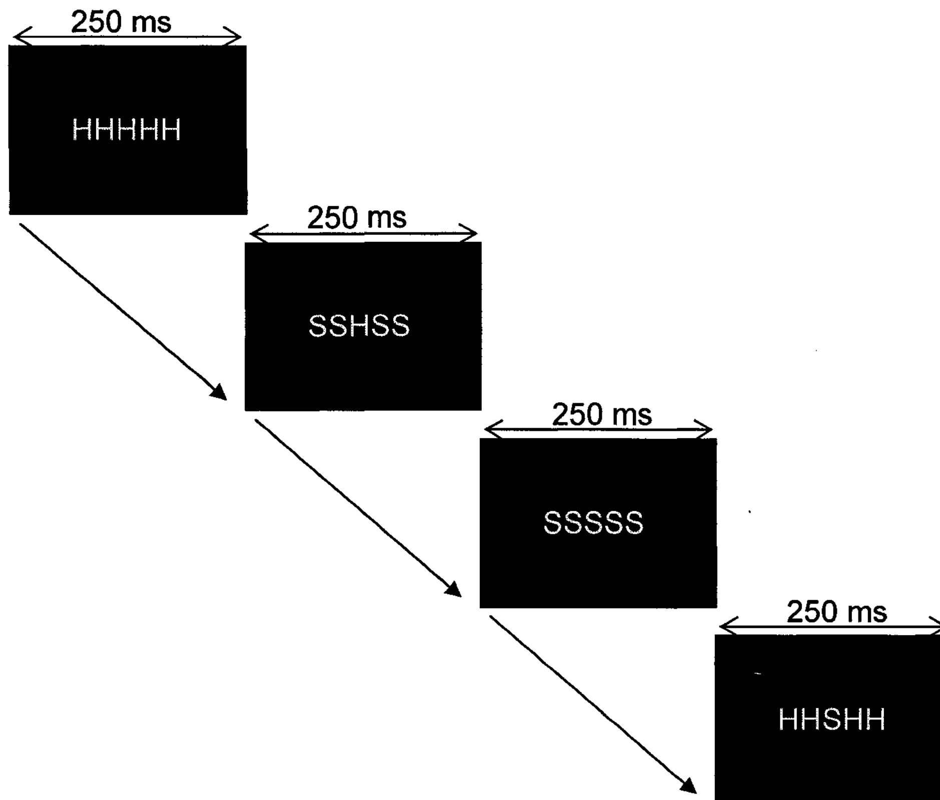

Figure 3.3. Schematic presentation of the visual letter flanker task.

Electrophysiological Recording Methods and Apparatus

EEG activity was recorded using the portable BioSemi ActiveTwo EEG system (BioSemi Inc., Amsterdam, Netherlands) with 32 pin-type Ag-AgCI sintered Active-electrodes inserted into a 32 channel head cap. EEG was recorded from 32 electrodes based upon the international 10-10 system, with the Common Mode Sense (CMS) active electrode and Driven Right Leg (DRL) passive electrode as the reference and ground respectively (http://www.biosemi.com/faq/cms&drl.htm). Electrooculograms (EOG)

were recorded from individual electrodes placed on the left and right outer canthus for horizontal movements and on the left supraorbital and infraorbital region for vertical movements. Four individual electrodes were placed on the left and right ear lobes and left and right mastoids. EEG signals were sampled at an analog-to-digital rate of 1024 Hz with a bandwidth of 268 Hz and recorded with a band pass of 0.16 – 100 Hz.

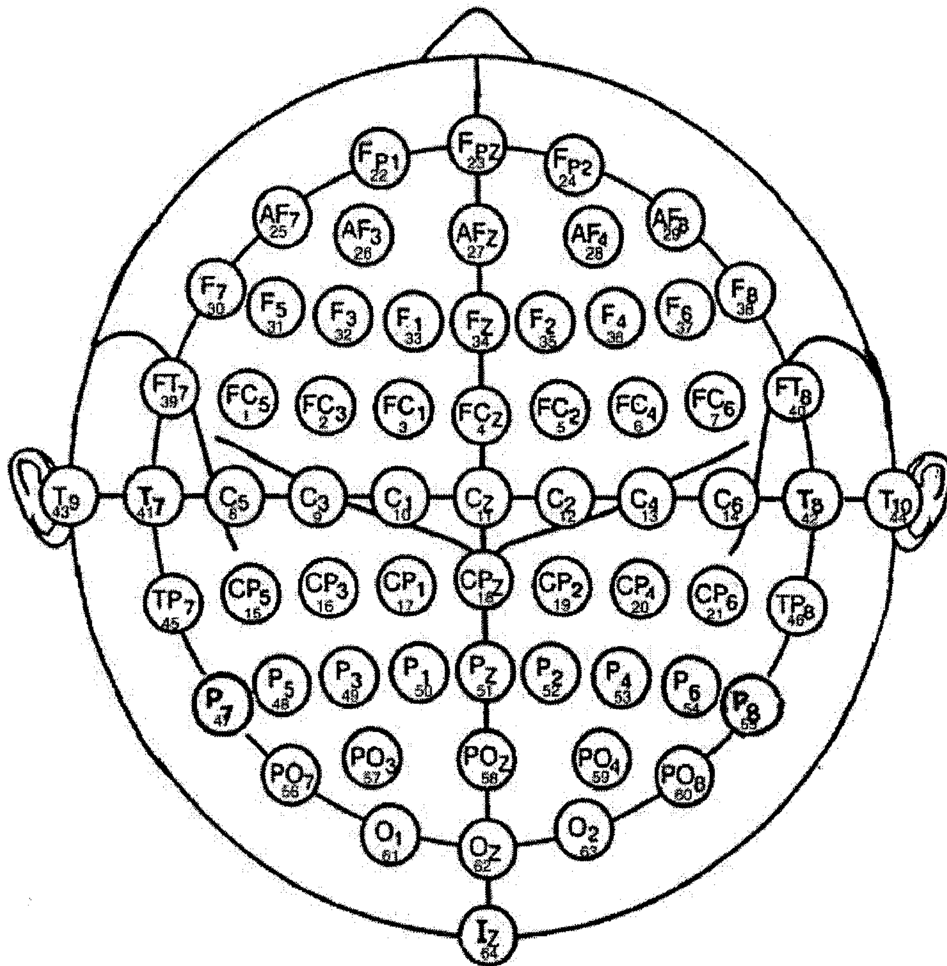

Figure 3.4. Schematic presentation of electrode sites for EEG recording.

EEG Data Reduction Analysis

All offline EEG analyses for all ERP tasks were conducted by using the Brain Vision Analyzer software (Brain Products GmbH,Münch en, Germany). The four

individual EOGs will be converted to vertical and horizontal bipolar EOG channels. All offline filtering for EEG data used a band pass of 0.23-30 Hz (24 dB/octave). EEG data was re-referenced offline to an average reference of both ears. Trials with deviations greater than ±100 μV on the EOG channels were eliminated (i.e., eye blink artifact rejection). The non-rejected trials were averaged to create ERP waveforms. To quantify peak amplitude and latency of ERP waveforms, the semiautomatic procedure in the Brain Vision Analyzer software was used.

Posner Cue Attention Task

Component Analysis

The component analysis procedure was based on Perchet and her colleagues (Perchet, Revol, Fourneret, Mauguière, & Garcia-Larrea, 2001). For ERP components the measured variables were peak amplitudes and peak latencies. Peaks and latencies were identified within the same latency windows for every subject. These windows were determined after inspection of the grand mean. The amplitude of each ERP component was measured relative to the 200 ms precue stimulus baseline. For cue-evoked components, the cue-P3 (the most positive peak between 250–400 ms after the cue) was measured. In response to the target, three components were distinguished: target-P1 (defined as the major positive deflection occurring 60 – 150 ms after the target), target-N1 (defined as the major negative deflection occurring 70 – 170 ms after the target), and target-P3 (defined as the major positive deflection occurring 260 – 440 ms after the target). In the "cue" situation, a slow negative potential occasionally appeared during the 500 ms preceding the target. It was labeled "contingent negative variation/readiness potential" (CNV/RP). Mean areas under this curve were computed in the window from

100 ms before the visual target to 200 ms after its presentation. Participants who had less than 15 trials were excluded for statistical data analysis.

Go/No-go Task

Component Analysis

The ERP component analysis was time-locked to the target stimulus in this task. All ERP waveforms were aligned to a pre-stimulus baseline of -100 to 0 ms before the target onset and an 800 ms post-onset of the target. ERPs were averaged separately for correct go stimuli and for successful no-go stimuli. Subsequently, the components were scored in the averaged ERP waveforms based on the visual inspection of the grand average waveforms. For the P2 component, peaks were scored in the 120 – 250 ms window after the stimulus onset at 4 sites (Fz, FCz, Cz, and Pz). For the N2 component, peaks were scored in the 150 – 350 ms window after the stimulus onset. The P3 amplitude was defined as the most positive peak in the 250 – 500 ms window after the stimulus onset.

Visual Letter Flanker Task

Component analysis

The ERP component analysis was time-locked to a response in this task. Trials with RT less than 200 ms were excluded from the averages (Pailing & Segalowitz, 2004). The ERP waveform was segmented from 600 ms pre-response to 800 ms post-response and the baseline was corrected from 600 ms pre-response to 400 ms pre-response. The error-related negativity (Ne/ERN) amplitude was measured at the FCz (but also scored at the Fz, Cz and Pz). Ne/ERN was the negative peak in the time window of -10 – 180 ms after the incorrect key press. The error positivity (Pe) following the ERN was quantified at Pz as the peak amplitude in the time window of 120 – 400 ms after the incorrect key press.

Participants who had less than 12 trials were excluded for statistical data analysis.

Behavioral Measure Instruments

Wechsler Abbreviated Scale of Intelligence (WASI)

The WASI is a battery of four sub-tests designed to provide a brief and reliable estimate of a person's intellectual functioning and is widely used in clinical, educational and research settings for ages 6 to 89 years (Wechsler, 1999). The WASI provids more information than is typically available from other brief intelligence tests. This efficient assessment yielded traditional verbal (VIQ), performance (PIQ) and full scale (FSIQ) scores and was linked to the WISC-III and WAIS-III. This linkage allowed estimating a range of FSIQ scores on the comprehensive batteries and increases the WASI's clinical utility. While the WASI was not intended to replace detailed assessment using the WISC-III and WAIS-III, it is an excellent instrument for quickly measuring an individual's general level of cognitive functioning. The WASI is unique because it allows the choice of whether to use the four or the two subtest format. This flexibility provided control over administration time and depth of assessment (Wechsler, 1999).

The four-subtest form resulted in FSIQ, VIQ, and PIQ scores and could be administered in as little as 50 minutes. The PIQ score included two different types of performance measures for richer information: Matrix Reasoning, measuring nonverbal fluid abilities; and Block Design, measuring visuomotor/coordination skills. The Vocabulary and Similarities subtests compose the Verbal Scale and yield a VIQ, which is a measure of crystallized abilities. The two-subtest form, used in this dissertation, provides an estimate of general intellectual ability and can be administered in about 30

minutes. This form includes Vocabulary and Matrix Reasoning, which only provides a FSIQ score.

The average alpha reliability coefficient of FSIQ for 2 subtests was .96. The test-retest reliability coefficient of FSIQ for 2 subtests was .88. The inter-rater reliability for Vocabulary was 0.98. These reliability coefficients were based on normal population (Wechsler, 1999).

One study examined the convergent and discriminant validity of the WASI and the Kaufman Brief Intelligence Test (K-BIT) for 85 psychiatric inpatients (Hays, Reas, & Shaw, 2002). The result revealed that the correlation between the WASI Full Scale and K-BIT Composite IQ scores was significant ($r = .89, p < .001$). The subtest scores using the multitrait-multimethod analysis showed that the K-BIT had higher internal consistency for its two subtests but less differentiation of cognitive functions than the WASI due to the larger number and diversity of the latter's subtests. The correlations among the WASI subtests were lower than among those for the K-BIT, therefore, the individual subtests of the WASI may tap a wider range of cognitive functions than the K-BIT and yield more clinically useful information than the K-BIT (Hays et al., 2002). The results suggested that the WASI seemed to be a valid screening measure of verbal, performance, and general intellectual ability for clinical use with an inpatient psychiatric population when the setting or patient preclude administration of a longer measure of intellectual ability.

Achenbach System of Empirically Based Assessment (ASEBA) Adult Self-Report (ASR)

The ASR incorporated many items of the 1997 edition of the Young Adult Self-Report (YASR) for ages 18-59 based on 15 years of research. Like the YASR, the

profiles for scoring the ASR included normed scales for adaptive functioning, empirically based syndromes, substance use, internalizing, externalizing, and total problems. In addition, the ASR profiles featured new DSM-oriented scales consisting of items that experts from 10 cultures identified as being very consistent with DSM-IV categories. The profiles also included a critical items scale consisting of items of particular concern to clinicians. The profiles displayed scale scores in relation to norms for each gender at ages 18-35 and 36-59, based on national probability samples. The ASR includes syndrome scales related to anxious/depressed, withdrawn, somatic complaints, thought problems, attention problems, and aggressive behavior. The ASR also has scales of substance use, critical items, internalizing, externalizing, and total problems. The DSM-oriented scales include depressive problems; anxiety problems; somatic problems; avoidant personality problems; attention deficit/hyperactivity problems; and antisocial personality problems.

The Conners' Adult Attention Rating Scale (CAARS)

The CAARS was designed to evaluate adults with ADHD aged 18 through 50 years and older. The CAARS includes short, long, and screening self-report and observer rating scale forms. The scales addresses ADHD symptoms as described in the DSM-IV. The long self-report version, used in this dissertation, includes 66 items and measures of Inattention/Memory problems, Hyperactivity/Restlessness, Impulsivity/Emotional Lability, Problems with Self-Concept, DSM-IV Inattentive Symptoms, DSM-IV Hyperactive-Impulsive Symptoms, DSM-IV ADHD Symptoms Total, and ADHD Index. The CAARS self-report forms norms were developed on 1,026 adults aged from18 to 80 years. Individuals who participated were from the United States and Canada.

Four types of reliability tests were completed on the CAARS. For the internal consistency, the Cronbach's alpha across age, subscales and forms for men ranged from .64 to .91 and for women ranged from .49 to .90. The mean inter-item correlations using Cronbach's alpha indicated that subscales and forms for men range from .31 to .68 and for women ranged from .26 to .63 across ages. Test-retest reliability ranged from 0.85 to 0.95. Information about the standard error of measurement (SEM) and standard error of prediction (SEP) were also provided.

Discriminant validity studies, differentiating between clinical and nonclinical groups, also were reported in the manual. The CAARS produced an overall correct classification rate of 85%. The ADHD Index also was cross-validated on a sample (N = 192) of ADHD and non-ADHD adults. Sensitivity was 71%, specificity was 75%, positive predictive power was 74%, negative predictive value was 72%, false positive rate was 25%, false negative rate was 29%, kappa coefficient was 0.458, and overall classification rate was 73%. These results indicated the ADHD Index may be used to identify adults who would benefit from a full assessment (Conners et al., 1999).

Construct validity was reported regarding current ADHD symptoms and retrospective reports of symptoms from childhood or adolescence and the relationship between self-report and observer ratings of symptoms (Conners et al., 1999). The CAARS had a moderate correlation with the Wender Utah Rating Scale (WURS).

The Adult Temperament Questionnaire (ATQ)

The ATQ was adapted from the Physiological Reactions Questionnaire developed by Derryberry and Rothbart (1988). Based upon results from a recent study (Rothbart, Ahadi, & Evans, 2000), it had been formulated as a self-report model of temperament

that includes general constructs of effortful control, negative affect, extraversion/ surgency, and orienting sensitivity. In the ATQ, the general constructs are referred to as factor scales and the sub-constructs are referred to as scales. The ATQ long form includes 177 items, and the short form included 77 items. Both forms included the same constructs.

For this dissertation, I only used the "effortful control" subscale (see Appendix C). The effortful control scale includes attentional control, inhibitory control, and activation control. For the ATQ, attentional control is defined as the ability to focus attention as well as to shift attention when desired, and inhibitory control refers to the capacity to suppress inappropriate approach behavior. Activation control is defined as the capacity to perform an action when there is a strong tendency to avoid it.

Behavioral Rating Inventory of Executive Function – Adult Version (BRIEF-A)

The BRIEF-A is a standardized measure assessing an adult's executive functions or self-regulation in his or her everyday environment (Roth, Isquith, & Gioia, 2005). It consists of a self-report and an informant report. The self-report form can be completed by adults 18-90 years of age without disabilities or disorders and with a wide variety of developmental, systemic, neurological, and psychiatric disorders such as attention disorders, learning disabilities, autism spectrum disorders, traumatic brain injury, multiple sclerosis, depression, mild cognitive impairment, dementias, and schizophrenia (Roth, Isquith, & Gioia, 2005). The informant report form can be completed and rated by an adult informant who is familiar with the examinee's everyday functioning. The informant report form can be used alone when the rated individual is unable to complete the self-report form. Using the self-report form in conjunction with the informant report

form provides a more clinically comprehensive picture of the rated individual. However, only the self-report form was used in this dissertation.

The BRIEF-A, composed of 75 items, was based on the original BRIEF and has nine nonoverlapped theoretically and empirically derived clinical scales that measure various aspects of executive functions; i.e., Inhibit, Self-Monitor, Plan/Organize, Shift, Initiate, Task Monitor, Emotional Control, Working Memory, and Organization of Materials. These clinical scales formed the Behavioral Regulation Index (*BRI*) and Metacognition Index (*MI*), and the two indexes formed the overall summary score, the Global Executive Composite (*GEC*). The BRIEF-A also includes three validity scales (Negativity, Inconsistency, and Infrequency).

The BRIEF-A has demonstrated evidence of reliability, validity, and clinical utility as an ecologically sensitive measure of executive functions in individuals with a range of conditions across a wide age range. The internal consistency was moderate to high for the self-report normative sample (alpha range = .73 – .90 for clinical scales; .93 – .96 for indexes and *GEC*) and high for the informant report normative sample (alpha range = .80 – .93 for clinical scales; .95 – .98 for indexes and *GEC*). In a mixed sample of clinical or healthy adults, the internal consistency was high for the self-report form (alpha range =.80 – .94 for clinical scales; .96 – .98 for indexes and *GEC*) and the informant report form (alpha range = .85 – .95 for clinical scales; .96 – .98 for indexes and *GEC*). The test-retest reliability across the clinical scales ranged from .82 – .93 over an average interval of 4.22 weeks for the self-report form and .91 – .94 over an average interval of 4.21 weeks for the informant report form. In terms of convergent validity, the self- and informant report form of the BRIEF-A scales, indexes, and *GEC* had demonstrated

significant correlations with self- and informant reports on the Frontal Systems Behavior Scale (FRSBE), Dysexecutive Questionnaire (DEX), and Cognitive Failures Questionnaire (CFQ). The BRIEF-A also demonstrated validity in clinical populations such as ADHD, multiple sclerosis, and traumatic brain injury. Several validity studies, which compared the BRIEF-A with the Clinical Assessment of Depression (CAD), the Geriatric Depression Scale (GDS), the Beck Depression Inventory-II (BDI-II), and the State Trait Anxiety Inventory (STAI), were also reported in the professional manual.

Self-Regulation Scale (SRS)

The SRS is a measure originally developed in Germany (Schwarzer, Diehl, & Schmitz, 1999). It is a measure of attention control in goal pursuit. In other words, the SRS evaluates how people maintain their focus of attention when pursuing a goal and facing difficulties in achieving the goal. The items of the SRS were essentially designed to reflect dispositional attention control and regulation (see Appendix D). For the SRS, attention control is defined as "a person's ability to focus his or her attention on a given task, to control and regulate external and internal distractions, and to work toward a desired goal or outcome" (Diehl, Semegon, & Schwarzer, 2006, p. 306). Each item is rated on a 4-point scale ranging from 1 (not at all true) to 4 (completely true), and responses are summed into a total score. The higher scores on this scale indicate that people have greater ability to control and maintain their attention.

The internal consistency of the German version of the SRS was .82 in two samples of 285 and 275 teachers. The SRS in cross-cultural research yielded internal consistency coefficients of .75, .74, and .73 in Costa Rica, Finland, and Poland respectively

(Luszczynska, Diehl, Gutiérrez-Doña, Kuusinen, & Schwarzer, 2004). The SRS was translated into English in 1999.

Diehl et al. (2006) investigated the reliability and validity of the English version of the SRS. In a sample of 443 undergraduate students at a state university in the Rocky Mountain area, internal consistency was .76 and item-total correlations range from .31 to .61. The test-retest reliability over 6 weeks was .62. For criterion validity, the SRS showed significant positive correlations with the Proactive Coping Scale, the Generalized Self-Efficiency Scale, and the academic self-efficacy score. In a heterogeneous sample of 330 adults aged from 19 to 87 years, internal consistency was .84 (Diehl et al., 2006).

Motivated Strategies for Learning Questionnaire (MSLQ)

The MSLQ is a widely used self-report instrument to study the relationship of college students' self-regulation and learning strategies. Specifically, it was designed to assess college students' motivational orientations and their use of different learning strategies in college courses (Printrich et al., 1991). The MSLQ consists of a motivational section and a learning strategies section. The motivation section assesses students' goals and value beliefs for a course, their beliefs about their skills to succeed in a course, and their anxiety about tests in a course. The learning strategy section examines the use of different cognitive and metacognitive strategies and the management of different resources. The cognitive strategies scale includes (a) rehearsal, (b) elaboration, (c) organization, and (d) critical thinking. Metacognitive strategies are assessed by one large scale that includes planning, monitoring, and regulating strategies. Resource management strategies scale includes (a) managing time and study environment, (b) effort management, (c) peer learning, and (d) help-seeking.

The total MSLQ includes 81 items. Items are scored on a 7-point Likert-type scale, from 1 (not at all true of me) to 7 (very true of me). Scale scores are constructed by taking the mean of the items that make up that scale. The MSLQ consists of 15 subscales, and these subscales could be used together or separately. The scales are modular to fit the needs of the researcher or instructor. The instrument can be given in class and takes approximately 20–30 minutes to administer.

For this dissertation, I only used the subscales of Metacognitive Self-Regulation and Effort Regulation (see Appendix E). Effort regulation was referred to as "the tendency to maintain focus and effort toward goals despite potential distractions" (Corno, 1994, p.229).

Woodcock Johnson III – Tests of Achievement Form C/Brief Battery (WJ III Brief Battery)

The WJ III Brief Battery is an academic measure for individuals ages 2 to 90+ years (Mather & Woodcock, 2007; Woodcock, Schrank, Mather, & McGrew, 2007). It includes 9 subtests (Letter-Word Identification, Applied Problem, Spelling, Passage Comprehension, Calculation, Writing Samples, Reading Fluency, Math Fluency, and Writing Fluency) and 11 clusters (Brief Achievement, Brief Reading, Brief Math, Brief Writing, Broad Reading, Broad Math, Broad Written Language, Academic Skills, Academic Applications, Academic Fluency, and Total Achievement). Examiners are able to obtain highly reliable test scores and high-quality interpretive information in very little testing time by administering only the clusters that met their assessment needs. The WJ III Brief Battery also has a test-by-test observation checklist that facilitates the documentation of qualitative test session observations important for interpreting testing behaviors and strategies. The WJ III Brief Battery may be especially useful for special

education reevaluations when a brief, but valid and reliable, measure of one or more academic areas is needed. The test administration may be conducted by a wide variety of personnel, which increases the practicality of implementing an individually-administered norm-referenced screening system. The WJ III Brief Battery provides raw scores (number correct, number of points, or number of errors), age or grade equivalents (reflected age or grade level at which the average score is the same as the subject's raw score), standard scores (SS; mean was 100, standard deviation was 15, and SS ranging from 0 to 200+), percentile ranks (PR; ranging from 0.10 to 99.90), relative proficiency index (RPI; ranging from 0/90 to 100/90), and discrepancy scores/variation procedures. In order to obtain these scores, the WJ III NU Compuscore and Profiles Program has to be used (Schrank & Woodcock, 2007). Technical information for the WJ III Brief Battery was based on the new WJ III NU, and the scores for the WJ III Brief Battery are obtained using the normative data for the WJ III NU. The psychometrics for the WJ III NU includes a recalculation of the normative data based on the projected 2005 U.S. census statistics. 8,782 subjects were selected for inclusion.

Due to the time constraints, only the Letter-Word Identification, Spelling, and Calculation subtests were used in this dissertation. These three subtests create the Academic Skill cluster. Only standard scores for each subtest and the cluster were used in the data analysis. Table 3.4 presents a summary of measurements used in this study.

Table 3.4. Summary of Measurements Used in this Dissertation

Measurements	Purposes of Measurements	Dependent Measures
• Wechsler Abbreviated Scale of Intelligence (WASI) – two subtest form (vocabulary and matrix reasoning)	To estimate full scale IQ	IQ scores
• Conners' Adult ADHD Rating Scale (CAARS)	To confirm current ADHD symptoms	T-scores of each of 8 subscales
• Adult Self-Report (ASR)	To examine if participants had symptoms of psychiatric disoders	T-scores of each of 25 subscales
• Go/no-go task (5 measures x 4 sites x 2 conditions)	To examine inhibition control	N2 amplitude and latency; P3 amplitude and latency; N2/P3 amplitude
• Visual letter flanker task (4 measures x 4 sites)	To examine performance monitoring	ERN amplitude and latency; Pe amplitude and latency
• Posner cue attention task (9 measues x 3 sites x 3 conditions)	To examine attentional control	Target-P1 amplitude and latency; Target-N1 amplitude and latency; Target-P3 amplitude and latency; Cue-P3 amplitude and latency; contingent negative variation (CNV)/ readiness potential (RP) area
• Adult Temperament Questionnaire (ATQ) – effortful control subscale	To examine aspect of effortful control in self-regulation	4 Raw scores
• Behavioral Rating Inventory of Executive Function – Adult version (BRIEF-A)	To examine aspects of executive function and self-regulation	T-scores of each of 12 subscales
• Self-Regulation Scale (SRS)	To examine aspect of attentional control	1 Raw score
• Motivated Strategies for Learning Questionnaire (MSLQ) – metacognitive self-regulation and effort regulation	To examine aspects of metacognitive self-regulation and effort regulation	2 Raw scores
• Woodcock-Johnson III Brief Battery – letter-word identification, spelling, and calculation	To examine academic skills (reading, spelling, math, and overall academic skill)	4 Standard scores

Data Analysis

An alpha level of .05 was used for this dissertation. Although this dissertation has clear directional hypotheses, very few studies have empirically examined group differences between college students with and without ADHD with similar research questions or hypotheses. Therefore, this dissertation could be considered exploratory in nature, and thus, the alpha level was not adjusted for multiple statistical tests.

Research Question One

Hypothesis 1a

Five separate 2x2x4 factorial ANOVAs were computed with Group (control vs. ADHD) as the between factor and with both Trial Type (go vs. no-go) and Site (Fz, FCz, Cz, & Pz) as repeated measures factors. The ANOVAs were used to determine if there were significant differences between the two groups with respect to the N2 amplitude, N2 latency, P3 amplitude, P3 latency, and the peak-to-peak amplitude of N2/P3 complex.

Hypothesis 1b

Two separate independent samples *t*-tests were used to determine if there were differences between groups with respect to the mean reaction time (RT) and SDRT (i.e., response variability).

Hypothesis 2a

Four separate independent samples *t*-tests were used to determine if there were differences between groups with respect to the error-related negativity (ERN) amplitude at FCz, ERN latency at FCz, Pe amplitude at Pz, and Pe latency at Pz.

Hypothesis 2b

A 2x4 factorial ANOVA with Group (control vs. ADHD) as the between factor and with Slowing (1st correct after error vs. 2nd correct after error) as the repeated measures factor was used to determine if there was a difference between groups in post-error slowing RT.

Two separate independent samples *t*-tests were used determine if there were differences between groups with respect to the mean RT of correct trials and the mean RT of error trials.

Hypothesis 3a

Two separate 2x3x2 factorial ANOVAs with Group (control vs. ADHD) as the between factor and with both Condition (Valid, Invalid, No) and Site (Pz vs. Oz) as repeated measures factors were used to determine if there were differences between groups with respect to the target-P1 amplitude and latency.

Four separate 2x3x3 factorial ANOVAs with Group (control vs. ADHD) as the between factor and with both Condition (Valid, Invalid, No) and Site (Cz, Pz, Oz) as repeated measures factors were used to determine if there were differences between groups with respect to the target-N1 amplitude and latency and the target-P3 amplitude and latency.

Hypothesis 3b

A 2x2x3 factorial ANOVA with Group (control vs. ADHD) as the between factor and with both Condition (Valid vs. Invalid) and Site (Fz, FCz, Cz) as repeated measures factors was used to determine if there was a difference between the two groups with respect to the CNV/RP area amplitude.

Hypothesis 3c

Two separate 2x2x3 factorial ANOVA with Group (control vs. ADHD) as the between factor and with both Condition (Valid vs. Invalid) and Site (Cz, Pz & Oz) as repeated measures factors were used to determine if there was difference between the two groups with respect to the cue-P3 amplitude and latency.

Hypothesis 3d

A 2x3 ANOVA with Group (control vs. ADHD) as the between factor and with Condition (Valid, Invalid, No-cue) as the repeated measures factor was used to determine if there was difference between the two groups with respect to the RT.

A 2x2 ANOVA with Group (control vs. ADHD) as the between factor and with Condition ([Valid – No] vs. [Invalid – No]) as the repeated measure factor was used to determine if there was a difference between the two groups with respect to the validity effect.

Hypothesis 4

Several *t*-tests were used to determine if there were group differences with respect to ATQ inhibition control, ATQ activation control, ATQ attention control, ATQ effortful control, BRIEF-A inhibit, BRIEF-A shift, BRIEF-A emotional control, BRIEF-A self-monitor, BRIEF-A BRI, BRIEF-A initiate, BRIEF-A working memory, BRIEF-A plan/organize, BRIEF-A task monitor, BRIEF-A organization of materials, BRIEF-A MI, BRIEF-A GEC, SRS, MSLQ metacognitive self-regulation strategy, and MSLQ effortful regulation.

Hypothesis 5

Four *t*-tests were used to determine if there were group differences with respect to letter-word identification, spelling, calculation, and academic skill.

Research Question Two

Pearson product-moment correlations were used to determine the relationship between the executive processes of self-regulation (i.e., ERP components of inhibition, attentional control, and performance monitoring) and behavioral regulation (i.e., ATQ, BRIEF-A, SRS, and MSLQ).

Research Question Three

First, Pearson product-moment correlations were used to determine the relationships between the executive processes of self-regulation and academic achievement (letter-word identification, spelling, calculation and academic skill) as well as the relationships between behavioral regulation indicators and academic achievement. Then, the ERP components and behavioral indicators, which were correlated with academic achievement, were used as the predicator variables and academic achievement was used as the criterion variables in the multiple regression procedures.

Research Question Four

Stepwise discriminant function analyses were used to determine which ERP components and self-reported self regulatory behaviors best discriminate or classify students with and without ADHD. The stepwise method may capitalize on chance associations and thus significance levels would be inaccurate. That is, the level would be numerically higher than the true alpha significance rate reported. Thus, a reported significance level of .05 may correspond to a true alpha rate of .10 or worse. Therefore,

leave-one-out cross-validation analyses were also used to confirm the results from stepwise discriminant function analyses.

Summary of Statistical Analyses

Table 3.5 and 3.6 present the summary of statistical analyses used for each research questions and hypotheses.

Table 3.5 Summary of Statistics Used for Each Hypothesis of Research Question One

Statistics	IV_1	IV_2	IV_3	DVs
•*Hypothesis 1a*: Five separate 2x2x4 ANOVAs with repeated measures on 2nd and 3rd factors	Group	Trial type (go vs. no-go)	Site	N2 amplitude & latency; P3 amplitude & latency; peak-to-peak amplitude of N2/P3
•*Hypothesis 1b*: Two separate independent samples *t*-tests	Group	N/A	N/A	Reaction time (RT); SDRT (i.e., response variability)
•*Hypothesis 2a*: Four separate independent samples *t*-tests	Group	N/A	N/A	error-related negativity (ERN) amplitude & latency at FCz, Pe amplitude & latency at Pz
•*Hypothesis 2b*: 2x4 ANOVA with repeated measures on 2nd factor	Group	Slowing (1st correct after error vs. 2nd correct after error)	N/A	RT
•*Hypothesis 3a*: Two separate 2x3x2 ANOVAs with repeated measures on 2nd and 3rd factors; four separate 2x3x3 ANOVAs with repeated measures on 2nd and 3rd factors	Group	Cue condition (valid, invalid, and no cue)	Site	Target-P1 amplitude & latency; Target-N1 amplitude and latency; Target-P3 amplitude & latency
•*Hypothesis 3b*: 2x2x3 ANOVA with repeated measures on 2nd and 3rd factors	Group	Cue condition (valid vs. invalid)	Site	CNV/RP area amplitude
•*Hypothesis 3c*: Two separate 2x2x3 ANOVAs with repeated measures on 2nd and 3rd factors	Group	Cue condition (valid vs. invalid)	Site	Cue-P3 amplitude and latency
•*Hypothesis 3d*: 2x3 ANOVA with repeated measures on 2nd factor	Group	Cue condition (valid, invalid, and no cue)	N/A	RT
•*Hypothesis 4*: Several independent samples *t*-tests	Group	N/A	N/A	Raw scores of ATQ, SRS, and MSLQ; T-scores of each subscale of BRIEF-A
•*Hypothesis 5*: Four independent samples *t*-tests	Group	N/A	N/A	Standard scores of letter-word identification, spelling, calculation, and academic skill

Note: IV = Independent Variable; DVs = Dependent Variables

Table 3.6. Summary for Statistics Used for Research Question Two, Three, and Four

Used Statistics	IVs or Predictors	DVs or Criterion
Research question two: Several Pearson product-moment correlations	ERP components of inhibition, attentional control, and performance monitoring	ATQ, BRIEF-A, SRS, and MSLQ
Research question three: Several multiple regression	ERP components of inhibition, attentional control, and performance monitoring; ATQ, BRIEF-A, SRS, and MSLQ	Standard scores of letter-word identification, spelling, calculation, and academic skill
Research question four: Stepwise discriminant function analyses	ERP components of inhibition, attentional control, and performance monitoring; ATQ, BRIEF-A, SRS, and MSLQ	Group (ADHD vs. Control)

Note. IVs = Independent variables; DVs = Dependent variables; Group = ADHD vs. control, Site = Fz, FCz, Cz, Pz, & Oz.

CHAPTER FOUR: RESULTS

This chapter contains information about the results with regard to each of the research questions and hypotheses. The first research question inquires if there are differences between adult students with and without ADHD in the areas of the executive processes of self-regulation (i.e., inhibition, attentional control, and performance monitoring), self-regulatory behaviors, and academic achievement. The results for the ERP paradigms will be presented first, followed by the results on the behavioral questionnaires.

The Go/No-go ERP Task

ERP Component Analyses – Indicators of Inhibitory Control

To test if students with ADHD displayed reduced inhibitory ability, I examined several event-related potential (ERP) components during the go/no-go task. The amplitude and latency of both N2 and P3 components as well as the peak-to-peak amplitude of the N2/P3 at 4 electrode sites and for each group are presented in Table 4.1. In general, control students had larger amplitudes and shorter latencies for each ERP component than students with ADHD.

N2 Amplitude and Latency

To examine the group difference in the N2 amplitude, a 2x2x4 factorial ANOVA was performed with Group (control vs. ADHD) as the between factor and with both Trial Type (go vs. no-go) and Site (Fz, FCz, Cz, & Pz) as the repeated measures factors. Analyses revealed a significant effect for Trial Type such that, for both groups, the N2

amplitude was larger for no-go trials than go trials, $F(1, 65) = 20.502, p < .0001$, $p\eta^2 = .24$. There was a significant main effect for Site such that, for both groups, the no-go N2 amplitude was maximal at FCz, followed by Cz, Fz, and Pz, $F(3, 195) = 12.736, p < .0001$, $p\eta^2 = .164$ (see Figure 4.1a & 4.1b). There was also a significant interaction effect for Trial Type x Site, $F(3, 195) = 15.384, p < .0001$, $p\eta^2 = .191$. However, main effect for Group was not significant, $F(1, 65) = 2.329, p = .132$, indicating that students with ADHD, as a group, had a similar inhibitory N2 amplitude to control students.

Table 4.1. Mean Peak Amplitude (in µV) and Latency (in ms) for Both Control Students and students with ADHD in the Go/No-go Task. Standard Deviations Are Shown in Parentheses.

	Control student				Students with ADHD			
	Pz	Cz	FCz	Fz	Pz	Cz	FCz	Fz
N2 amplitude								
Go trial	-1.45	-1.66	-3.04	-3.38	-1.30	-1.09	-2.14	2.43
	(3.23)	(2.23)	(2.33)	(2.19)	(2.58)	(2.21)	(2.02)	(1.87)
No-go trial	-2.87	-4.80	-6.12	-4.33	-2.00	-3.63	-4.32	-2.81
	(2.79)	(5.41)	(5.67)	(4.98)	(3.32)	(5.14)	(5.05)	(3.74)
N2 latency								
Go trial	191.31	219.19	241.84	248.65	196.32	250.35	260.31	261.07
	(37.24)	(35.72)	(29.21)	(31.99)	(43.17)	(47.23)	(39.06)	(41.87)
No-go trial	203.44	251.23	272.46	274.70	220.00	269.26	280.06	278.97
	(38.04)	(37.87)	(15.97)	(23.75)	(52.34)	(35.34)	(34.11)	(45.55)
P3 amplitude								
Go trial	7.15	6.04	4.68	2.79	7.02	5.66	4.13	2.30
	(2.54)	(2.65)	(3.03)	(2.81)	(3.28)	(2.71)	(2.71)	(2.23)
No-go trial	13.46	14.83	13.56	9.23	12.30	13.26	11.78	7.87
	(4.56)	(4.60)	(5.44)	(5.09)	(441)	(4.53)	(4.82)	(4.24)
P3 latency								
Go trial	327.50	380.01	383.29	371.03	344.78	403.02	403.21	391.55
	(37.33)	(38.78)	(36.67)	(34.82)	(61.34)	(52.26)	(44.40)	(49.33)
No-go trial	384.61	395.19	393.21	391.95	400.28	412.98	415.28	404.43
	(34.11)	(37.72)	(34.20)	(38.12)	(51.81)	(51.77)	(49.71)	(50.88)
N2/P3 peak-to-peak amplitude								
Go trial	8.60	7.70	7.72	6.17	8.32	6.75	6.27	4.73
	(4.52)	(3.17)	(3.34)	(2.56)	(3.75)	(2.88)	(2.58)	(2.06)
No-go trial	16.33	19.63	19.68	13.56	14.30	16.89	16.10	10.68
	(5.61)	(7.15)	(7.10)	(5.89)	(4.59)	(6.44)	(5.99)	(4.70)

To examine the group difference in the N2 latency, an identical 2x2x4 factorial ANOVA was performed. Analyses revealed a significant effect for Trial Type such that, for both groups, the N2 latency was longer for no-go trials than go trials, $F(1, 65) = 58.398, p < .0001, p\eta^2 = .473$. There was a significant main effect for Site, $F(3, 195) = 95.860, p < .0001, p\eta^2 = .712$. There was also a significant main effect of Group, $F(1, 65) = 4.967, p = .029, p\eta^2 = .071$, indicating that students with ADHD had a longer N2 latency than control students.

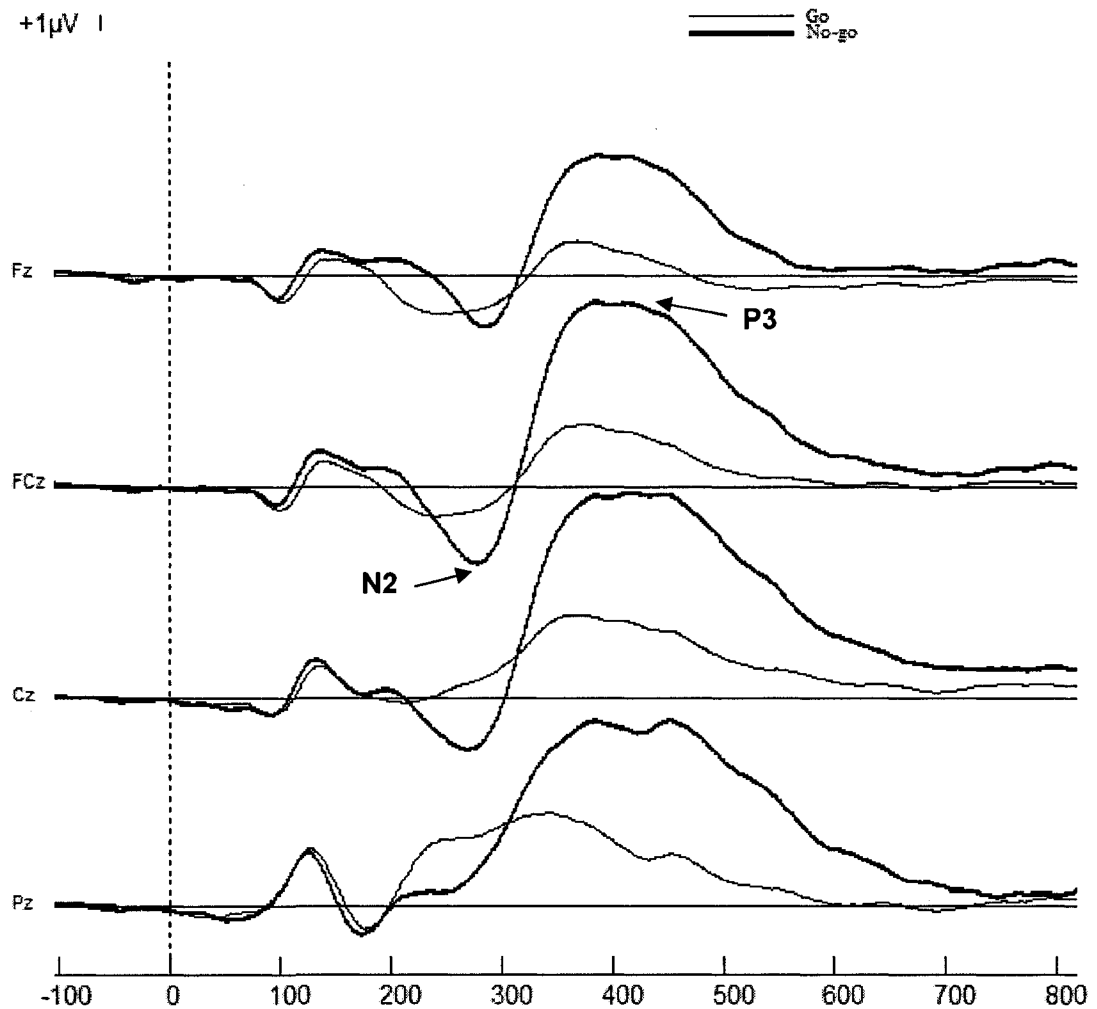

Figure 4.1a. The grand average waveforms of students without ADHD in the go/no-go task.

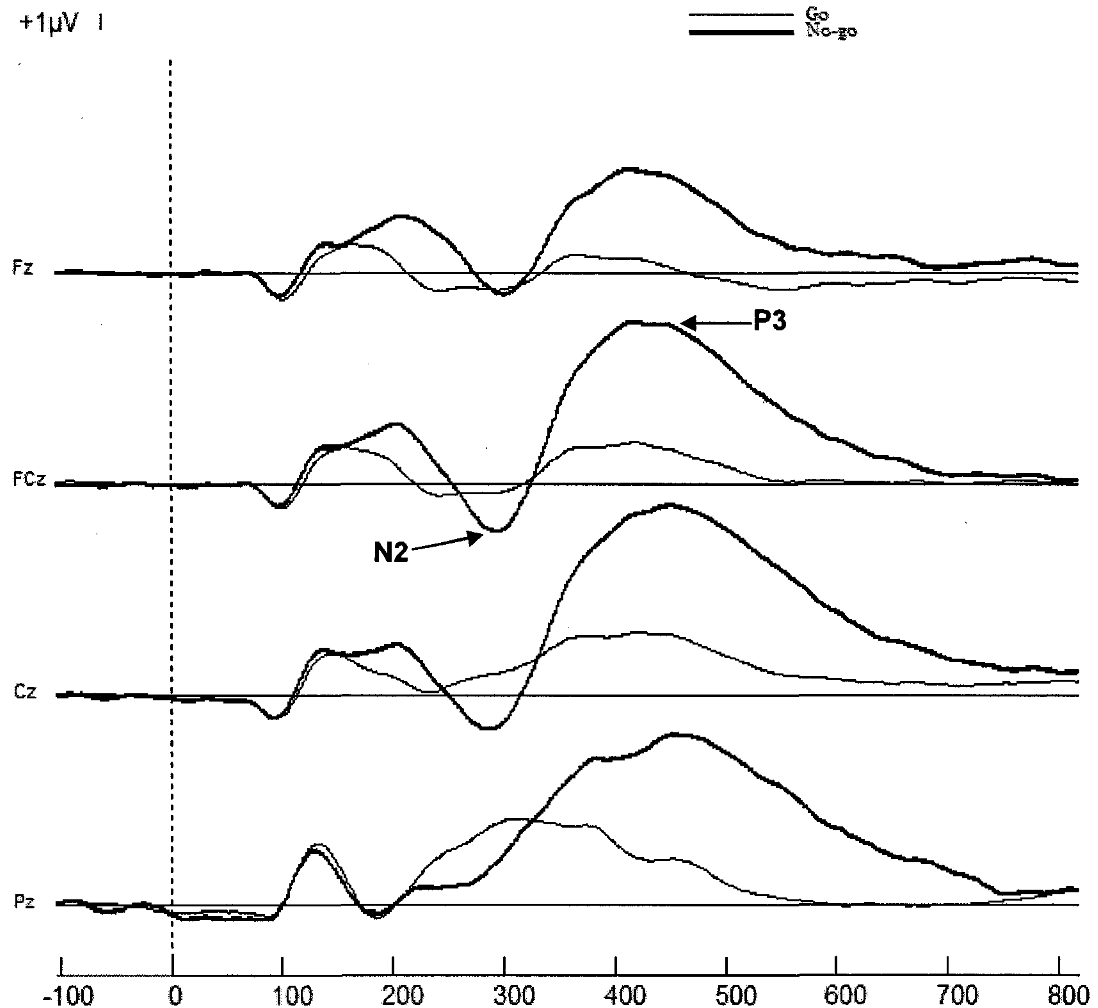

Figure 4.1b. The grand average waveforms of students with ADHD in the go/no-go task.

P3 Amplitude and Latency

To examine the group difference in the P3 amplitude, a 2x2x4 factorial ANOVA was performed. Again, analyses revealed significant main effects for Trial Type, $F(1, 65) = 391.104, p < .0001, p\eta^2 = .857$, Site, $F(3, 195) = 76.166, p < .0001, p\eta^2 = .806$ and Trial Type x Site, $F(3, 195) = 22.623, p < .0001, p\eta^2 = .677$. The P3 amplitude was larger for no-go trials than go trials, and the no-go P3 amplitude was maximal at Cz for both groups. However, there was no main effect for Group, $F(1, 65) = 1.603, p = .210$,

indicating that students with ADHD had a similar attentional inhibitory P3 amplitude to control students.

To examine the group difference in the P3 latency, a separate ANOVA was performed. The results were similar to the findings of the N2 latency. Analyses revealed a significant effect for Trial Type such that, for both groups, the P3 latency was longer for no-go trials than go trials, $F(1, 65) = 39.088, p < .0001$, $p\eta^2 = .376$. There was a significant main effect for Site, $F(3, 195) = 32.592, p < .0001$, $p\eta^2 = .334$, and Trial Type x Site, $F(3, 195) = 25.065, p < 00001$, $p\eta^2 = .278$. There was also a significant main effect of Group, $F(1, 65) = 4.911, p = .030$, $p\eta^2 = .070$, indicating that students with ADHD had a somewhat longer P3 latency than control students.

N2/P3 Peak-to-Peak Amplitude

Since studies including children and adolescents with ADHD have found abnormalities in the N2/P3 complex relative to healthy controls (e.g., Liotti et al., 2005), I also compared the group difference in the N2/P3 peak-to-peak amplitude using an ANOVA. Analyses revealed a significant Group effect, $F(1, 65) = 4.836, p = .031$, $p\eta^2 = .069$, indicating that students with ADHD had a smaller N2/P3 peak-to-peak amplitude than control students. Other significant results were also found: Trial Type, $F(1, 65) = 298.715, p < .0001$, $p\eta^2 = .821$; Site, $F(3, 195) = 39.777, p < .0001$, $p\eta^2 = .380$; and Trial Type x Site, $F(3, 195) = 45.754, p < .0001$, $p\eta^2 = .413$.

Reaction Time and Number of Errors Data Analysis for the Go/No-go ERP Task

To examine if students with ADHD had different response behaviors compared to control students, I examined the reaction times in the go/no-go task. Table 4.2 presents the means and standard deviations for reaction time (RT), RT variability (SDRT), RT

variability coefficient and error of commission (EOC) for each group. The independent samples *t*-test comparing two groups only revealed a significant group difference in SDRT, $t(66) = 2.120, p = .038, d = .51$.

Table 4.2. Reaction Time Means (Standard Deviations) in Milliseconds and 95% Confidence Intervals (CIs) for Control Students and Students with ADHD in the Go/No-go Task

	Control students	Students with ADHD	*t*	*p*	*d*
Reaction time					
M (SD)	309.38 (34.09)	322.72 (46.81)	1.329	n.s.	.32
95% CI	297.08 to 321.67	306.89 to 338.56			
RT variability					
M (SD)	73.13 (18.55)	84.36 (24.34)	2.120	.038	.51
95% CI	66.44 to 79.81	76.13 to 92.60			
RT variability coefficient					
M (SD)	0.24 (0.05)	0.26 (0.07)	1.887	n.s.	.33
95% CI	0.22 to 0.25	0.24 to 0.28			
Error of commission					
M (SD)	6.30% (2.53%)	7.19% (2.59%)	1.419	n.s.	.14
95% C	5.39% to 7.22%	6.31% to 8.06%			

Note. *Degree of freedom (df) = 66; p-value = two-tailed*

The Visual Letter Flanker ERP Task

ERP Component Analyses – Indicators of Monitoring Processing

To test if students with ADHD displayed deficient monitoring ability, I examined several event-related potential (ERP) components during the visual letter flanker task. Table 4.3 presents the amplitude and latency of both error-related negativity (ERN) and Pe components at 4 electrode sites and for each group. In general, control students had a larger amplitude and longer latency for the ERN component at each site than students with ADHD. However, students with ADHD had a larger amplitude and longer latency for the Pe component than control students.

Table 4.3. Mean Peak Amplitude (in µV) and Latency (in ms) for Both Control Students and Students with ADHD in the Visual Letter Flanker Task. Standard Deviations Are Shown in Parentheses.

	Control students				Students with ADHD			
	Pz	Cz	FCz	Fz	Pz	Cz	FCz	Fz
ERN amplitude	-0.12 (3.85)	-6.43 (5.36)	-8.60 (5.54)	-7.37 (4.94)	0.94 (3.57)	-3.92 (3.76)	-5.48 (2.99)	-4.43 (2.84)
ERN Latency	114.42 (45.07)	74.08 (29.27)	77.01 (31.49)	87.79 (40.16)	94.33 (32.29)	59.72 (16.45)	63.39 (26.70)	70.43 (40.97)
Pe Amplitude	8.04 (4.59)	5.71 (3.96)	3.33 (4.95)	0.29 (4.88)	6.45 (4.06)	6.91 (4.13)	4.87 (4.50)	2.26 (3.62)
Pe Latency	297.28 (76.25)	252.83 (71.56)	248.28 (66.92)	254.41 (77.21)	273.96 (86.38)	225.16 (83.29)	225.10 (83.98)	231.23 (97.17)

ERN Amplitude and Latency

To examine the group difference in the ERN amplitude, a 2x4 factorial ANOVA was performed with Group (control vs. ADHD) as the between factor and with Site (Fz, FCz, Cz & Pz) as the repeated measures factor. Analyses revealed a significant effect for Site such that, for both groups, the ERN was maximal at FCz, followed by Cz, Fz, and Pz, $F(3, 177) = 70.369, p < .0001$, $p\eta^2 = .544$ (see Figure 4.2a & 4.2b). There was also a significant group effect, $F(1, 59) = 8.522, p = .005$, $p\eta^2 = .126$, indicating that control students had larger ERN than students with ADHD. An independent samples *t*-test confirmed that control students had a larger ERN than students with ADHD at FCz, $t(59) = 2.697, p = .010, d = .71$.

A separate ANOVA analysis for the ERN latency revealed a significant effect for Site such that, for both groups, the ERN latency was longest at Pz, followed by Fz, FCz, and Cz, $F(3, 177) = 21.368, p < .0001$, $p\eta^2 = .266$. There was also a significant group effect, $F(1, 59) = 7.769, p = .007$, $p\eta^2 = .116$, indicating that control students had a longer

ERN latency than students with ADHD. Independent samples *t*-tests did not confirm that control students had a longer ERN latency than students with ADHD at FCz, $t(59) = 1.829, p = .073, d = .47$, but did confirm a longer ERN latency at Cz, $t(59) = 2.329, p = .025, d = .61$.

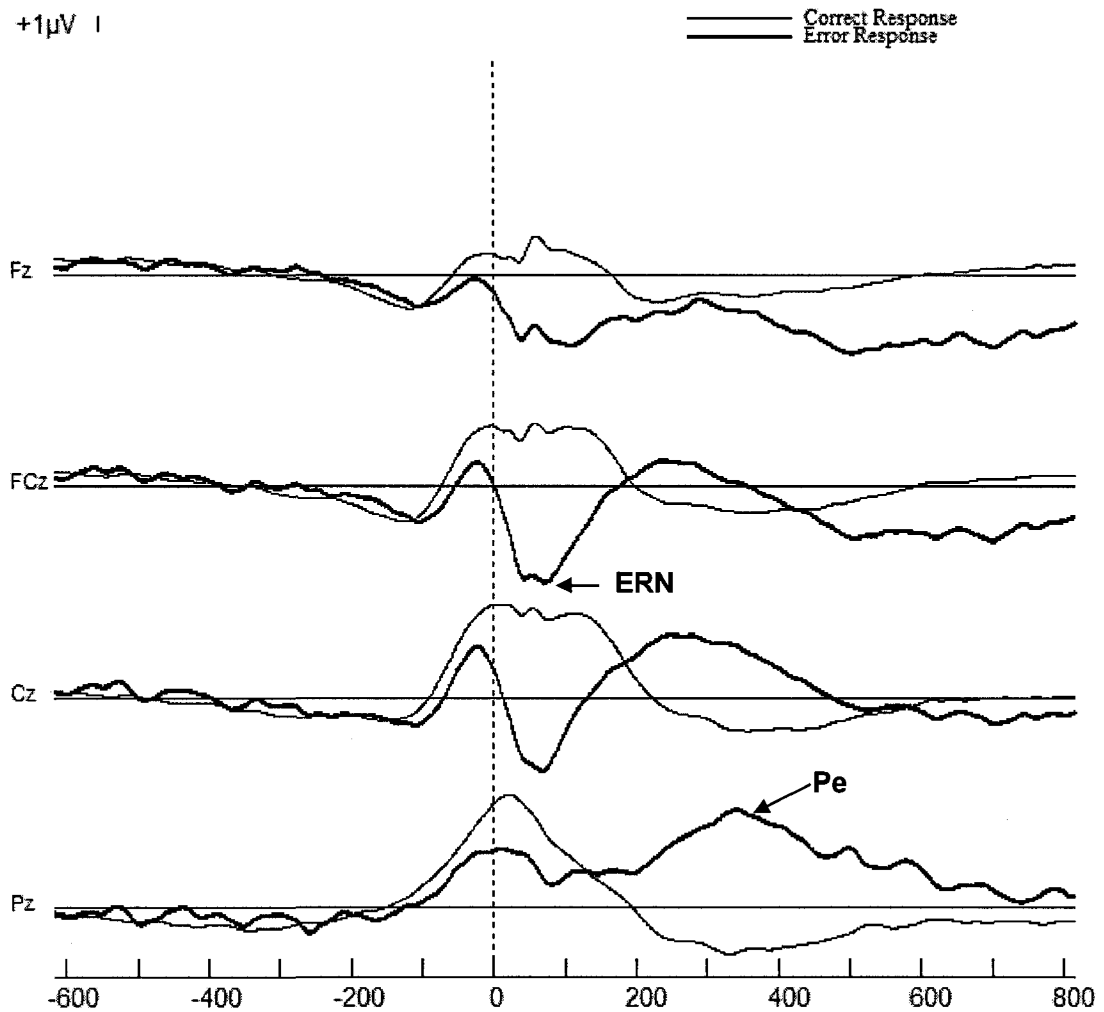

Figure 4.2a. The grand average waveforms of students without ADHD in the visual letter flanker task.

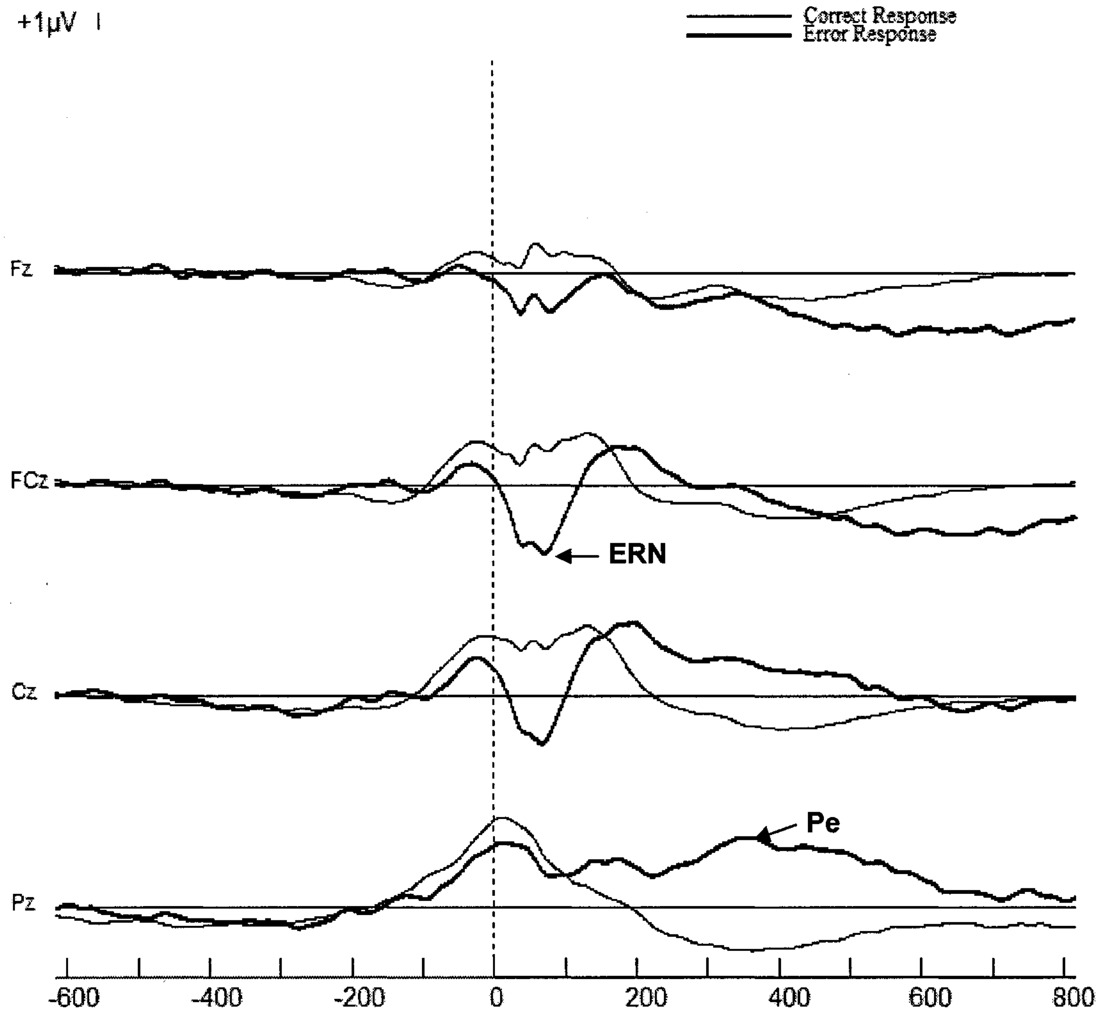

Figure 4.2b. The grand average waveforms of students with ADHD in the visual letter flanker task.

Pe Amplitude and Latency

To examine the group difference in the Pe amplitude, a 2x4 factorial ANOVA was performed. Although there was no group difference in the Pe amplitude, the results revealed a significant effect for Site, $F(3, 177) = 42.888, p < .0001$, $p\eta^2 = .421$, such that, the Pe was maximal at Pz, followed by Cz, FCz, and Fz for control students. For ADHD students, the Pe was maximal at Cz, followed by Pz, FCz, and Fz. An independent samples *t*-test did not confirm that control students had larger Pe than students with

ADHD at Pz, $t(59) = 1.440, p = .155$. For the Pe latency, an identical ANOVA was performed and revealed a significant effect for Site, $F(3, 177) = 9.524, p < .0001$, $p\eta^2 = .139$, indicating that the Pe latency was longest at Pz. There was no group difference in the Pe latency.

Reaction Time and Post-error Slowing Data Analysis for the Visual Letter Flanker ERP Task

Reaction Times

To examine if students with ADHD had different response behaviors compared to control students, I examined the reaction times in the visual letter flanker task. Table 4.4 presents the means and standard deviations for reaction time (RT) for both correct and incorrect responses, RT variability for both correct and incorrect responses, error rate and omission rate for each group. Independent samples *t*-test comparing two groups revealed several significant group differences (see Table 4.4).

Post-error Slowing

To examine if the two groups demonstrated a difference in post-error slowing, a 2x2 factorial ANOVA was performed with Group (control vs. ADHD) as the between factor and with Slowing (first correct after error vs. correct + 1) as the repeated measures factor. Post-error slowing is thought to be a compensatory mechanism geared toward improving performance on subsequent trials. Analyses revealed a significant effect for Group, $F(1, 66) = 5.139, p = .027$, $p\eta^2 = .072$, and Slowing, $F(1, 66) = 21.311, p < .0001$, $p\eta^2 = .244$, indicating that both groups displayed post-error slowing. In control students, the mean RT for "first correct after error" was 412.72 ms ± 67.05 while the mean RT for "correct + 1" was 389.66 ms ± 36.51. In students with ADHD, the mean RT for "first

correct after error" was 442.28 ms ± 66.85 while the mean RT for "correct + 1" was 420.94 ms ± 57.91. An independent samples *t*-test comparing two groups for "first correct after error" revealed no group difference, $t(66) = 1.817, p = .074$. For "correct + 1", the *t*-test revealed a group difference, $t(66) = 2.626, p = .011, d = .64$. When comparing the difference score (i.e., "first correct after error" – "correct + 1") between the two groups, an independent samples *t*-test revealed no group difference.

Table 4.4. Means (Standard Deviations) in Milliseconds and 95% Confidence Intervals (CIs) for Control Students and Students with ADHD in the Visual Letter Flanker Task.

	Cormal students	Students with ADHD	*t*	*P*	*d*
Correct RT					
M (SD)	395.78 (40.01)	428.75 (59.56)	2.705	.009	.64
95% CI	381.36 to 410.21	408.60 to 448.90			
Incorrect RT					
M (SD)	339.34 (36.31)	361.64 (61.71)	1.839	n.s.	.43
95% CI	326.25 to 352.43	340.76 to 382.52			
Correct RT variability					
M (SD)	88.16 (21.56)	106.47 (31.76)	2.747	.008	.67
95% CI	80.38 to 95.93	95.73 to 117.22			
Incorrect RT variability					
M (SD)	73.44 (29.07)	92.31 (48.65)	1.965	n.s.	.46
95% CI	62.96 to 83.92	75.85 to 118.77			
Error rate					
M (SD)	11.22% (4.33%)	12.51% (5.63%)	1.049	n.s.	.25
95% CI	9.66% to 12.78%	10.60% to 14.41%			
Omission Rate					
M (SD)	0.98% (1.59%)	1.13% (0.88%)	0.494	n.s.	.12
95% CI	0.40% to 1.55%	0.83% to 1.43%			

Note. *Degree of freedom (df) = 66; p-value = two-tailed*

The Posner Cue Attention Task

ERP Component Analyses – Indicators of Attention Processing

To test if students with ADHD displayed reduced attention control ability, I examined several event-related potential (ERP) components during the Posner cue

attention task. The data analyses were based on the Perchet et al (2001) study. Table 4.5 presents the means and standard deviations for the amplitude and latency of the target-P1. Table 4.6 presents the means and standard deviations for the amplitude and latency of the target-N1, target-P3, and cue-P3 components. Table 4.7 presents the means and standard deviations for the mean area amplitude of the CNV/RP.

Brain Response to Target Stimulus

P1 amplitude and latency. To examine the difference in the P1 amplitude, a 2x3x2 factorial ANOVA was performed with Group (control vs. ADHD) as the between factor and with both Condition (Valid, Invalid, No cue) and Site (Pz vs. Oz) as repeated measures factors. Analysis revealed that there was no effect of Group for the amplitude. There was a main effect for Condition, $F(2, 118) = 24.781, p < 0.0001$, $p\eta^2 = 0.296$. A close to significant Group x Condition interaction effect, $F(2, 118) = 3.035, p = .052$, $p\eta^2 = .049$. There was a significant effect for Site on the amplitude of the response, $F(1, 59) = 43.563, p < .0001$, $p\eta^2 = .452$, and also a Condition x Site interaction, $F(2, 118) = 15.158$, $p < .0001$, $p\eta^2 = .204$.

To examine the difference in the P1 latency, another 2x3x2 ANOVA was performed. The result revealed a effect for Group, $F(1, 59) = 4.057, p =.049$, $p\eta^2 =.064$. A significant Group x Condition interaction, $F(2, 118) = 6.628, p = .002$, $p\eta^2 = .101$, reflected that ADHD students had a shorter P1 latency than control students, especially in "invalid cue" condition. There was no significant effect for Condition, $F(2, 118) = 2.650$, $p = .075$, $p\eta^2 = .043$. There was no main effect for Site (see Figure 4.3a & 4.3b).

Table 4.5. Mean Peak Amplitude (in μV) and Latency (in ms) for Both Control Students and Students with ADHD in the Posner Cue attention Task.

	Control students		Students with ADHD	
	Oz	Pz	Oz	Pz
Target-P1 amplitude				
Valid cue	2.41 (2.40)	-0.40 (2.86)	0.94 (3.59)	-1.21 (2.78)
Invalid cue	3.11 (4.74)	0.66 (4.24)	1.64 (4.17)	-0.70 (3.22)
No cue	2.41 (2.94)	3.34 (2.89)	3.59 (3.28)	2.85 (3.09)
Target-P1 latency				
Valid cue	98.94 (30.35)	108.74 (17.35)	107.24 (30.15)	106.69 (21.07)
Invalid cue	113.55 (29.54)	115.30 (25.48)	96.22 (30.43)	87.34 (37.85)
No cue	116.01 (25.02)	113.08 (23.65)	106.63 (28.05)	108.61 (27.49)

Note. *Standard deviations were shown in parentheses.*

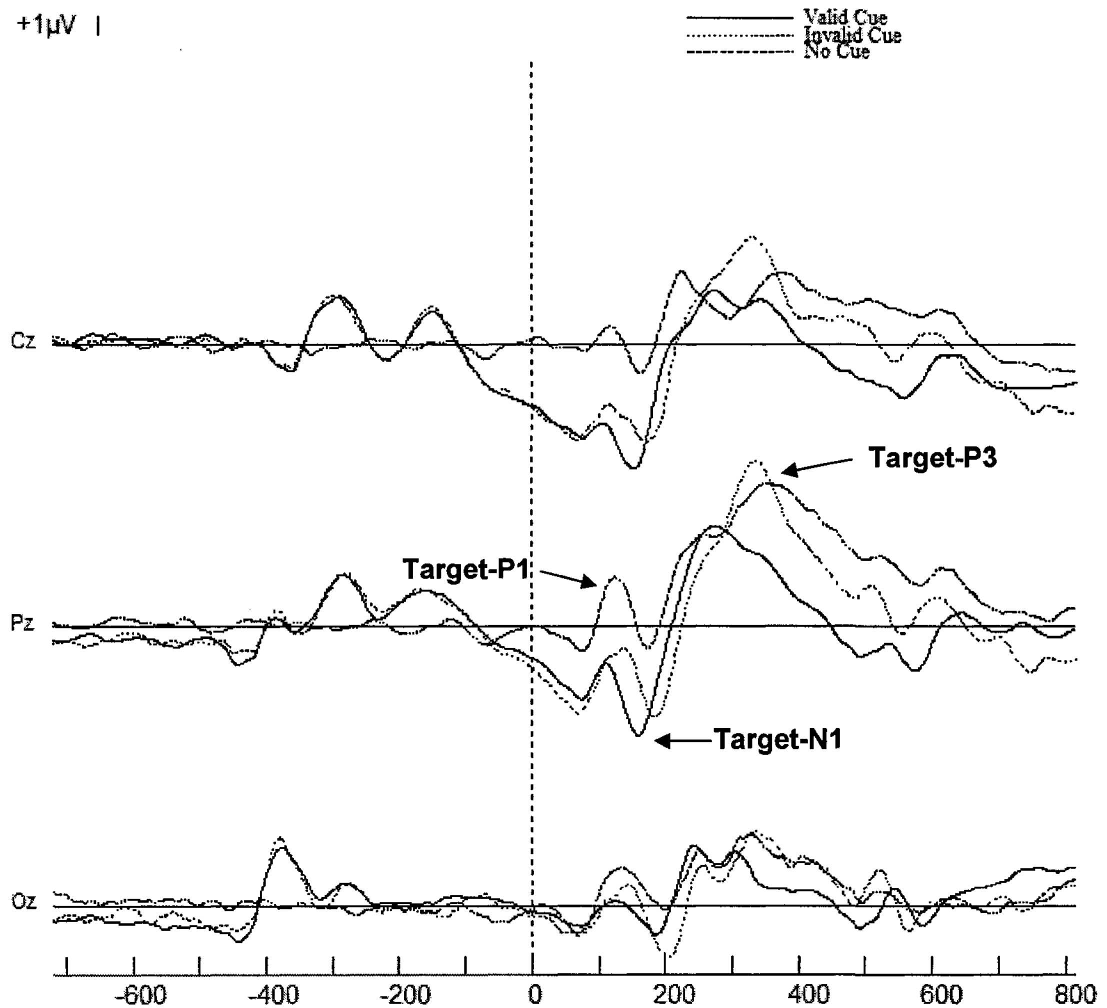

Figure 4.3a. The grand average waveforms of students without ADHD in the Posner cue attention task.

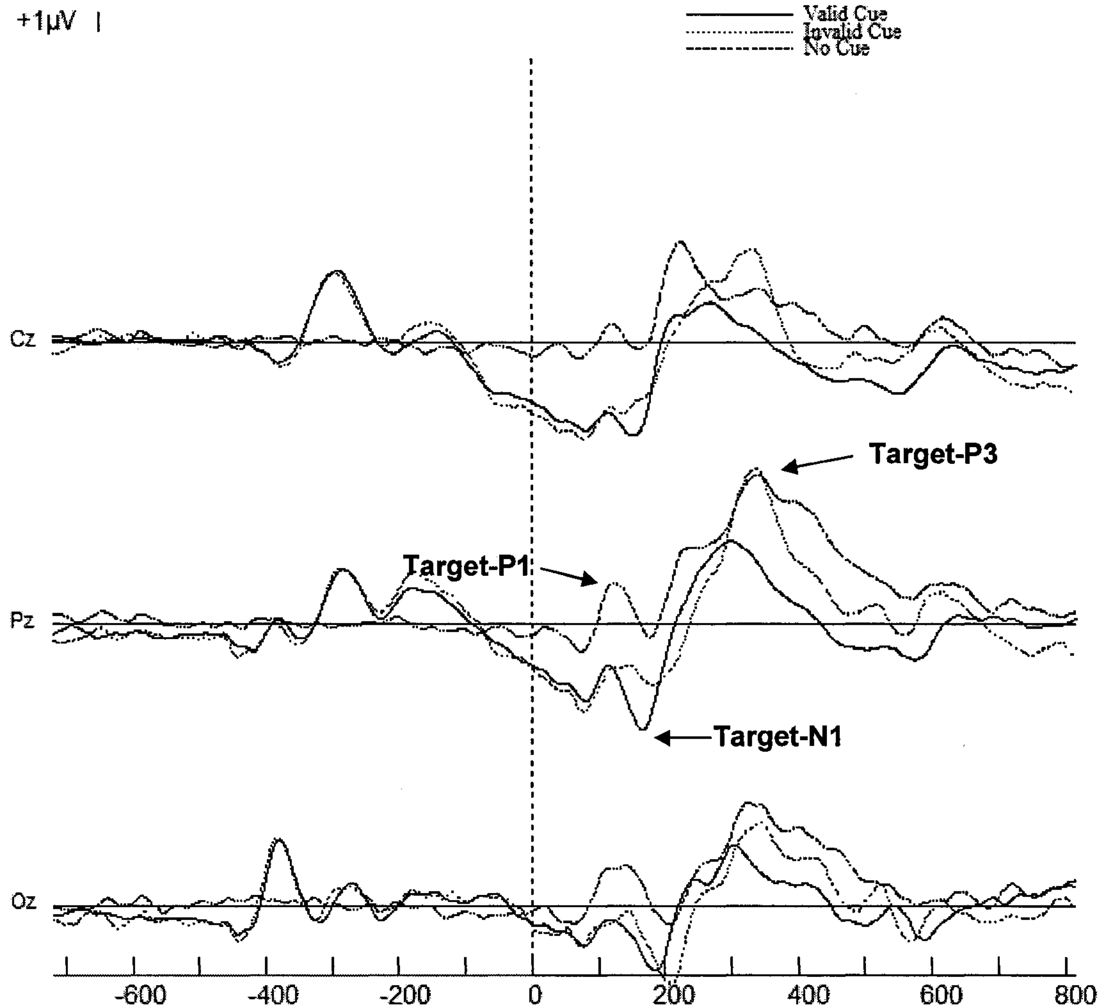

Figure 4.3b. The grand average waveforms of students with ADHD in the Posner cue attention task.

N1 amplitude and latency. To compare the N1 amplitude difference between two groups, a 2x3x3 factorial ANOVA was performed with Group (control vs. ADHD) as the between factor and with both Condition (Valid, Invalid, No cue) and Site (Cz, Pz, Oz) as the repeated measure factors. The analyses revealed no Group main effect. There was a main effect of Condition, $F(2, 118) = 39.378, p < .0001$, $p\eta^2 = .400$. There was also a significant effect for Site on the amplitude of the response, $F(2, 118) = 12.524, p < .0001$, $p\eta^2 = 0.175$, and also a Condition x Site interaction, $F(4, 224) = 9.770, p < .0001$, $p\eta^2$

= .142, as well as a close to significant Group x Site interaction, $F(2, 118) = 3.013$, $p =$ .053, $p\eta^2 = .049$.

To examine the difference in the N1 latency, a similar 2x3x3 ANOVA was performed. The result revealed a effect for Group, $F(1, 59) = 4.919$, $p = .030$, $p\eta^2 = .077$, and Condition, $F(2, 118) = 5.619$, $p = .005$, $p\eta^2 = .087$. A significant Group x Condition interaction, $F(2, 118) = 7.108$, $p = .001$, $p\eta^2 = .108$, confirmed that ADHD students had a shorter N1 latency than control students, especially in the “invalid cue” condition. There was also a significant Site effect, $F(2, 118) = 15.167$, $p < .0001$, $p\eta^2 = .204$, with the shortest latency at Cz and the longest latency at Oz (see Figure 4.3a & 4.3b).

P3 amplitude and latency. A 2x3x3 factorial ANOVA was performed to examine the difference in the P3 amplitude between the two groups. Similar to the P1 and N1 amplitudes, there was no Group main effect. The results revealed a main effect of Condition, $F(2, 118) = 40.899$, $p < 0.0001$, $p\eta^2 = 0.409$. There were also effects for Site, $F(2, 118) = 36.872$, $p < .0001$, $p\eta^2 = .385$ and Condition x Site interaction, $F(4, 224) =$ 5.991, $p = .001$, $p\eta^2 = .092$, reflecting a higher P3 amplitude at Pz in the “invalid cue” condition.

A 2x2x3 ANOVA was used to examine the P3 latency difference between groups. The results were similar to the P3 amplitude, with a close to significant Group effect, $F(1, 59) = 3.040$, $p = .086$, Condition effect, $F(2, 118) = 22.035$, $p < .0001$, $p\eta^2 = .272$, Site effect, $F(2, 118) = 3.472$, $p = .034$, $p\eta^2 = .056$, and Condition x Site interaction effect, $F(4, 224) = 8.152$, $p = .001$, $p\eta^2 = .121$ (see Figure 4.3a & 4.3b).

Brain Response to Cue Stimulus

P3 amplitude and latency. A 2x2x3 factorial ANOVA with Group (control vs. ADHD) as the between factor and with both Condition (Valid vs. Invalid) and Site (Cz, Pz & Oz) as repeated measures factors was used to determine if there was a difference between two groups. Again, there was no Group main effect. Analysis revealed a Condition main effect, $F(1, 62) = 10.918, p = .002$, p$\eta^2 = .150$. There was also a Site main effect, $F(2, 124) = 14.023, p < .0001$, p$\eta^2 = .184$. For the P3 latency, another 2x2x3 ANOVA did not find any significant effects (see Figure 4.4a & 4.4b).

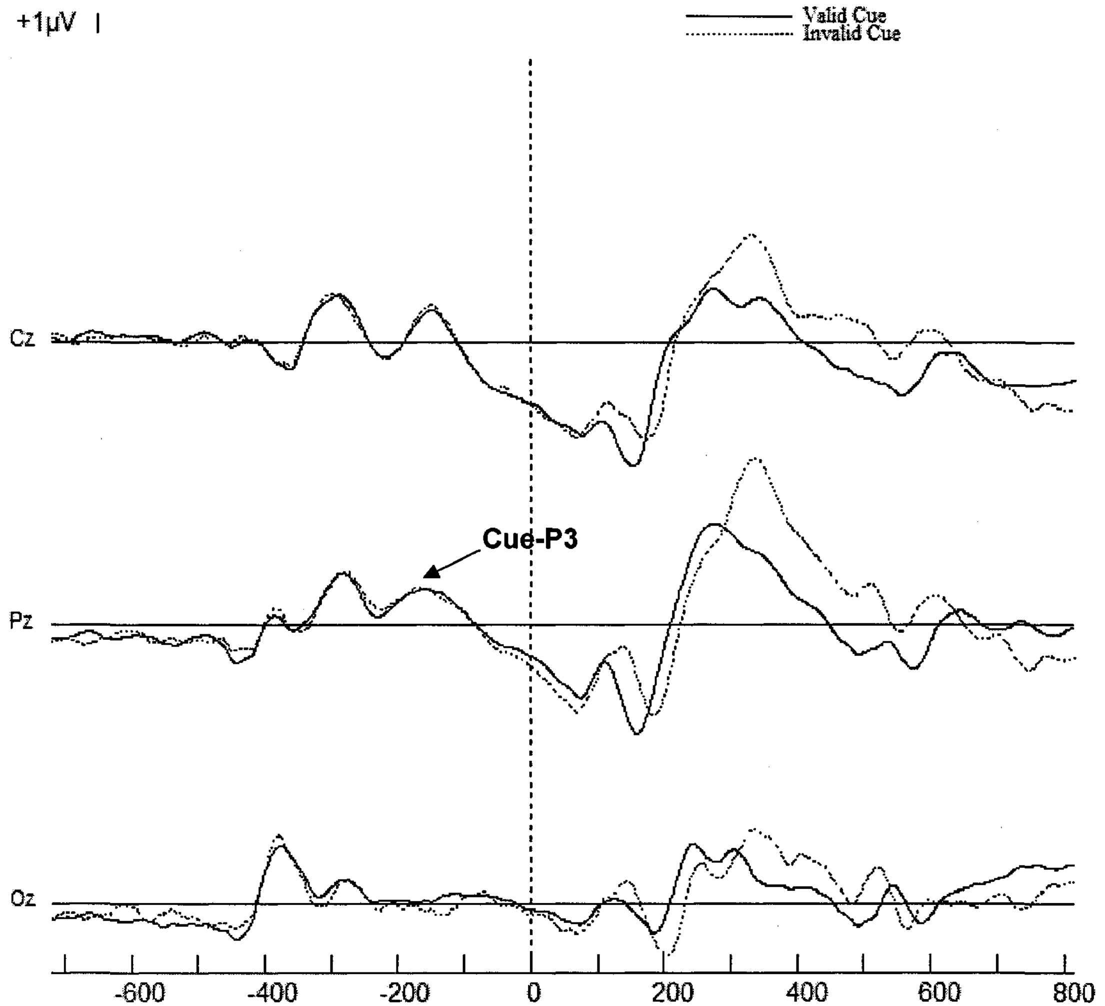

Figure 4.4a. The grand average waveforms (cue-P3) of students without ADHD in the Posner cue attention task.

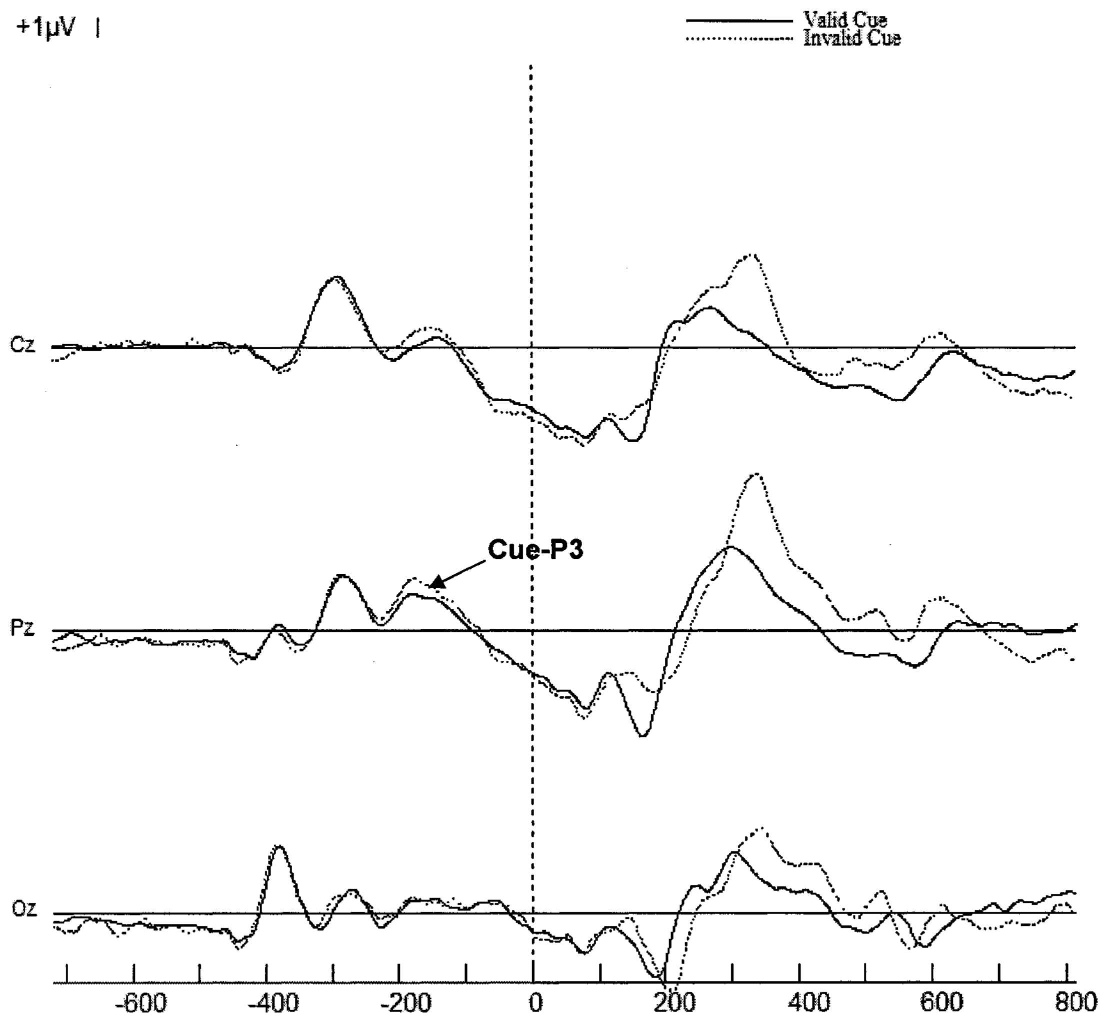

Figure 4.4b. The grand average waveforms (cue-P3) of students with ADHD in the Posner cue attention task.

Table 4.6. Mean Peak Amplitude (in μV) and Latency (in ms) for Both Control Students and Students with ADHD in the Posner Cue attention Task. Standard Deviations Are Shown in Parentheses.

	Control students			Students with ADHD		
	Oz	Pz	Cz	Oz	Pz	Cz
Target-N1 amplitude						
Valid cue	-2.10	-5.76	-6.94	-3.91	-5.60	-5.53
	(3.23)	(3.39)	(2.54)	(4.39)	(3.59)	(2.64)
Invalid cue	-3.27	-4.62	-6.21	-3.78	-4.88	-5.21
	(5.13)	(4.71)	(4.09)	(4.93)	(4.17)	(3.47)
No Cue	-2.01	-2.47	-2.55	-2.47	-1.94	-2.19
	(3.04)	(3.16)	(1.91)	(3.66)	(2.85)	(2.44)
Target-N1 latency						
Valid cue	153.83	158.61	145.10	163.54	154.02	136.40
	(35.86)	(14.94)	(18.58)	(31.82)	(24.30)	(25.76)
Invalid cue	167.46	159.11	147.39	145.20	129.36	122.13
	(37.37)	(26.84)	(28.87)	(40.95)	(42.18)	(32.97)
No cue	164.94	158.14	151.74	165.50	157.75	148.62
	(37.75)	(29.62)	(25.51)	(38.69)	(32.59)	(28.61)
Target-P3 amplitude						
Valid cue	4.37	6.16	3.47	4.65	5.49	2.72
	(2.65)	(3.27)	(2.81)	(4.09)	(3.55)	(3.20)
Invalid cue	5.99	10.33	6.46	6.79	9.57	6.23
	(5.19)	(4.95)	(3.42)	(4.49)	(4.03)	(4.20)
No cue	4.84	8.41	5.03	7.04	8.68	4.06
	(3.84)	(4.36)	(3.14)	(3.53)	(4.34)	(3.03)
Target-P3 latency						
Valid cue	331.26	311.52	319.67	325.10	309.08	312.07
	(55.39)	(41.00)	(40.68)	(39.96)	(31.81)	(47.78)
Invalid cue	359.78	332.67	335.03	343.44	324.98	314.85
	(46.94)	(28.65)	(38.68)	(49.67)	(27.01)	(34.72)
No cue	334.56	358.63	359.24	342.68	339.39	340.85
	(38.48)	(37.69)	(43.03)	(36.95)	(30.71)	(44.35)
Cue-P3 amplitude						
Valid cue	3.20	3.52	2.35	2.72	3.31	1.49
	(1.87)	(2.59)	(2.95)	(2.64)	(2.81)	(1.78)
Invalid cue	3.14	4.32	2.83	3.45	4.46	2.39
	(3.43)	(2.66)	(2.44)	(2.45)	(2.69)	(2.48)
Cue-P3 latency						
Valid cue	321.48	335.48	329.59	336.20	336.77	335.68
	(56.77)	(37.89)	(45.32)	(34.83)	(38.49)	(45.99)
Invalid cue	320.28	331.64	337.04	330.28	326.46	329.19
	(53.47)	(40.96)	(39.80)	(43.29)	(35.74)	(44.29)

Preparatory Brain Response (CNV/RP Area)

A 2x2x3 factorial ANOVA with Group (control vs. ADHD) as the between factor and with both Condition (Valid vs. Invalid cue) and Site (Fz, FCz, Cz) as repeated measures factors was used to detect if there was a difference between to groups. Again, the analysis did not find a Group main effect. The result only revealed a significant Site effect, $F(2, 124) = 14.279, p < .0001$, $p\eta^2 = .187$ (see Figure 4.5a & 4.5b).

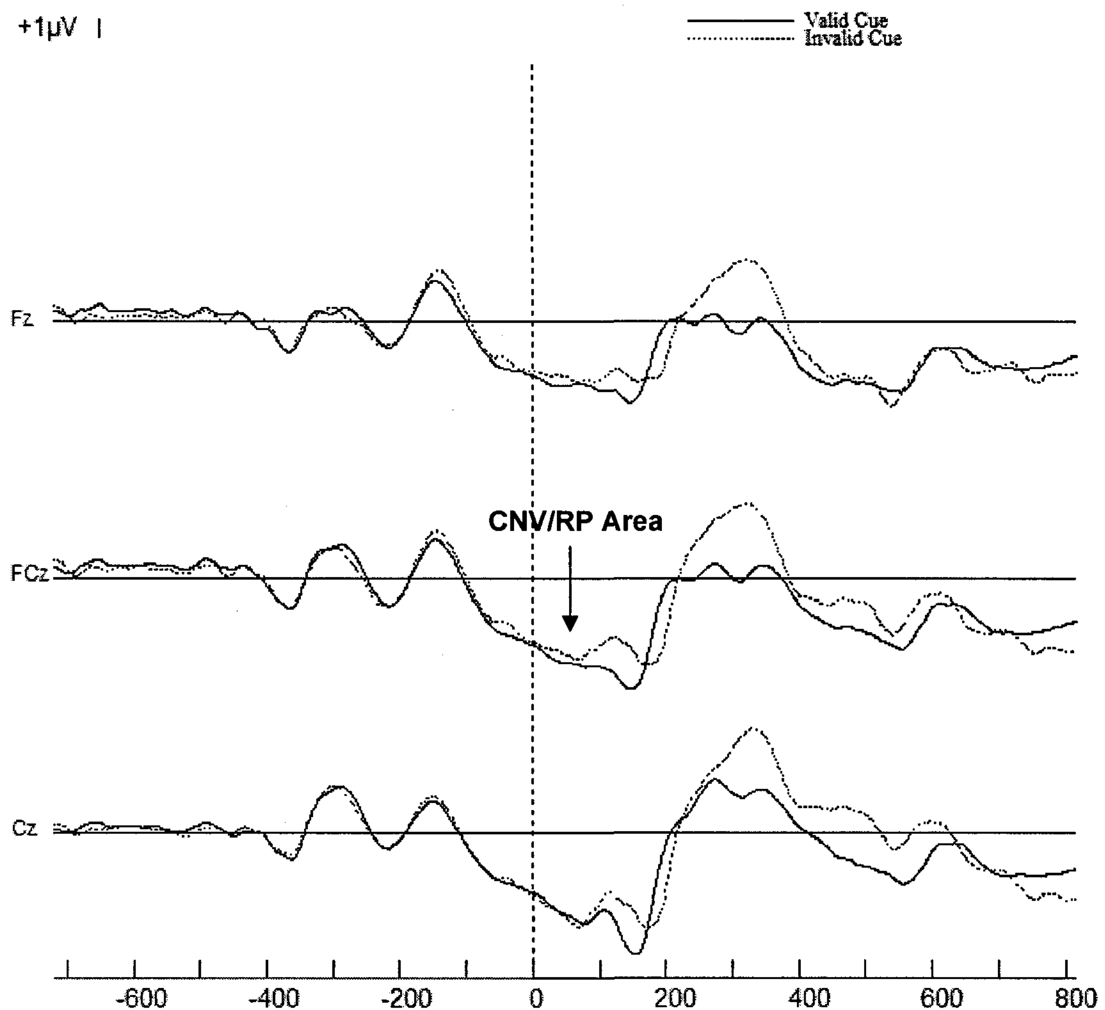

Figure 4.5a. The grand average waveforms (CNV/RP) of students without ADHD in the Posner cue attention task.

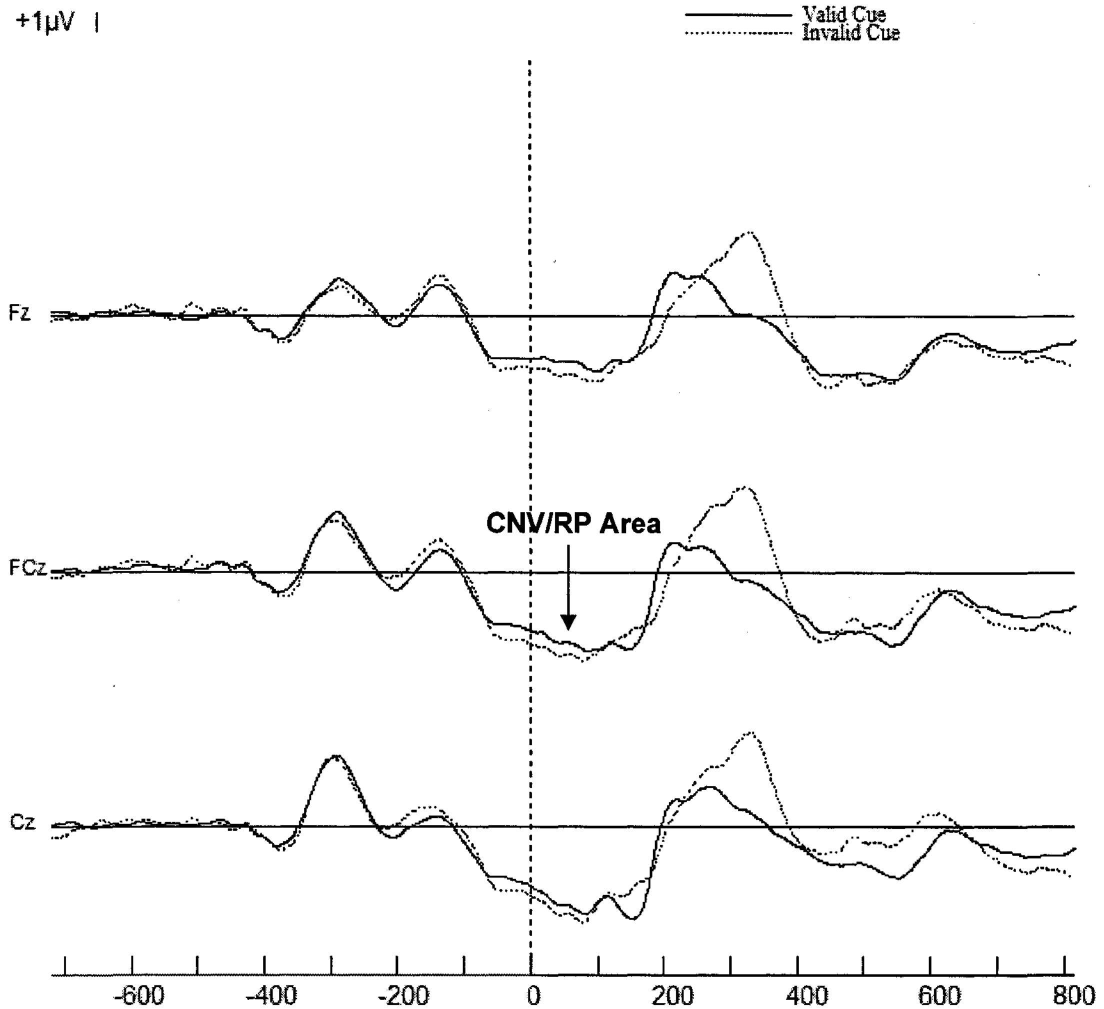

Figure 4.5b. The grand average waveforms (CNV/RP) of students with ADHD in the Posner cue attention task.

Table 4.7. Mean Area Amplitude (in μV x ms) for Both Control Students and Students with ADHD in the Posner Cue Attention Task. Standard Deviations Are Shown in Parentheses.

	Control students			Students with ADHD		
	Cz	FCz	Fz	Cz	FCz	Fz
CNV/RP area amplitude						
Valid cue	1138.91	1210.89	973.85	1064.93	989.37	782.13
	(471.46)	(582.54)	(623.86)	(598.45)	(545.23)	(450.02)
Invalid cue	1117.87	1116.21	898.52	1167.21	1169.13	999.64
	(494.77)	(579.58)	(404.66)	(608.71)	(566.75)	(482.80)

Reaction Time Data Analysis for the Posner Cue Attention Task

To examine if students with ADHD had different response behaviors compared to control students, I examined the reaction times in the Posner cue attention task. Table 4.8 presents the means and standard deviations of reaction time (RT) for each condition and each group. In general, the RT was the slowest for "no cue" and fastest for "valid cue" in both groups. Control students had a faster RT than students with ADHD for each cue condition.

A 2x3 ANOVA with Group (control vs. ADHD) as the between factor and with Condition (Valid, Invalid, No cue) as the repeated measures factor was used to test if there was a difference in RT between groups. The results indicated a significant Group main effect, $F(1, 67) = 6.202, p = .015$, $p\eta^2 = .085$, as well as a significant Condition main effect, $F(2, 134) = 255.235, p < .0001$, $p\eta^2 = .792$ but no interaction effect.

To further confirm whether there was a "validity effect" for both groups, a 2x2 ANOVA with Group (control vs. ADHD) as the between factor and with Condition ([Valid – No] vs. [Invalid – No]) as the repeated measures factor was performed. The results revealed no Group main effect, but revealed a Condition main effect, $F(1, 67) = 222.213, p < .0001$, $p\eta^2 = .768$ and no interaction effect, indicating that both groups demonstrate a validity effect.

Table 4.8. Reaction Time Means (Standard Deviations) in Milliseconds and 95% Confidence Intervals (CIs) for Control Students and Students with ADHD in the Posner Cue Attention Task.

	Control Students	Students with ADHD
Valid cue condition RT		
M (SD)	275.28 (26.06)	293.95 (28.45)
95% CI	265.88 to 284.68	284.46 to 303.43
Invalid cue condition RT		
M (SD)	321.19 (27.23)	339.00 (32.45)
95% CI	311.37 to 331.00	328.18 to 349.82
No cue condition RT		
M (SD)	347.84 (31.41)	357.54 (30.47)
95% CI	336.52 to 359.17	347.38 to 367.70

Behavioral Questionnaires Related to Self-Regulation

Behavioral Rating Inventory of Executive Function – Adult version (BRIEF-A)

To examine if students with ADHD had different self-regulatory behaviors measured by BRIEF-A as compared to control students, I examined the T-scores of each subscale of BRIEF-A. Table 4.9 presents the means and standard deviations of T-score for each factor in BRIEF-A. Independent samples *t*-tests comparing the two groups revealed significant group differences on all subscales. ADHD students had higher scores than control students, indicating that they perceived more self-regulation problems on the BRIEF-A.

Table 4.9.BRIEF-A Means (Standard Deviations) and 95% Confidence Intervals (CIs) for Control Students and Students with ADHD

	Control students	ADHD students	*t*	*p*	*d*
Inhibit					
M (SD)	47.44 (8.05)	60.64 (10.56)	5.834	< .0001	1.39
95% CI	44.54 to 50.34	57.07 to 64.21			
Shift					
M (SD)	47.16 (7.68)	56.28 (10.54)	4.035	< .0001	.98
95% CI	44.39 to 49.92	52.71 to 59.84			
Emotional control					
M (SD)	44.53 (7.68)	50.31 (11.68)	2.434	.018	.58
95% CI	41.76 to 47.30	46.35 to 54.26			
Self-Monitor					
M (SD)	45.41 (8.69)	53.89 (12.54)	3.270	.002	.78
95% CI	42.27 to 48.54	49.65 to 58.13			
BRI					
M (SD)	45.00 (6.98)	55.72 (11.01)	4.849	< .0001	1.15
95% CI	42.48 to 47.52	52.00 to 59.45			
Initiate					
M (SD)	46.44 (7.64)	60.00 (12.10)	5.588	< .0001	1.32
95% CI	43.68 to 49.19	55.91 to 64.09			
Working memory					
M (SD)	51.72 (9.09)	68.31 (11.05)	6.709	< .0001	1.63
95% CI	48.44 to 55.00	64.57 to 72.04			
Plan/organize					
M (SD)	47.75 (6.45)	62.89 (11.73)	6.690	< .0001	1.57
95% CI	45.43 to 50.07	58.92 to 66.86			
Task monitor					
M (SD)	50.53 (8.15)	65.25 (13.80)	5.423	< .0001	1.28
95% CI	47.59 to 53.47	60.58 to 69.92			
Organization of material					
M (SD)	47.94 (11.25)	55.17 (13.63)	2.368	.021	.58
95% CI	43.88 to 51.99	50.56 to 59.78			
MI					
M (SD)	48.44 (7.57)	64.56 (12.54)	6.494	< .0001	1.53
95% CI	45.71 to 51.17	60.31 to 68.80			
GEC					
M (SD)	46.69 (6.86)	61.33 (11.25)	6.560	< .0001	1.55
95% CI	44.22 to 49.16	57.53 to 65.14			

Note. *Degree of freedom (df) = 66; p-value = two-tailed.*

Adult Temperament Questionnaire (ATQ), Self-regulation Scale (SRS), and Motivated Strategies for Learning Questionnaire (MSLQ)

To examine if students with ADHD had different self-regulatory behaviors measured by ATQ, SRS, and MSLQ as compared to control students, I examined the raw scores of ATQ, SRS, and MSLQ. Table 4.10 presents the means and standard deviations of raw scores for each factor in ATQ, SRS, and MSLQ. Independent samples *t*-tests comparing the two groups revealed significant group differences on all the scales with ADHD students showing more problems in self-regulation.

Table 4.10. Means (Standard Deviations) and 95% Confidence Intervals (CIs) for Control Students and Students with ADHD in the ATQ, SRS, and MSLQ.

	Control students	ADHD students	*t*	*p*	*d*
ATQ inhibition control					
M (SD)	50.97 (8.73)	42.86 (10.25)	3.487	.001	.85
95% CI	47.82 to 54.12	39.39 to 46.33			
ATQ activation control					
M (SD)	57.94 (8.86)	44.58 (12.08)	5.142	< .0001	1.25
95% CI	54.74 to 61.13	40.50 to 48.67			
ATQ attention control					
M (SD)	54.47 (12.55)	36.92 (10.86)	6.184	< .0001	1.50
95% CI	49.94 to 58.99	33.24 to 40.59			
ATQ effortful control					
M (SD)	54.46 (8.24)	41.45 (9.20)	6.106	< .0001	1.48
95% CI	51.48 to 57.43	38.34 to 44.57			
SRS					
M (SD)	31.19 (4.76)	23.42 (4.47)	6.941	< .0001	1.69
95% CI	29.47 to 32.90	21.90 to 24.93			
MSLQ metacognitive self-regulation					
M (SD)	56.97 (10.90)	49.56 (11.11)	2.771	.007	.67
95% CI	53.04 to 60.90	45.80 to 53.32			
MSLQ effort regulation					
M (SD)	21.03 (4.08)	18.19 (4.08)	2.859	.006	.70
95% CI	19.56 to 22.50	16.81 to 19.58			

Note. *Degree of freedom (df) = 66; p-value = two-tailed.*

Academic Achievement

To examine if students with ADHD had different academic achievement scores compared to control students, I examined three subtests from the Woodcock-Johnson III Brief Battery. Table 4.11 presents the means and standard deviations of standard scores for each academic achievement subtest and the overall academic skill standard score. Independent samples *t*-tests comparing the two groups revealed significant group differences in Spelling, $t(66) = 2.639, p = .010$ and Academic Skill, $t(66) = 2.546, p = .013$.

Table 4.11. Academic Achievement Means (Standard Deviations) and 95% Confidence Intervals (CIs) for Control Students and Students with ADHD

	Control students	ADHD students	*t*	*p*	*d*
Letter-word identification					
M (SD)	109.31 (6.74)	103.81 (17.03)	1.712	n.s.	.42
95% CI	106.88 to 111.74	98.04 to 109.57			
Spelling					
M (SD)	114.28 (9.84)	108.47 (8.31)	2.639	.010	.64
95% CI	110.73 to 117.83	105.66 to 111.28			
Calculation					
M (SD)	110.91 (8.87)	108.28 (7.13)	1.353	n.s.	.33
95% CI	107.71 to 114.11	105.86 to 110.69			
Academic skill					
M (SD)	113.81 (7.75)	109.25 (7.03)	2.546	.013	.62
95% CI	111.02 to 116.61	106.87 to 111.63			

Note. *Degree of freedom (df) = 66; p-value = two-tailed.*

Interrelationships between Inhibition, Monitoring, and Attention

To examine the second research question that asks if there were any relationships between event-related potential (ERP) components with respect to inhibition, monitoring, and attention and behavioral indicators of self-regulation in students with and without ADHD respectively, Pearson product-moment analyses were used. Table 4.12 presents the percentage of significant correlations between each behavioral questionnaire and each

ERP task. Among those correlations, the results revealed that the Adult Temperament Questionnaire (ATQ) did not correlate with the ERP components of performance monitoring (i.e., ERN and Pe) in either control students or ADHD students.

Although the percentage of significant correlations was low for each of the ERP tasks, the results indicated that there were some relationships between behavior indicators of self-regulation and the ERP components of inhibition, performance monitoring, and attention. Also, the results revealed that several self-reported behavioral indicators of self-regulation were correlated with all three aspects of executive processes of self-regulation. This finding may imply that good self-regulatory behaviors require cooperation between inhibition, performance monitoring, and attention. Appendix F presents more detailed information regarding the correlation results.

Table 4.12 The Percentage of Significant Correlations between Each ERP Task and Each Behavioral Questionnaire

	BRIEF-A	ATQ	SRS	MSLQ
• *Control students*				
Inhibition ERP components	2.92% (14 out of 480)	1.25% (2 out of 160)	5.00% (2 out of 40)	3.75% (3 out of 80)
Performance monitoring ERP components	4.17% (8 out of 192)	0.00% (0 out of 64)	12.50% (2 out of 16)	9.38% (3 out of 32)
Attention ERP components	3.47% (50 out of 1440)	3.96% (19 out of 480)	0.83% (1 out of 120)	4.17% (10 out of 240)
• *ADHD students*				
Inhibition ERP components	3.13% (15 out of 480)	0.63% (1 out of 160)	5.00% (2 out of 40)	2.50% (2 out of 80)
Performance monitoring ERP components	5.21% (10 out of 192)	0.00% (0 out of 64)	0.00% (0 out of 16)	6.25% (2 out of 32)
Attention ERP components	4.51% (65 out of 1440)	3.75% (18 out of 480)	1.67% (2 out of 120)	5.83% (14 out of 240)

Predicting Academic Achievement

To examine the third research question which asked if the ERP components and behavioral indicators of self-regulation predicted or accounted for the significant amount of variance in academic achievement performance in students with and without ADHD, respectively, multiple regression analyses were used.

Letter-Word Identification

Control Students

To predict or account for variance in letter-word identification in control students, Pearson product-moment correlation analyses were applied first to determine which ERP components and behavioral indicators of self-regulation were related to letter-word identification. Pearson correlation results only revealed that Pz go N2 latency and Fz no cue target-P1 amplitude were significantly related to letter-word identification. These two predictors were entered together in a multiple regression analysis using the standard score of letter-word identification as the criterion. The regression analysis revealed that Pz go N2 latency and Fz no cue target-P1 amplitude were both significant predictors and accounted for 36.6% variance of the letter-word identification score, $R^2 = .417$, adjusted $R^2 = .366$, $F(2,23) = 8.22$, $p = .002$ (see Table 4.13).

Table 4.13. Summary of Multiple Regression Analysis for Predicting Letter-Word Identification in Control Students

Criterion	Predictor	*B*	*SE B*	*β*	*t*	*p*
Letter-word identification	Pz go N2 latency	.070	0.027	0.422	2.640	.015
	Fz no cue target-P1 amplitude	1.525	0.543	0.449	2.809	.010

Students with ADHD

The correlation analysis revealed that neither ERP components nor behavioral indicators of self-regulation were significantly related to letter-word identification. Therefore, the multiple regression analysis was not conducted because there were no significant relationships.

Spelling

Control Students

The correlation analysis revealed that only two components, FCz valid cue target-P1 latency and Pz invalid cue target-P1 latency, were significantly related to spelling. These two predictors were entered together in a multiple regression analysis using the standard score of spelling as the criterion. The regression analysis revealed that FCz valid cue target-P1 latency and Pz invalid cue target-P1 latency were both significant predictors and accounted for 37.4% variance of the spelling score, $R^2 = .424$, adjusted $R^2 = .374$, $F(2,23) = 8.45$, $p = .002$ (see Table 4.14).

Table 4.14. Summary of Multiple Regression Analysis for Predicting Spelling in Control Students

Criterion	Predictor	B	$SE\ B$	β	t	p
Spelling	FCz valid cue target-P1 latency	0.173	0.065	0.429	2.673	.014
	Pz invalid cue target-P1 latency	-0.165	0.063	-0.421	-2.621	.015

Students with ADHD

The correlation analysis revealed that five components were significantly related to spelling; these components were Oz no cue target-P1 amplitude, Fz no cue target-N1 amplitude, Oz valid cue target-P3 latency, Oz valid cue target-P3 amplitude, and Oz no cue target-P3 amplitude. These predictors were entered together in a multiple regression

analysis using the standard score of spelling as the criterion. The regression analysis revealed that these predictors accounted for 39.7% variance of the spelling score, R^2 = .501, adjusted R^2 = .397, $F(5,24) = 4.82$, $p = .003$, but none of the predictors was significant when entered together probably due to multicolinearity. Therefore, a stepwise multiple regression analysis was used for the purpose of reducing multicolinearity. A two-step stepwise multiple regression analysis revealed that Fz no cue target-N1 amplitude and Oz no cue target-P1 amplitude were the only significant variables, and they accounted for 38.3% variance of the spelling score, R^2 = .426, adjusted R^2 = .383, $F(2,27) = 10.02$, $p = .001$ (see Table 4.15).

Table 4.15. Summary of Multiple Regression Analysis for Predicting Spelling in Students with ADHD

Criterion	Predictor	*B*	*SE B*	*β*	*t*	*p*
Spelling *Full model*						
	Oz no cue target-P1 amplitude	0.803	0.489	0.311	1.642	.114
	Fz no cue target-N1 amplitude	-1.343	0.724	-0.319	-1.854	.076
	Oz valid cue target-P3 latency	-0.055	0.040	-0.236	-1.379	.181
	Oz valid cue target-P3 amplitude	0.470	0.450	0.221	1.043	.307
	Oz no cue target-P3 amplitude	-0.027	0.561	-0.011	-0.049	.961
Spelling *Final stepwise model*						
	Fz no cue target-N1 amplitude	-1.970	0.625	-0.468	-3.151	.004
	Oz no cue target-P1 amplitude	0.974	0.383	0.377	2.539	.017

Calculation

Control Students

The correlation analysis revealed that several components were significantly related to calculation; they were Pz go N2 latency, Pz no-go N2 latency, Cz no-go N2 amplitude, Fz valid cue target-P1 latency, Fz no cue target-P1 latency, Fz valid cue target-N1 latency, Cz invalid cue target-P3 amplitude, Cz valid cue cue-P3 latency, FCz valid cue cue-P3 latency, Fz valid cue cue-P3 latency, Cz valid cue CNV/RP area amplitude, FCz valid cue CNV/RP area amplitude, Cz invalid cue CNV/RP area amplitude, FCz invalid cue CNV/RP area amplitude, and Fz no cue CNV/RP area amplitude. These predictors were entered together in a multiple regression analysis using the standard score of calculation as the criterion. The regression analysis revealed that these predictors accounted for 63.9% variance of the calculation score, $R^2 = .855$, adjusted $R^2 = .639$, $F(15,10) = 3.95$, $p = .017$, but none of the predictors was significant when entered together probably due to multicolinearity. Therefore, a stepwise multiple regression analysis was used for the purpose of reducing multicolinearity. A three-step stepwise multiple regression analysis revealed that Cz valid cue cue-P3 latency, Fz no cue target-P1 latency, and Cz no-go N2 amplitude were significant variables and accounted for 70.4% variance of the calculation score, $R^2 = .739$, adjusted $R^2 = .704$, $F(3, 22) = 20.81$, $p < .0001$ (see Table 4.16).

Table 4.16. Summary of Multiple Regression Analysis for Predicting Calculation in Control Students

Criterion	Predictor	*B*	*SE B*	*β*	*t*	*P*
Calculation *Full model*						
	Pz go N2 latency	-0.004	0.074	-0.017	-0.056	.956
	Pz no-go N2 latency	0.112	0.123	0.447	0.913	.383
	Cz no-go N2 amplitude	-0.247	0.421	-0.135	-0.587	.570
	Fz valid cue target-P1 latency	0.084	0.077	0.219	1.096	.299
	Fz no cue target-P1 latency	-0.005	0.156	-0.013	-0.032	.975
	Fz valid cue target-N1 latency	0.046	0.094	-0.113	0.483	.640
	Cz invalid cue target-P3 amplitude	0.434	0.734	0.142	0.592	.567
	Cz valid cue cue-P3 latency	0.062	0.064	0.282	0.967	.356
	FCz valid cue cue-P3 latency	0.058	0.132	0.272	0.439	.670
	Fz valid cue cue-P3 latency	-0.004	0.133	-0.015	-0.032	.975
	Cz valid cue CNV/ RP area amplitude	-0.010	0.012	-0.487	-0.883	.398
	FCz valid cue CNV/ RP area amplitude	0.013	0.010	0.652	1.304	.221
	Cz invalid cue CNV/ RP area amplitude	0.013	0.011	0.702	1.212	.253
	FCz invalid cue CNV/RP area amplitude	-0.010	0.008	-0.625	-1.310	.220
	Fz no cue CNV/RP area amplitude	-0.010	0.008	-0.242	-1.243	.242
Calculation *Final stepwise model*						
	Cz valid cue cue-P3 latency	0.103	0.026	0.466	3.903	.001
	Fz no cue target-P1 latency	0.165	0.045	0.431	3.670	.001
	Cz no-go N2 amplitude	-0.766	0.211	-0.417	-3.630	.001

Students with ADHD

The correlation analysis revealed that neither ERP components nor behavioral indicators of self-regulation were significantly related to calculation. Therefore, the multiple regression analysis was not able to perform because there were no significant relationships.

Academic Skill

Control Students

The correlation analysis revealed that several components were significantly related to academic skill; they were Pz go N2 latency, Fz valid cue target-P1 latency, FCz valid cue target-P1 latency, Fz no cue target-P1 latency, Fz valid cue target-N1 latency, Cz valid cue cue-P3 latency, FCz valid cue cue-P3 latency, and FCz invalid cue CNV/RP area amplitude. These predictors were entered together in a multiple regression analysis using the standard score of academic skill as the criterion. The regression analysis revealed that these predictors accounted for 59.6% variance of the academic skill score, $R^2 = .725$, adjusted $R^2 = .596$, $F(8,17) = 5.62$, $p = .001$, but none of the predictors was significant when entered together probably due to multicolinearity. Therefore, a stepwise multiple regression analysis was used for the purpose of reducing multicolinearity. A four-step stepwise multiple regression analysis revealed that Cz valid cue cue-P3 latency, FCz invalid cue CNV/RP area amplitude, Pz go N2 latency, and Fz no cue target-P1 latency were significant variables and accounted for 62.6% variance of the academic skill score, $R^2 = .686$, adjusted $R^2 = .626$, $F(4, 21) = 11.47$, $p < .0001$ (see Table 4.17).

Table 4.17. Summary of Multiple Regression Analysis for Predicting Academic Skill in Control Students

Criterion	Predictor	*B*	*SE B*	*β*	*t*	*p*
Academic skill *Full model*						
	Pz go N2 latency	0.051	0.026	0.268	1.992	.063
	Fz valid cue target-P1 latency	-0.058	0.090	-0.192	-0.643	.529
	FCz valid cue target-P1 latency	0.113	0.099	0.337	1.140	.270
	Fz no cue target-P1 latency	0.099	0.045	0.328	2.180	.044
	Fz valid cue target-N1 latency	0.014	0.072	0.045	0.200	.844
	Cz valid cue cue-P3 latency	0.047	0.045	0.274	1.062	.303
	FCz valid cue cue-P3 latency	0.004	0.037	0.023	0.105	.918
	FCz invalid cue CNV/RP area amplitude	0.005	0.002	0.386	2.941	.009
Academic skill *Final stepwise model*						
	Cz valid cue cue-P3 latency	0.064	0.023	0.369	2.792	.011
	FCz invalid cue CNV/RP area amplitude	0.005	0.002	0.407	3.294	.003
	Pz go N2 latency	0.058	0.024	0.302	2.372	.027
	Fz no cue target-P1 latency	0.090	0.039	0.301	2.336	.030

Students with ADHD

The correlation analysis only revealed that Fz no cue target-N1 amplitude and Oz valid cue target-P3 amplitude were significantly related to academic skill. These two predictors were entered together in a multiple regression analysis using the standard score of academic skill as the criterion. The regression analysis revealed that only Fz no cue

target-N1 amplitude was significant. These two predictors accounted for 31% variance of the academic skill score, $R^2 = .358$, adjusted $R^2 = .310$, $F(2,27) = 7.51$, $p = .003$ (see Table 4.18).

Table 4.18. Summary of Multiple Regression Analysis for Predicting Academic Skill in Students with ADHD

Criterion	Predictor	*B*	*SE B*	*β*	*t*	*p*
Academic skill	Fz no cue target-N1 amplitude	-1.935	0.627	-0.535	-3.088	.005
	Oz valid cue target-P3 amplitude	0.215	0.118	0.449	0.680	.503

Classification of Students with and without ADHD

To examine the fourth research question which asked if some combination of ERP components and behavioral indicators of self-regulation could classify students with and without ADHD, stepwise discriminant function analyses were used to determine which ERP components and behavioral indicators of self-regulation were the significant predictors to identify the two groups.

Go/No-go ERP Task

N2 Component

To examine whether the N2 components from the Go/No-go ERP task (see Appendix G) could be useful to classify students with and without ADHD, a stepwise discriminant function analysis (DA) procedure was applied to select useful subsets of the N2 components and to evaluate the order of importance of these N2 components. The stepwise DA revealed that 2 of 16 components, Cz go N2 latency and Fz go N2 amplitude, were the only significant components in correctly classifying the original groups of students with 70.1% accuracy ($\lambda = .798$, $p = .001$). The control students were 77.4% correctly classified while students with ADHD were 63.9% correctly classified.

The cross-validation using leave-one-out procedure (described in Chapter 3) also confirmed that 70.1% of the cross-validated groups of students were correctly classified.

P3 component

The stepwise DA revealed that 1 of 16 components (see Appendix G), FCz no-go P3 latency, was the only significant component to correctly classify the original groups of students with 55.2% accuracy ($\lambda = .937, p = .041$). The control students were 51.6% correctly classified while students with ADHD were 58.3% correctly classified. The cross-validation using leave-one-out procedure also confirmed that 55.2% of the cross-validated groups of students were correctly classified.

Visual Letter Flanker ERP Task

ERN Component

The stepwise DA revealed that 1 of 8 components (see Appendix G), Fz ERN amplitude, was the only significant component to correctly classify the original groups of students with 72.1% accuracy ($\lambda = .876, p = .005$). The control students were 65.5% correctly classified while students with ADHD were 78.1% correctly classified. The cross-validation using leave-one-out procedure also confirmed that 72.1% of the cross-validated groups of students were correctly classified.

Posner Cue Attention Task

Target-P1 Component

The stepwise DA revealed that 4 of 30 components (see Appendix G), Pz invalid cue target-P1 latency, Fz valid cue target-P1 amplitude, Oz no cue target-P1 amplitude, and Oz valid cue target-P1 amplitude were the only significant components to correctly classify the original groups of students with 77.0% accuracy ($\lambda = .651, p < .0001$). The

control students were 79.3% correctly classified while students with ADHD were 75.0% correctly classified. The cross-validation using leave-one-out procedure also confirmed that 77.0% of the cross-validated groups of students were correctly classified.

Target-N1 Component

The stepwise DA revealed that 3 of 30 components (see Appendix G), Pz invalid cue target-N1 latency, FCz valid cue target-N1 amplitude, and Oz valid cue target-N1 amplitude were the only significant components to correctly classify the original groups of students with 83.6% accuracy ($\lambda = 0.667, p < 0.0001$). The control students were 86.2% correctly classified while students with ADHD were 81.2% correctly classified. The cross-validation using leave-one-out procedure confirmed that 78.7% of the cross-validated groups of students were correctly classified.

Target-P3 Component

The stepwise DA revealed that 3 of 30 components (see Appendix G), Oz no cue target-P3 amplitude, Pz valid cue target-P3 amplitude, and FCz no cue target-P3 latency, were the only significant components to correctly classify the original groups of students with 63.9% accuracy ($\lambda = 0.789, p = 0.003$). The control students were 62.1% correctly classified while students with ADHD were 65.6% correctly classified. The cross-validation using leave-one-out procedure confirmed that 62.3% of the cross-validated groups of students were correctly classified.

Behavioral Questionnaires

The stepwise DA revealed that scores of 2 of 19 subscales from 4 questionnaires (see Appendix G), SRS score and BRIEFA-Working memory T score, were the only significant scales to correctly classify the adults with 80.6% accuracy ($\lambda = .532, p <$

.0001). Both control students and students with ADHD were 80.6% correctly classified. The cross-validation using leave-one-out procedure also confirmed that 80.6% of the cross-validated groups of students were correctly classified.

Summary of Results

Table 4.19 presents the findings of three ERP tasks. ADHD students were significantly different from control students in both N2 and P3 latencies of the go/no-go task, the ERN amplitude, and both target-P1 and N1 latencies of the Posner task.

Table 4.19. Summary of Results from Three ERP Tasks

ERP Task	Group	Condition	Site	Condition x Site
• ***Go/no-go task***				
N2 amplitude	n.s.	go vs. no-go***	***	***
N2 latency	*	go vs. no-go***	***	n.s.
P3 amplitude	n.s.	go vs. no-go***	***	***
P3 latency	*	go vs. no-go***	***	***
N2/P3 peak-to-peak amplitude	*	go vs. no-go***	***	***
• ***Visual letter flanker task***				
ERN amplitude at FCz	**			
ERN latency at Cz	**			
Pe amplitude at Pz	n.s.			
Pe latency at Pz	n.s.			
• ***Posner cue attention task***				
Target-P1 amplitude	n.s.	valid, invalid, no cue***	***	***
Target-P1 latency	*	n.s.	n.s.	n.s.
Target-N1 amplitude	n.s.	valid, invalid, no cue***	***	***
Target-N1 latency	*	valid, invalid, no cue**	***	n.s.
Target-P3 amplitude	n.s.	valid, invalid, no cue***	***	***
Target-P3 latency	n.s.	valid, invalid, no cue***	*	***
Cue-P3 amplitude	n.s.	valid, invalid cue**	***	n.s.
Cue-P3 latency	n.s.	n.s.	n.s.	n.s.
CNV/RP area amplitude	n.s.	n.s.	***	n.s.

Note. n.s. = not significant; * = $p < .05$; ** = $p < .01$; *** = $p < .001$

Behavioral Questionnaires

The results indicated that ADHD students were significantly different from control students in all behavioral indications of self-regulation, $p < .0001$, except for BRIEF-A emotional control, $p < .02$, BRIEF-A self-monitor, $p < .01$, BRIEF-A organization of material, $p < .05$, ATQ inhibition control, $p = .001$, both MSLQ metacognitive self-regulation and effort regulation, $p < .01$ (see Table 4.20).

Table 4.20. Summary of Results from Behavioral Questionnaires

Behavioral indicators of self-regulation	Group effect
BRIEF-A inhibit	***
BRIEF-A shift	***
BRIEF-A emotional control	**
BRIEF-A self-monitor	**
BRIEF-A BRI	***
BRIEF-A initiate	***
BRIEF-A working memory	***
BRIEF-A plan/organize	***
BRIEF-A task monitor	***
BRIEF-A organization of material	*
BRIEF-A MI	***
BRIEF-A GEC	***
ATQ attention control	***
ATQ activation control	***
ATQ inhibition control	***
ATQ effortful control	***
SRS	***
MSLQ metacignitive self-regulation	**
MSLQ effort regulation	**

Note. * = $p < .05$; ** = $p < .02$; *** = $p < .001$

Academic Achievement

The results indicated that ADHD students were significantly different from control students in both spelling and academic skill, $p < .02$, but no difference in both letter-word identification and calculation.

Predicting Academic Achievement

Table 4.21 presents the results of variance of academic achievement accounted by some combination of ERP components in both control students and ADHD students.

Table 4.21. Summary of Variance Accounted for Academic Achievement Using Simultaneous Multiple Regression

Academic achievement	Control students	ADHD students
Letter-word identification	36.6% **	n.s.
Spelling	37.4% **	39.7% **
Calculation	63.9% *	n.s.
Academic skill	59.6% **	31% **

Note: * = $p < .02$; ** = $p < .005$.

Classification of Control Students and ADHD Students

Table 4.22 presents the classification results of both control students and ADHD students using ERP components and behavioral questionnaires. The target-N1 component in the Posner cue attention task had the highest accuracy of correct classification.

Table 4.22. Summary of Accuracy of Correct Classification of Control Students and ADHD Students

	Overall	Control	ADHD
• Go/no-go task – N2 component	70.1% **	77.4%	63.9%
• Go/no-go task – P3 component	55.2% *	51.6%	58.3%
• Visual letter flanker task – ERN component	72.1% **	65.5%	78.1%
• Posner cue attention task – target-P1 component	77% ***	79.3%	75%
• Posner cue attention task – target-N1 component	83.6% ***	86.2%	81.2%
• Posner cue attention task – target-P3 component	63.9 **	62.1%	65.6%
• Behavioral indicators of self-regulation	80.6% ***	80.6%	80.6%

Note. * = $p < .05$; ** = $p < .005$, *** = $p < .001$.

CHAPTER FIVE: DISCUSSION

Summary of Findings

This dissertation examined the relationship of self-regulation and academic achievement in college students with and without ADHD by means of three event-related potential (ERP) tasks, four behavioral questionnaires, and one achievement test. The ERP tasks were used to investigate the underlying executive processes of self-regulation. In general, students with ADHD demonstrated deficient executive processes as compared to control students in the ERP tasks.

For *research hypothesis 1*, students with ADHD had smaller amplitudes and longer latencies in both N2 and P3 components as compared to control students in the go/no-go ERP task. Also, students with ADHD displayed more reaction time (RT) variability than control students.

For *research hypothesis 2*, students with ADHD had smaller error-related negativity (ERN) amplitude and shorter ERN latency relative to control students in the visual letter flanker ERP task. In terms of the Pe component, students with ADHD had a larger amplitude and shorter latency than control students. For behavioral RT performance, students with ADHD were slower in both correct and incorrect trials and displayed more RT variability as compared to control students.

For *research hypothesis 3*, students with ADHD had smaller amplitudes of the target-P1 component, target-N1 component, and target-P3 component in general as

compared to control students in the Posner cued attention ERP task. Also, students with ADHD were slower in their RT performance than control students.

For *research hypothesis 4*, behavioral questionnaires were used to examine the behavioral manifestation of self-regulation. In general, students with ADHD perceived themselves having difficulties in their self-regulatory behaviors when compared with control students. For the Adult Temperament Questionnaire (ATQ), students with ADHD had lower raw scores in inhibition control, activation control, attention control and effortful control than control students. Students with ADHD had higher T-scores on all Behavioral Rating Inventory of Executive Function-Adult version (BRIEF-A) subscales as compared to control students. For the Self-regulation Scale (SRS), students with ADHD had lower raw scores than control students. For the Motivated Strategies for Learning Questionnaire (MSLQ), students with ADHD had lower raw scores in metacognitive self-regulatory strategy and effort regulation than control students.

For *research hypothesis 5*, the achievement test was used to determine academic performance. The results indicated that students with ADHD had significantly lower scores in spelling and academic skill than control students.

In terms of the relationship between ERP components and behavioral indicators of self-regulation (*research question 2*), control students in general displayed a stronger relationship between ERP components and behavioral indicators of self-regulation than students with ADHD. Also, more ERP components in control students were related to behavioral indicators of self-regulation as compared to students with ADHD.

The most important part of this dissertation, *research question 3*, was to examine the relationship of self-regulation and academic achievement in students with and without

ADHD. In control students, the results indicated that ERP components could predict or account for individual differences in four different domains of academic performance. However, behavioral indicators of self-regulation did not account for a significant amount of variance. The ERP components accounted for 36.6% of the variance of the letter-word identification score, 37.4% of the variance of the spelling score, 63.9% of the variance of the calculation score and 59.6% of the variance of the academic skill score.

For students with ADHD, ERP components could predict or account for individual differences in two different domains of academic performance although behavioral indicators of self-regulation, again, did not account for the variances. The ERP components accounted for 38.3% of the variance of the spelling score and 31% of the variance of the academic skill score. For both control and ADHD students, ERP components that supposedly represent underlying executive processes of self-regulation were more significant predictors explaining or accounting for performance in academic performance than self-reported self-regulation scores.

Moreover, for *research question 4*, the results indicated that ERP components could be the electrophysiological markers to distinguish between students with and without ADHD. The Cz go N2 latency and Fz go N2 amplitude from the go/no-go task correctly classified the students with overall 70.1% accuracy. The Fz ERN amplitude from the visual letter flanker task correctly classified the students with overall 72.1% accuracy. The Pz invalid cue target-P1 latency, Fz valid cue target-P1 amplitude, Oz no cue target-P1 amplitude, and Oz valid cue target-P1 amplitude from the Posner cued attention task correctly classified the students with overall 77.0% accuracy. The Pz invalid cue target-N1 latency, FCz valid cue target-N1 amplitude, and Oz valid cue target-N1 amplitude

from the Posner cue attention task correctly classified the students with overall 83.6% accuracy.

Executive Processes of Self-Regulation

The purpose of this dissertation was to examine if there were differences between college students with and without ADHD in the areas of the executive processes of self-regulation (i.e., inhibition, attentional control, and performance monitoring). The following discussion will focus on those three executive processes of self-regulation.

Inhibition Control/Response Inhibition

Hypothesis: Students with ADHD will display reduced inhibitory ability as measured during the go/no-go ERP paradigm when compared to students without disabilities.

This dissertation examined one research hypothesis regarding the inhibition control difference among college students with and without ADHD on a visual go/no-go task. The go/no-go task was administered to evaluate behavioral performance and to record event-related potential (ERP) correlates of inhibition control or response inhibition.

Behavioral Performance in Inhibition Control

Due to impulsivity symptom, students with ADHD should have faster reaction time (RT). However, the results indicated that students with ADHD were slower in their responses than control students although there was no significant group difference in their RT on go trials. In terms of error rate (i.e., error of commission), students with ADHD did not differ from control students, suggesting that students with ADHD are able to slow down their response to decrease their error rate such that they enhance their inhibition control to achieve optimal performance.

With respect to SDRT (i.e., response variability), the finding confirmed the expectation that students with ADHD responded more variably than control students. This finding seems to support the response variability hypothesis of ADHD (Castellanos et al., 2005); i.e., more variability exists in the adult ADHD population, and the response variability problem may be seen across the life span of persons with ADHD. Moreover, increased variability in speed has been suggested to reflect an inconsistent effort or state regulation (Sanders, 1983). This increased variability may indicate that students with ADHD might be inefficient in their state regulation as compared to control students in the present study.

ERP Correlates of Inhibition Control

To explore the ERP correlates of inhibition control, stimulus-locked N2 and P3 components were examined. Both control students and students with ADHD had clear N2 and P3 components.

N2/P3 effect. The peak-to-peak amplitude of N2/P3 is a behavioral inhibition index in the stop task (e.g., MacLaren et al., 2007). The results in this present study indicated that students with ADHD had significantly smaller peak-to-peak amplitude of N2/P3 relative to control students, suggesting an inefficient response inhibition in students with ADHD. This finding is in line with the result of MacLaren et al. (2007). It has been indicated that the N2 and P3 components are difficult to unravel because they overlap in time, and they may reflect separate aspects of inhibition and attention. Nevertheless, it is no surprise that students with ADHD in this dissertation had smaller peak-to-peak amplitude of N2/P3 as compared to control students, reflecting inefficient response inhibition.

Although the absolute means for N2 and P3 peak amplitudes were smaller in students with ADHD than control students, the two groups were not significantly different from each other. The significant difference with the N2/P3 complex but not individual peaks (i.e., N2 and P3 peaks) may be that the complex had enough statistical power to display a group difference. With more participants, it is possible that the individual peaks (i.e., N2 and p3 peaks) might also be significant.

N2 effect. The results revealed that students with ADHD displayed a smaller N2 amplitude than control students, but there were no significant group difference. The results also revealed that there was no significant group x trial type interaction, but a significant main effect for trial type (go vs. no-go). These findings suggested that both control students and students with ADHD display some inhibitory control (i.e., larger nogo-N2 than go-N2). This lack of evidence of response inhibition deficit in students with ADHD was consistent with the finding of Wiersema et al. (2006) who reported no difference between adults with ADHD and healthy controls using a similar go/no-go task. But this finding was not in line with the main conclusion of the review on adult ADHD literature of Hervey et al. (2004) as well as results of some studies using the stop-signal task (e.g., Bekker et al., 2005). Wiersema et al. (2006) have argued that the lack of response inhibition deficit in adults with ADHD in their study might be likely due to a lesser amount of task demands and high functioning of their sample. They pointed out that their task might be too easy for adults, which was not thoroughly taxing the inhibition system. On the other hand, their ADHD subjects had high IQ and were better able to perform normally on these relatively simple tasks of response inhibition. The result of the N2 effect in this dissertation seemed to fit well into these two explanations.

The go/no-go task used in this dissertation was similar to the one used in Wiersema et al. (2006), and students with ADHD in this dissertation had a mean IQ of 113.22, which is high.

The comorbidity in students with ADHD in this dissertation may be another reason accounting for no evidence of inhibition control deficit. As mentioned by Hervey et al. (2004), comorbidities in the ADHD samples may affect task performance and, therefore, contribute to inconsistent results in inhibition. Moreover, studies using methylphenidate (MPH) medication have revealed its effect on response inhibition in adults with ADHD (e.g., Aron et al., 2003). In this dissertation, only a few students with ADHD took MPH whereas most students with ADHD took Adderall. It is not clear whether Adderall will improve inhibition control in students with ADHD because no current studies address the effect of Adderall on inhibition control in adults with ADHD. Further studies need to address these issues (i.e., task complexity, function of ADHD, comorbidity, and medications) in order to clarify response inhibition or inhibition control in the adult ADHD population.

With respect to the N2 latency, results revealed that there was a group difference in the N2 latency, and both groups had longer no-go-N2 latency relative to the go-N2. Students with ADHD in general had longer N2 latency than that of control students. This longer N2 latency in students with ADHD likely indicated that they exhibited inhibitory regulation problems (Yong-Liang et al., 2000), even though they were able to successfully stop the response with an error rate similar to control students. In this case, the observed delay in N2 with ADHD students may directly indicate sluggish response inhibition or inhibition control.

P3 effect. The results of the P3 amplitude were similar to the N2 amplitude, suggesting that both students with and without ADHD had similar attentional processing of response inhibition, as indexed by the P3 amplitude. Wiersema et al. (2006) reported that slow RT was accompanied by smaller P3 amplitude in their study and suggested that insufficient state regulation persisted in adults with ADHD. Although students with ADHD in this dissertation displayed significantly slower RT but non-significant smaller P3 amplitude than control students, more studies are still required to confirm this insufficient state regulation in adults with ADHD.

Although the P3 amplitude was not significant different between the two groups, students with ADHD exhibited less P3 amplitude relative to control. This finding seemed to be somewhat consistent with the result of Rodriguez and Baylis (2007). They found that students with ADHD had significantly smaller P3 amplitude than control students and suggested that students with ADHD are less sensitive to nogo stimuli and exhibit impulse control deficit.

With respect to the P3 latency, the finding was nearly identical to the result of the N2 latency. The delayed P3 latency in students with ADHD may imply a poorly functioning inhibitory mechanism. Moreover, the early deficiency in the N2 component could, in turn, further delay the self-evaluative process indexed by the P3 component.

In general, the findings regarding the N2/P3 and both N2 and P3 latencies in students with ADHD may still provide some evidence for Barkley's behavioral inhibition model, which emphasizes that response inhibition or inhibitory control deficit is the core deficit of ADHD.

Performance Monitoring/Error Monitoring

Hypothesis: Students with ADHD will display reduced error monitoring ability as compared to students without disabilities.

Another research hypothesis of this dissertation was to investigate the performance monitoring/error monitoring in college students with and without ADHD. For this purpose, a visual letter flanker task was administered to evaluate the behavioral performance and to record event-related potential (ERP) correlates of performance monitoring/error monitoring. Currently, my understanding is that there is no published study regarding error monitoring in college students/adults with ADHD. Therefore, there is not much literature to compare to my findings.

Behavioral Performance in Error Monitoring

The behavioral performance results indicated that students with ADHD had significantly slower reaction time (RT) on correct trials and more RT variability on correct trials than control students. Although there were no significant group differences in RT on incorrect trials and no difference in RT variability on incorrect trials, students with ADHD demonstrated overall slower RT and more RT variability than control students. These findings are in line with the outcome of some child ADHD error processing studies (e.g., Jonkman, van Melis, Kemner, & Markus, 2007) and RT studies (e.g., Leth-Steensen, Elbaz, & Douglas, 2000), suggesting that college students with ADHD are slower in their responses to stimuli in order to maintain optimal on-task behavior. The response variability hypothesis of ADHD (e.g., Castellanos et al., 2005) seems plausible in college students with ADHD.

To investigate erroneous behavior, post-error slowing and error rate often have been used. In speeded choice RT tasks, slow responses on post-error trials are thought to reflect error awareness (Rabbitt, 1966). In the present dissertation, both groups had similar error rates and both demonstrated post-error slowing, suggesting that the ability to adjust response strategies and the ability to suppress impulsive responding also seem to be efficient in students with ADHD. The absence of post-error slowing in children with ADHD has been previously reported (e.g., Schachar et al., 2004); however, no published studies have reported whether post-error slowing is absent or apparent in adults with ADHD.

ERP Correlates of Error Monitoring

To explore the ERP correlates of error monitoring, response locked error-related negativity (ERN) and Pe components were examined. Both control students and students with ADHD had clear ERN and Pe components.

ERN effect. The present ERN amplitude was maximal at FCz and decreased from anterior to posterior sites in both groups. This centro-frontal topography is consistent with some adult studies (e.g., Falkenstein, Hohnsbein, Hoorman, & Blanke, 1990; Gehring et al., 1993), suggesting that the finding in students with ADHD is valid.

The results revealed that there were two group differences in this dissertation. First, the ERN amplitude was significantly smaller in students with ADHD, suggesting that inefficient performance monitoring may underlie the lower ability to implement adequate control in ADHD students as compared to control students. This group difference is in line with the outcome of some child ADHD studies that children with ADHD had smaller or reduced ERN amplitude when compared to control children (e.g., Liotti et al., 2005;

van Meel, Heslenfeld, Oosterlaan, J., & Sergeant, 2007). Although students with ADHD had a smaller ERN amplitude than control students, they were still able to adjust the degree of slowing (i.e., post-error slowing observed in ADHD students), suggesting that early error detection processing or preconscious awareness of the commission of an active error (Nieuwenhuis, Ridderinkhof, Blom, Band, & Kok, 2001) may be still intact in students with ADHD. However, studies also find that the ERN amplitude could be influenced by task difficulty/complexity in both healthy adults and typically developing children (Hogan, Vargha-Khadem, Kirkham, & Baldeweg, 2005; Mathewson, Dywan & Segalowitz, 2005; Santesso & Segalowitz, 2008), or influenced by increased uncertainty during task performance in healthy adults (Pailing & Segalowitz, 2004). Future studies need to determine whether inefficient or deficient error processing in adults with ADHD might depend on increased task demands or uncertainty.

Another group difference in error-related ERP was a shorter latency of the ERN in students with ADHD. The mean peak ERN latency at FCz in normal students was 77.01 ms while it was 63.39 ms in students with ADHD. Falkenstein, Hoorman, Christ, and Hohnsbein (2000) have argued that the ERN can be time-locked to response determination instead of strictly to incorrect response. The response determination "is defined as the process of the (correct) mapping of a stimulus to the appropriate response. So, the outcome of 'response determination' is usually the neural representation of the required response' (p. 88). The shorter latency of the ERN in students with ADHD could be likely due to a longer interval between their response determination and their actual response. In other words, the time needed to stop or adjust an erroneous response also should be longer in students with ADHD because the results showed that ADHD students

had longer RTs than control students. However, it is possible that the time for ADHD students to cognitively recognize an error commission may not be substantially longer than control students. Therefore, the RT would occur later to a greater amount than the ERN, which makes it look like the ERN latency was shorter in students with ADHD than control students.

Personality trait framework of the ERN. Studies have demonstrated that certain personality traits may moderate people's response to an error. For example, Vidal, Hasbroueq, Grapperon, and Bonnet (2000) have proposed that ERN represents an emotional response to perceived errors. Similarly, Luu, Collins, and Tucker (2000) reported that healthy individuals who scored high on negative effect and emotionality had enhanced ERN amplitude. Furthermore, studies have found that individuals with antisocial behavior or impulsiveness characteristics display smaller ERN amplitude (de Bruijn et al., 2006; Ruchsow, Spitzer, Gron, Grothe, & Kiefer, 2005; Ruchsow et al., 2006). In order to understand whether students with ADHD fit well into this framework, some correlation analyses were employed, as exploration and thus will be reported in the discussion section rather than in the results section.

In this dissertation, since students with ADHD reported on the Behavioral Rating Inventory of Executive Function-Adult version (BRIEF-A) having difficulty in emotional control as compared to control students, I explored whether emotional control was related to ERN in students with ADHD. Unfortunately, there was no relationship between emotional control and the ERN. However, interestingly there was a positive relationship between emotional control and the Pe. Furthermore, correlation analyses revealed that the ERN either at Fz or Pz was correlated with DSM hyperactivity/impulsivity, DSM

avoidant personality, and DSM antisocial personality. These results suggested that students with ADHD seem to fit into this personality trait framework.

Pe effect. In terms of the Pe component, the present Pe was maximal at Pz in control students, which is consistent with other studies (e.g., Falkenstein et al., 1990, 2000; O'Connell et al. 2007). However, the Pe was maximal at Cz in students with ADHD. This topographical difference might be due to the chosen time window for picking the Pe component. In this dissertation, the time window used for picking the maximal Pe component was 120 – 400 ms. Most studies have used a time window of 200 – 500 ms to pick the so-called "late" Pe component. Studies have shown that the late Pe is maximal at Pz while the early Pe is maximal at Cz (Ruchsow et al., 2005; van Veen & Carter, 2002). Therefore, it is possible that the early Pe was larger than the late Pe in students with ADHD, so that the early Pe was more likely picked rather than the late Pe. However, this will need to be further confirmed.

In contrast to the ERN results, students with ADHD did not differ from control students in either Pe amplitude or latency. In general, the results indicated that students with ADHD had enhanced Pe amplitudes at Cz, FCz, and Fz as compared to control students, but there were no significant differences between the two group. The Pe has been interpreted as a sign of enhanced conscious processing or evaluative processing of relevant events. The Pe enhancement in students with ADHD might mean that they needed to exert more allocation of attention to important events (such as an error) to maintain their task performance, thereby increasing awareness of the error or increased evaluation of the error. And this increasing awareness of the error or increased evaluation of the error may help their studying at school.

Although my results did not reveal significant group differences in the Pe enhancement, studies have shown that medication; i.e., methylphenidate (MPH) has a positive effect on Pe amplitude enhancement in children with ADHD (Jonkman et al., 2007). Since 27 students with ADHD in this dissertation have taken a variety of medications for a long period of time, it is possible that these medications may have some effects on the Pe. Therefore, ADHD students exhibited increased Pe amplitudes across the EEG recording sites. Currently, however, there are no published studies to address the medication effect on Pe in adults with ADHD. Further studies need to determine whether different medications have different effects on Pe in adults with ADHD.

On the other hand, child ADHD studies have found inconsistent results on the Pe amplitude. For example, both the Overtoom et al. (2002) and Wiersema et al. (2005) studies found smaller Pe amplitudes, but larger Pe amplitudes were found in the Burgio-Murphy et al. (2007) study. The difference between these studies may be due to different tasks employed in the studies. Thus, further studies should consider the effect of task complexity Pe in the adults with ADHD population.

Neurological Model of Error Monitoring and ADHD

Parallel error monitoring. Studies have found that the error-related negativity (ERN) and Pe reflect different functional aspects of error monitoring processing (Falkenstein et al., 2000; Nieuwenhuis et al., 2001; Overbeek, Nieuwenhuis, & Ridderinkhof, 2005; O'Connell et al., 2007). The ERN is suggestive of a rapid internal detection mechanism that is unaffected by the conscious experience of errors, while the Pe presents conscious awareness of committing an error. Yordanova and her colleagues (2004) point out that automatic error detection is not a compulsory condition for error

awareness, suggesting that the ERN and Pe represent a distinct parallel error functioning system (Yordanova, Falkenstein, Hohnsbein, & Kolev, 2004). Functionally, Davies and her colleagues (2001) reported that in healthy adults the Pe might be a P3 response generated when the subject realizes that an error is being initiated. Similarly, O'Connell et al. (2007) recently demonstrated that the Pe amplitude in healthy adults was significantly correlated with tonic EEG measures of cortical arousal and suggested that the Pe represents a P3-like facilitation of information processing and could be modulated by subcortical arousal system.

In addition, studies have found that the ERN and Pe are generated from the different part of brain. Dipole source ERP studies have argued that the ERN is generated in the caudal part of the anterior cingulate cortex (ACC), whereas the generation of the Pe comes from the rostral ACC and the super parietal cortex (Herrmann, Rommler, Ehlis, Heidrich, & Fallgatter, 2004; van Boxtel, van der Molen, & Jennings, 2005; van Veen & Carter, 2002). Other studies also confirmed that the ERN is generated from the caudal region of the ACC, whereas the Pe is either associated with both bilateral prefrontal cortex and parietal cortical generators (Hester, Foxe, Molholm, Shpaner, & Garavan, 2005) or generated from a more anterior ACC region and the posterior cingulate-precuneus (O'Connell et al., 2007). These studies collectively show the evidence that the ERN and Pe represent a different, but parallel functional system of error monitoring.

This parallel error monitoring system seems to support the findings of students with ADHD in this dissertation. Students with ADHD had a smaller ERN amplitude but enhanced Pe amplitude, suggesting that students with ADHD are able to automatically detect errors but just not as well as control students. Also, the following error awareness

processing may have helped them to maintain error monitoring such that they were able to achieve optimal task performance. Therefore, their error rates were similar to those of normal students, and, alternatively, the relative ease of the task may have promoted greater attention to errors. Furthermore, Seidman et al. (2006) have found that adults with ADHD have smaller ACC volume compared with normal adults. The finding of smaller ERN amplitude in students with ADHD might correspond with the outcome of Seidman et al. (2006).

Reinforcement learning model. Holroyd and Coles (2002) have proposed that the mesencephalic dopamine system is involved in the production of the ERN. In this model, the ERN may be the result of the basal ganglia monitoring behavior, and the mesencephalic dopamine system conveys a negative reinforcement learning signal to the ACC whenever a situation is worse than expected. The ACC is using this signal to adjust the cognitive system and performance of the task at hand or correctly select appropriate motor actions through reinforcement learning. Accordingly, this model proposes that the ERN size depends on the size of the dopaminergic error signal; that is, the larger the ERN, the larger the signal.

This reinforcement learning model might be able to explain the diminished ERN amplitude observed in students with ADHD in this dissertation. Studies have suggested that ADHD has disturbances within the fronto-ventral-striatal reward network and also has deficits in dopamine transporter (DAT1) genes or dopamine-4 receptor (DRD4) genes (see Kieling, Goncalves, Tannock, & Castellanos, 2008 for review). The disturbance in the neural network and deficit in dopamine genes may be strongly related to abnormal error monitoring in ADHD.

Attention Control

Hypothesis: Students with ADHD will display reduced attentional control ability as measured during the Posner cue attention task when compared to students without disabilities.

To the investigator's knowledge, this research is the first study that has examined if attention control differences, indexed by behavioral performance and event-related potentials (ERPs), exist among college students with and without ADHD during a forewarned, spatially cued motor reaction task (the 'Posner' paradigm). A few significant differences between students with and without ADHD were observed in the Posner paradigm as revealed by both behavioral responses and ERP components following target stimuli. With respect to the behavioral responses, students with ADHD displayed slower reaction times (RTs) in all conditions relative to control students, suggesting that ADHD students are not able to anticipate or process the target location as efficiently as control students. The ERP components results may suggest the existence of divergent levels of stimulus processing in ADHD.

Attentional Orienting

Target-P1 effect. The enhancement of the P1 component to target stimuli at attended locations in visuospatial tasks has been interpreted as a sensory gain control or amplification mechanism (Mangun & Hillyard, 1990). This mechanism reflects a top-down control over the flow of visual information from striate to extrastriate cortex, thus amplifying signals from stimuli at attended locations and suppressing information from unattended locations (Clark & Hillyard, 1996).

In this dissertation, both students with and those without ADHD displayed enhancement of the P1 amplitude for the invalid cue target compared to the valid cue target. However, based the amplification mechanism, the P1 amplitude for the invalid cue target should be smaller than that for the valid cue target. This opposite finding may be due to two reasons. First, the numbers of trials for the valid cue target were three times as compared to those for the invalid cue target. With more trials, the amplitude will be smaller in the averaged ERP waveform. Second, the participants may use different processing mechanism instead of the amplification. Future studies involving individuals with ADHD are required to see if results will be similar to those found in this dissertation.

With respect to the P1 latency, there was a significant group difference between students with and without ADHD. In control students, the P1 latency in the valid cue condition was shorter than that in the invalid cue condition. However, students with ADHD had a longer latency in the valid cue condition than in the invalid cue condition. It is not clear why students with ADHD had an earlier P1 component in the invalid cue condition relative to the valid cue condition because they had slower RT in the invalid cue condition relative to the valid cue condition. One explanation related to this finding could be that in order to achieve optimal task performance and make fewer orientation errors, students with ADHD might need to initiate target stimulus processing earlier in the invalid cue target. Consequently, they had to suppress or ignore that invalid cue information to orient their attention toward the target.

In terms of the no cue condition, both students with and without ADHD exhibited larger P1 amplitude at Pz relatively to the valid cue and invalid cue conditions. This finding for the no cue P1 may be in conflict with the top-down or amplification

mechanism, however, it is consistent with the findings of the Hopfinger and Mangun (1998). Hopfinger and Mangun (1998) have found that the P1 amplitude is larger for the no cue target during a longer stimulus onset asynchrony (1000 ms; i.e., time between the last trial and the appearance of the not cue target stimulus). In this study, the time before the no cue target appeared on the screen was at least 1500 ms. Thus, consistent with Hopfinger and Mangun, it is not surprising that both groups had a larger no cue target-P1 amplitude than in both the valid cue and the invalid cue conditions.

Visual Discrimination

Target-N1 effect. Previous studies have indicated that the visual N1 is larger for attended-location stimuli (e.g., valid cue condition) than for unattended-location stimuli (e.g., invalid cue condition) in spatial cueing tasks (e.g., Mangun & Hillyard, 1990). However, this enhancement of the N1 amplitude may have a different operating mechanism than the P1 component. The P1 component reflects a top-down or amplification mechanism whereas Luck (1995) has proposed that the N1 component reflects a limited-capacity discriminative process of attended stimuli because (a) it reflects an enhanced processing of stimuli at the attended location, (b) it may be present only when participants perform a discrimination task at the attended location, and (c) it appears to be reduced when the time between consecutive stimuli at the attended location is short. Moreover, Vogel and Luck (2000) have argued that the discrimination process of the N1 component is operating within the focus of attention. Therefore, the N1 amplitude might be larger under conditions when such discrimination is quick.

In this dissertation, both students with and without ADHD exhibited an enhancement of the N1 amplitude for the valid cue target. This result is supported by

previous literature (e.g., Eimer 1994), and students with ADHD seemed to be as able to operate their discrimination process as control students. In the valid cue condition, both cue and target are at the same location. When the participants first attended to the cue location, the target appeared at the same location after the cue. The discrimination process would operate within the focus of attention (the cue location) and become rapid. With respect to the invalid cue condition, the cue and target are at the opposite condition. When the participants first attended to the cue location, the target appeared at the opposite location after the cue. The participants had to shift attention and orient their attention toward the target location. The discrimination process would not operate within the focus of attention (the cue location) and become slow.

With respect to the N1 latency, there was a significant group difference between students with and without ADHD. In control students, the N1 latency in the valid cue condition was shorter than that in the invalid cue condition. However, students with ADHD had a longer latency in the valid cue condition than in the invalid cue condition. This finding is similar to the finding of the P1 latency. The earlier N1 component in students with ADHD observed in the invalid cue condition might be due to the early processing of the P1 component in students with ADHD in the invalid cue condition.

Target Identification

Target-P3 effect. The results revealed that there were no group differences in either amplitude or latency of the P3, suggesting that the timing and characteristics of target stimulus identification were similar in both students with and without ADHD. When comparing validity conditions, both groups had the shortest latency in the valid cue condition and the longest latency in the no cue condition. Since the P3 component

reflects the time needed for target stimulus evaluation (Picton, 1992), it is possible that the cue stimulus may help to facilitate the target-P3 processing, so that the target-P3 latency was shortest in the valid cue condition.

When comparing the RT with the P3 latency, it seems that the RT in control students was generally shorter than their P3 latency in three conditions. This quicker motor response possibly may be due to efficient visual discrimination, so that they could make a motor response quickly. In students with ADHD, however, their RT was generally longer than their P3 latency. This might be due to sluggish cognitive tempo leading to slower responses. Or another possible explanation could be that students with ADHD have developed some compensatory strategies in order to achieve optimal task performance. Further studies need to clarify the relationship between the RT and target-P3 latency to better understand the underlying operating mechanism between students with and without ADHD.

Anticipatory ERP Response

CNV/RP effect. The contingent negative variation (CNV) is a slow negative deflection brainwave that occurs in the time period between a warning and an imperative stimulus, and is considered to be an expectancy and preparatory process (see McCallum 1988, for review). Two distinct CNV components have been identified and related to expectancy and preparatory processes. The early CNV component is associated with the orienting response while the later CNV component reflects the anticipation of the imperative stimulus and the preparation of a motor response to the imperative stimulus. When the warning and the imperative stimulus are relatively close, which is less than one second, the CNV could be considered to reflect mainly a readiness potential (RP); that is,

an event directing the anticipation and the preparation of a motor response (Perchet & Garcia-Larrea, 2005). Therefore, Perchet & Garcia-Larrea (2005) label the slow negativity as CNV/RP when the time period between a warning and an imperative stimulus is less than one second.

In this dissertation, the results revealed that there was no significant group difference in the CNV/RP area amplitude between students with and without ADHD, suggesting that both groups are able to anticipate the target and prepare a motor response. Although there was no significant validity condition effect, the CNV/RP was slightly larger in the valid condition than that in the invalid condition for control students whereas the CNV/RP was slightly larger in the invalid condition than that in the valid condition for students with ADHD. Moreover, when comparing students with and without ADHD, students with ADHD displayed smaller CNV/RP relative to students without ADHD in the valid cue condition whereas students with ADHD displayed larger CNV/RP in the invalid cue condition. These findings suggested that the mechanism for the anticipation of the target and the preparation of a motor response are different between students with and without ADHD across the validity conditions. It is possible that students with ADHD might anticipate and prepare themselves more to achieve optimal task performance during the invalid cue condition. However, further studies need to classify how the validity conditions influence the mechanism of the CNV/RP in students with and without ADHD.

Cueing Process

Cue-P3 effect. The results revealed that there were no significant differences in either amplitude or latency between students with and without ADHD. There were also

no differences in amplitude and latency between the valid and invalid cues. These findings may suggest that both groups displayed a similar cueing process.

Perchet et al. (2001) have indicated that a shorter cue-P3 latency in the "valid" than in the "invalid" condition is an indicator of using the spatial features of the cue to ameliorate target stimulus processing. However, neither group exhibited a shorter cue-P3 latency in the valid than in the invalid condition, suggesting that both groups might just use the cue stimulus to prepare their motor responses rather than using the spatial features of the cue to ameliorate target stimulus processing.

Diagnostic Utility of the ERP Tasks

Hypothesis: *Some ERP components will be able to discriminate or classify students with and without ADHD.*

This dissertation examined a research question regarding whether the event-related potential (ERP) components could be used to classify students with and without ADHD. For the purpose of discriminating among students with and without ADHD, the ERP components under each task condition were used as the input variables in several separate stepwise discriminant analyses. Among the several separate stepwise discriminant analyses, the results of discriminant functions revealed that the target-N1 component in the Posner cue attention task had the highest percentages of accuracy to differentiate students with and without ADHD. The target-P1 component in the Posner cue attention task was the second, and the ERN component in the visual letter flanker task was the third. Those findings suggested that the Posner cue attention task might be better to use for clinical utility than the other two tasks because it had the highest percentage of classification accuracy.

The classification was fairly good with approximately 75% of the participants were correctly classified. However, there were several misclassified participants based on the discrimination result. It is possible that some of the misclassifications might be related to clinical misjudgment, comorbidity problems, and lack of current ADHD symptoms in students with ADHD. Also, some of the control students had high T-scores on the Conners' Adult ADHD Rating Scale (CAARS) and Adult Self-Report (ASR) but did not fall into the clinical diagnostic range. If the ERP components are sensitive to students with ADHD, then one might anticipate that control students might be classified as ADHD before clinical behavioral symptoms become discernible. Another reason for some of misclassifications might be due to the individual variability within groups. Since half of students with ADHD had taken medications, they may have brain responses similar to control students; whereas some of control students had brain responses similar to students with ADHD due to age or personality characteristics.

The discriminant function analysis should be cross-validated on a new data-set (Smith, Johnstone, & Barry, 2003). Smith et al. (2003) have indicated that principal component analysis (PCA) is the best way of reducing a data-set for cross-validation studies when using the ERP components. Future data analysis for this dissertation should consider using the PCA to confirm the discriminant analysis results.

Self-Regulation and Academic Achievement

The main purpose of this dissertation was to examine whether there was a relationship between self-regulation and academic achievement in college students with and without ADHD. The results indicated that the executive processes of self-regulation (i.e., some of ERP components) were related to academic achievement in students with

and without ADHD. The following discussion focuses on behavioral measures of self-regulation, academic achievement, and the relationship between self-regulation and academic achievement.

Behavioral Measures of Self-Regulation

Hypothesis: *Students with ADHD will display deficient behavioral manifestations of regulation as compared to students without disabilities.*

As expected, the results revealed that students with ADHD reported more problems or difficulties on subscales of the Adult Temperament Questionnaire (ATQ), Behavioral Rating Inventory of Executive Function-Adult version (BRIEF-A), Self-regulation Scale (SRS), and Motivated Strategies for Learning Questionnaire (MSLQ) than students without ADHD. These findings suggested that students with ADHD perceive themselves having difficulty regulating their behavior in daily life activities.

With respect to the ATQ, students with ADHD considered themselves as experiencing problems in effortful control. Effortful control, a construct related to temperament and behavior regulation, has been defined as the ability to inhibit a dominant response in order to perform a subdominant response. It also plays a major role in planning and controlling attention and related behavior (Rothbart et al., 2004). The finding about effortful control in students with ADHD in this study echoes the nature of ADHD behavioral problems, that is, individuals with ADHD have difficulty inhibiting impulsive behavior and controlling their attention.

The findings from the BRIEF-A support Barkley's behavioral inhibition model and suggest that deficits in executive function and self-regulation in individuals with ADHD may persist into adulthood. However, Rabin and colleagues (2006) argued whether the

BRIEF-A could accurately evaluate executive function deficits in adults. In their study, there was no strong correlation between the BRIEF-A and standardized neuropsychological tests of executive function in adults with mild cognitive impairment and cognitive complaints (Rabin et al., 2006). This concern should not be the case in this dissertation because the ERP tasks used in this study were good measures of neurophysiological function. Also, the ERP components were significantly correlated with the BRIEF-A.

In terms of the Self-regulation Scale (SRS), students with ADHD reported more difficulty in attentional control of self-regulatory behaviors as compared to students without ADHD. This finding suggests that students with ADHD could not focus their attention on a given task, such that they could not efficiently control and regulate external and internal distractions. Therefore, they would not be able to work toward a desired goal or outcome. Moreover, the SRS was the other significant behavioral indicator used to classify students with and without ADHD in the discriminant function analysis, suggesting that the SRS could be possibly a useful measure to identify students with ADHD; however, more studies are required to confirm its usefulness in classifying students with ADHD.

The results of the Motivated Strategies for Learning Questionnaire (MSLQ) revealed that students with ADHD did not use metacognitive self-regulation and effort regulation strategies efficiently as compared to students without ADHD. As Printrich (2003) points out, if individuals could use these two strategies efficiently they could better manage their learning in school. Therefore, the findings might suggest that students with ADHD probably do not use their self-regulation ability (e.g., time management and

the capacity to learn vicariously) efficiently to assist their learning in the classroom. Further studies are required to investigate what kind of learning strategies are often used by students with ADHD.

However, when interpreting the results from self-report measures, one must be cautious. Burgess and colleagues (1998) have stated that neuropsychological performance tests are better to examine everyday problems than self-report measures because self-report measures tend to have flaws, such that self-reporters may perceive themselves exhibiting more or fewer symptoms then they actually have (Burgess, Alderman, Evans, Emslie, & Wilson, 1998). Also, the validity of self-report measures may not be accurate and will depend greatly on the type of behavior investigated (Danckaerts, Heptinstall, Chadwick, & Taylor, 1999). Furthermore, a variety of factors, such as age, format of questions, and type of rating scale used could influence how individuals rate their behaviors (Mahone, Zabel, Levey, Verda, & Kinsman, 2002). Therefore, in this dissertation it is possible that students with ADHD who have struggled with their ADHD symptoms could overestimate their problems or difficulties whereas students with ADHD who did not struggle with their ADHD symptoms could underestimate their problems or difficulties. Future data analysis for this dissertation should focus on the validity of the results in students with and without ADHD.

Academic Achievement

Hypothesis: Students with ADHD will display poor academic performance as compared to students without disabilities.

This dissertation attempted to examine the research hypothesis regarding academic achievement differences among college students with and without ADHD. The results

revealed that students with ADHD exhibited difficulties in spelling and academic skill as compared to students without ADHD. This finding might support the connotation that academic difficulties in individuals with ADHD persist into college (Weyandt & Dupaul, 2006). In terms of spelling, the result of a 5-year longitudinal follow-up study indicated that individuals with comorbid reading disability (RD) and ADHD are at increased risk for a negative outcome in spelling as adolescents and young adults (Willcutt et al., 2007). It seems that comorbid problems would exacerbate academic difficulties in students with ADHD. The significant spelling difference among students with and without ADHD in this dissertation seems to correspond with this idea. Students with ADHD in this dissertation have comorbid problems along with ADHD, and a few of them report having a RD or learning disability.

In this dissertation, the two groups were not significantly different from each other in letter-word identification and calculation. However, with respect to calculation (a mathematical skill), Biederman et al. (1993) found that adults with ADHD performed significantly less well on tests of math as compared to control adults. This contradiction between the findings in math skill of this study and the Biederman et al. (1993) study may be due to a couple of reasons. First, the ADHD sample in this dissertation was college students whereas the ADHD sample in Biederman et al. (1993) study was community adults. Usually, individuals who are in an educational setting do better on math tests than individuals who are not in an educational setting. Second, students with ADHD in this dissertation had slightly higher average IQ than those in the Biederman et al. (1993) study. Therefore, it is possible that students with ADHD in this dissertation would perform better on math tests than adults with ADHD in the community. And third,

the contradictory finding in math skill may be due to the tests used. However, it is not clear whether the math test used in this dissertation is easier or more difficult than that used in Biederman et al. (1993) study.

Relationship between Self-Regulation and Academic Achievement

Hypothesis: *The executive processes of self-regulation and behavioral regulation will account for a significant amount of variance in academic performance in students with and without ADHD.*

As expected, the results revealed that there was a relationship between self-regulation and academic achievement. The ERP components, indicative of the executive processes of self-regulation, could account for a significant amount of the variance in each subtest of academic achievement. However, surprisingly none of the behavioral indicators of self-regulation accounted for a significant amount of the variance in any subtest of academic achievement. This raises the question whether the aspects of academic achievement investigated in this dissertation do not require any self-regulatory skills or behaviors or whether these behavioral measures are just not sensitive enough to actually determine relationships with academic performance.

In this dissertation, the Adult Temperament Questionnaire (ATQ) effortful control, Behavioral Rating Inventory of Executive Function – Adult version (BRIEF-A), and Self-regulation Scale (SRS) examine self-regulatory behaviors or behaviors related to executive function in daily life situations. So these three questionnaires are not specific to school learning situations whereas only the Motivated Strategies for Learning Questionnaire (MSLQ) is related to school learning situations. However, the MSLQ used in this dissertation only investigated two self-regulatory aspects in learning. Therefore, it

is possible that the behavioral indicators of self-regulation investigated in this dissertation may not relate to learning or education. On the other hand, the performance during the achievement test itself may require more attention and cognitive control, which are more related to the underlying executive processes. Therefore, it is possible that self-regulatory behaviors may not relate to one time test performance, but may relate to overall learning outcomes. However, more studies are needed to understand the relationship between self-regulatory behaviors and academic achievement tests.

Findings of the relationship between self-regulation and academic achievement in this dissertation seem to correspond with some child studies. In a neuropsychological behavioral study, Blair and Razza (2007) found that aspects of children's self-regulation abilities, including shifting, focused attention, and impulsive inhibition, are uniquely related to emerging academic ability and accounted for greater variation in early academic progression in 141 3- to 5-years old children from low-income families. In this dissertation, results revealed that the abilities related to inhibition and attention orienting account for variance in letter-word identification in students without ADHD based on the ERP measures. This finding seems to make sense. In letter-word identification, the participants have to look at the word and read it aloud to the examiner. The participants need to attentionally orient to the word and inhibit inaccurate pronunciation before they actually read it aloud. However, none of the ERP components or behaviors accounted for a significant amount of variance in students with ADHD in letter-word identification.

With respect to spelling, the attention related ERP components accounted for significant variance in both students with and without ADHD. In the test of spelling, the

participants have to listen to the word and then write it down on the test sheet. Therefore, they have to pay attention and listen to the word carefully.

In terms of calculation, the abilities related to attention and inhibition accounted for variance in students without ADHD. In the test of calculation, the participants have to work on arithmetic. Therefore, they have to attentionally orient to the digit symbols, identify the symbols, and inhibit inaccurate thinking in order to do arithmetic correctly. However, none of the ERP components and behaviors accounted for variance in students with ADHD.

With respect to academic skill, the abilities related to attention and inhibition accounted for significant variance in students without ADHD whereas the ability related to attention accounted for variance in students with ADHD. This finding suggests that attentional processing plays a key role during the test of academic performance.

Implications for Education

The results of this dissertation have several implications for education. First, this dissertation demonstrated that students with ADHD exhibited deficient academic skill on the achievement test as compared to control students. Academic skill in this dissertation was an aggregate measure of reading decoding, math calculation, and spelling of single-word responses (Mather et al., 2007). The difference in academic skill between the two groups was mainly from spelling because there was a significant group difference in spelling among students with and without ADHD. Therefore, to improve writing task performance in students with ADHD, educators need to understand that spelling may play an essential role for part of writing performance. Educators can help students with

ADHD to be aware of or recognize that one of their difficulties in writing might be partially due to incorrect spelling.

The second implication for education is the relationship of self-regulation and academic achievement. The results revealed that abilities related to attention and inhibition control are two main indicators related to academic performance. When teachers deliver lectures to a class that includes students with ADHD, their instructions should be specific and avoid unclear and distracting information so that students with ADHD are able to better orient their attention to course information. Also, teachers can teach ADHD students some self-control strategies for their classroom learning, such as self-cueing through self-talk, so that they might be better able to keep track of teachers' instructions. Furthermore, educators have to provide accommodation and modification when it is necessary for students with ADHD to help them focus their attention in the classroom.

The third implication for education would be that educators have to recognize comorbid problems in students with ADHD. Sometimes, school failures in college students with ADHD may be due to comorbid problems. Educators should know about resources available for students and encourage them to seek external assistance, from the resource for disabled students center, the writing center, and/or the psychological counseling center.

Implications for Occupational Therapy

The results of this dissertation have several implications for occupational therapy. First, when providing OT services for the ADHD population, therapists should recognize that the underlying brain processing deficits of ADHD students involve problems with

attention control, inhibition control, and performance monitoring. When dealing with these underlying processing deficits, therapists may want to focus some of their treatment goals on these processes. Therapists can use their task analysis skills to examine whether poor attention control involves poor task performance in individuals with ADHD or lack of performance monitoring for that specific task. If poor attention control is the main reason for specific tasks, therapists can use similar tasks to increase attention span and focused attention. If lack of performance monitoring is the main reason, then therapists could use meta-cognition training to increase self-awareness.

The second implication for occupational therapy is that therapists can implement the questionnaires (such as the BRIEF-A) used in this dissertation to evaluate the current daily behavioral problems in individuals with ADHD. Therapists can also use these questionnaires as the treatment outcome measures to see how daily behavioral problems change overtime after receiving OT services. In evidence-based practice, these questionnaires could possibly provide some evidence regarding how OT services have an effect on individuals with ADHD.

The third implication would be that occupational therapists could be trained to understand and interpret results from EEG/ERP studies in clinical populations through continued education. Therapists will have better understanding about brain processes of clinical populations (e.g., the EEG pattern and ERP responses) they work with, such as individuals with ADHD. Moreover, therapists should consider working with clinical neuroscientists or neurologists who conduct EEG/ERP studies. Collaborations between therapists and neuroscientists may lead to more studies that examine how treatment or intervention programs alter brain processes of clinical populations.

Limitation and Future Research

There are several limitations in this dissertation. First, the participants were all Caucasians except for one African American. Also, all participants were from a western university. This limits the generalizability of the findings to an elite group of college educated individuals in the United States. A recommendation for a future study is to use a randomized stratified sample across the universities in the United States to examine whether there are similar findings. Second, the ADHD participants were college students, which may limit the generalizability of the findings to general adult ADHD population. It would be interesting to use a community-based adult ADHD population and see if similar results are found for future research. This would broaden and deepen the findings of this current dissertation. A third limitation was the sample size of 77 participants. If possible, future studies should incorporate larger sample sizes in order to increase power to detect differences.

A forth limitation was the validity of participants' reporting the existence of an ADHD diagnosis. They were not required to provide evidence that they had been diagnosed. The identification of ADHD participants were only verified by self-reported questionnaires, and half of them did not have current ADHD symptoms. Therefore, they should be validated by psychiatrists/psychologists before entering the study. Verifying the diagnosis by psychiatrists/psychologists would provide additional information, such as the severity. Doing so would also ensure that certain analyses, such as the discriminant function analysis, are run appropriately.

A fifth limitation was the comorbid problems among the ADHD participants. In the ADHD participants, a variety of comorbidities existed. Therefore, the ADHD sample in

this dissertation was more heterogeneous not homogeneous. Some lock of group differences might be due to heterogeneity. Future studies should use a homogeneous ADHD sample to examine if there are similar results. In addition, most of ADHD participants in this dissertation took medications and were not abstinent from medications for at least 48 hours prior to testing in the study. Further studies should wash out the medication effect before subjects with ADHD participate in the study.

Finally, this dissertation only examines some cognitive aspects of self-regulation and a limited measure of academic achievement. Future studies need to expand to other aspects of self-regulation, such as emotional regulation, and to more academic achievement skills in order to obtain more clear picture with respect to the relationship between self-regulation and academic achievement.

Conclusion

The results of this dissertation revealed that there was a relationship between self-regulation and academic achievement in college students with and without ADHD. The ERP components, representative of the executive processes of self-regulation, accounted for a significant amount of the variance in performance on academic achievement tests. There were also significant group differences in executive processes of self-regulation, behavioral indicators of self-regulation, and academic achievement. The results also indicated that there was a relationship between executive processes of self-regulation and behavioral indicators of self-regulation. Furthermore, both executive processes of self-regulation and behavioral indicators of self-regulation could be used to differentiate students with ADHD from students without ADHD. The classification results of the ERP

tasks indicated its clinical utility for diagnostic procedures with more refinement of the measures.

REFERENCES

Achenbach, T. M., & Rescorla, L. A. (2003). *Manual for the ASEBA Adult Forms & Profiles*. Burlington, VT: University of Vermont, Research Center for Children, Youth, & Families.

Alvarez, J. A., & Freides, D. (2004). Research on attention deficit hyperactivity disorder using the covert orienting paradigm of Posner. *Developmental Neuropsychology, 26*, 627-645.

Aman, C. J., Robert, R. J., & Pennington, B. F. (1998). A neuropsychological examination of the underlying deficit in attention deficit hyperactivity disorder: Frontal lobe versus right parietal lobe theories. *Developmental Psychology, 34*, 956-969.

American Psychiatric Association. (1994). *Diagnostic and statistical manual of mental disorders* (4th Ed.). Washington, DC: Author.

American Psychiatric Association. (2000). *Diagnostic and statistical manual of mental disorders* (4th Ed., Text Revision). Washington, DC: Author.

Aron, A. R., Dowson, J. H., Sahakian, B. J., & Robbins, T. W. (2003). Methylphenidate improves response inhibition in adults with attention-deficit/hyperactivity disorder. *Biological Psychiatry, 54*, 1465-1468.

Aron, A. R. & Poldrack, R. A. (2005). The cognitive neuroscience of response inhibition: Relevance for genetic research in ADHD. *Biological Psychiatry, 57*, 1285-1292.

Banfield, J. F., Wyland, C. L., Macrae, C. N., Münte, T. F., & Heatherton, T. F. (2004). The cognitive neuroscience of self-regulation. In R. F. Baumeister, & K. D. Uohs (Eds.), *Handbook of self-regulation: Research, theory, and applications* (pp. 62-83). New York, NY: The Guilford Press.

Barkley, R. A. (1996). Linkages between attention and executive functions. In G. R. Lyon & N. A. Krasnegor (Eds.), *Attention, memory, and executive function* (pp. 307-325). Baltimore, MD: Paul Brookes.

Barkley, R. A. (1997a). Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of ADHD. *Psychological Bulletin, 121*, 65-94.

Barkley, R. A. (1997b). *ADHD and the nature of self-control*. New York: Guilford Press.

Barkley, R. A. (1998). *Attention-deficit/hyperactivity disorder: A handbook of for diagnosis and treatment* (2nd Ed.). New York: The Guilford Press.

Barkley, R. A. (2001). The executive functions and self-regulation: An evolutionary neuropsychological perspective. *Neuropsychology Review, 11*, 1-29.

Barkley, R. A. (2004). Attention-deficit/hyperactivity disorder and self-regulation: Taking an evolutionary perspective on executive functioning. In R. F. Baumeister, & K. D. Uohs (Eds.), *Handbook of self-regulation: Research, theory, and applications* (pp. 301-323). New York, NY: The Guilford Press.

Barkley, R. A. (2006). *Attention-deficit/hyperactivity disorder: A handbook of for diagnosis and treatment* (3rd Ed.). New York: The Guilford Press.

Barkley, R.A., Fischer, M., Smallish, L., & Fletcher, K. (2002). The persistence of attention-deficit/hyperactivity disorder into young adulthood as a function of reporting source and definition of disorder. *Journal of Abnormal Psychology, 111*, 279-289.

Bekker, E. M., Overtoom, C. C. E., Kooij, J. J. S., Buitelaar, J. K., Verbaten, M. N., & Kenemans, J. L. (2005). Disentangling deficits in adults with attention-deficit/hyperactivity disorder. *Archives of General Psychiatry, 62*, 1129-1136.

Berger, A., Kofman, O., Livneh, U., & Henik, A. (2007). Multidisciplinary perspectives on attention and the development of self-regulation. *Progress in Neurobiology, 82*, 256-286.

Biederman, J. (2005). Attention-deficit/hyperactivity disorder: A selective overview. *Biological Psychiatry, 57*, 1215-1220.

Biederman, J., Faraone, S., Spencer, T., Wilens, T., Norman, D., Lapsey, K. A., et al. (1993). Patterns of psychiatric comorbidity, cognition, and psychosocial functioning in adults with attention deficit hyperactivity disorder. *American Journal of Psychiatry, 150*, 1792-1798.

Biederman, J., Monuteaux, M. C., Mick, E., Spencer, T., Wilens, T. E., Silva, J. M., et al. (2006). Young adult outcome of attention deficit hyperactivity disorder: A controlled 10-year follow-up study. *Psychological Medicine, 36*, 167-179.

Biederman, J., Pitty, C., Fried, R., Fontanella, J., Doyle, A. E., Seidman, L., J., et al. (2006). Impact of psychometrically defined deficits of executive functioning in adults with attention deficit hyperactivity disorder. *American Journal of Psychiatry, 163*, 1730-1738.

Blair, C. & Razza, R.P. (2007). Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. *Child Development, 78*, 647-663.

Boekaerts, M., Pintrich, P. R., & Zeidner, M. (Eds.). (2000). *Handbook of self-regulation.* San Diego, CA: Academic Press.

Boonstra, A. M., Kooij, J. J. S., Oosterlaan, J., Sergeant, J. A., & Buitelaar, J. K. (2005). Does methylphenidate improve inhibition and other cognitive abilities in adults with childhood-onset ADHD? *Journal of Clinical and Experimental Neuropsychology, 27*, 278-298.

Borkowski, J. G., & Burke, J. E. (1996). Theoris, models, and measurements of executive functioning: An information processing perspective. In G. R. Lyon & N. A. Krasnegor (Eds.), *Attention, memory, and executive function* (pp. 235-261). Baltimore, MD: Paul Brookes.

Brocki, K. C., & Bohlin, G. (2004). Executive functions in children aged 6 to 13: A dimensional and developmental study. *Developmental Neuropsychology, 26*, 571-593.

Bridgett, D. J., & Walker, M. E. (2006). Intellectual functioning in adults with ADHD: A meta-analytic examination of full scale IQ differences between adults with and without ADHD. *Psychological Assessment, 18*, 1-14.

Brown, T. E. (1996). *Brown Attention-Deficit Disorder Scales Manual.* San Antonio, TX: The Psychological Corporation.

Brown, T. E. (2006). Executive functions and attention deficit hyperactivity disorder: Implications of two conflicting views. *International Journal of Disability, Development and Education, 53*, 35-46.

Burgess, P.W., Alderman, A., Evans, J., Emslie, H., & Wilson, B.A. (1998). The ecological validity of tests of executive function. *Journal of the International Neuropsychological Society, 4*, 547-558.

Burgio-Murphy, A., Klorman, R., Shaywitz, S. E., Fletcher, J. M., Marchione, K. E., Holahan, J. et al., (2007). Error-related event-related potentials in children with attention-deficit hyperactivity disorder, oppositional defiant disorder, reading disorder, and math disorder. *Biological Psychology, 75*, 75-86.

Carter, C. S., Braver, T. S., Barch, D. M., Botvinick, M. M., Noll, D., Cohen, J. D. (1998). Anterior cingulated cortex, error detection and the on-line monitoring of performance. *Science, 280*, 747-749.

Carver, C. S. (2004). Self-regulation of action and affect. In R. F. Baumeister, & K. D. Uohs (Eds.), *Handbook of self-regulation: Research, theory, and applications* (pp. 13-39). New York, NY: The Guilford Press.

Carver, C. S., & Scheier, M. F. (2000). On the structure of behavioral self-regulation. In M. Boekaerts, P. R. Pintrich, & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 41-84). San Diego, CA: Academic Press.

Casey, B. J., Castellanos, F. X., Giedd, J. N., Marsh, W. L., Hamburger, S. D., Schubert, A. B., et al. (1997). Implication of right frontostriatal circuitry in response inhibition and attention-deficit/hyperactivity disorder. *Journal of the American Academy of Child and Adolescent Psychiatry, 36*, 374-383.

Castellanos, F. X., Margulies, D. S., Kelly, C., Uddin, L. Q., Ghaffari, M., Kirsch, A., et al. (2008). Cingulate-precuneus interactions: A new locus of dysfunction in adult attention-deficit/hyperactivity disorder. *Biological Psychiatry, 63*, 332-337.

Castellanos, F. X., Sonuga-Barke, E. J. S., Scheres, A., Di Martino, A., Hyde, C., & Walters, J. R. (2005). Varieties of attention-deficit/hyperactivity disorder-related intra-individual variability. *Biological Psychiatry, 57*, 1416-1423.

Ciesielski, K. T., Harris, R. J., & Cofer, L. F. (2004). Posterior brain ERP patterns related to the go/no-go task in children. *Psychophysiology, 41*, 882-892.

Clark, V. P., & Hillyard, S. A. (1996). Spatial selective attention affects early extrastriate but not striate components of the visual evoked potential. *Journal of Cognitive Neuroscience, 8*, 387-402.

Conners, C. K., Erhardt, D., & Sparrow, M. A. (1999). *Conners' Adult ADHD Rating Scales, Technical Manual.* New York: Multihealth Systems, Inc.

Corbetta, M., & Shulman, G. (2002). Control of goal-directed and stimulus-driven attention in brain. *Nature Reviews Neuroscience, 3*, 201-215.

Corno, L. (1994). Student volition and education: Outcomes, influences, and practices. In B. J. Zimmerman & D. H. Schunk (Eds.), *Self-regulation of learning and performance* (pp. 229-254). Hillsdale, NJ: Lawrence Erlbaum Associates.

Coull, J. T. (1998). Neural correlates of attention and arousal: Insights from electrophysiology, functional neuroimaging and psychopharmacology. *Progress in Neurobiology, 55*, 343–361.

Danckaerts, M., Heptinstall, E., Chadwick, O., & Taylor, E. (1999). Self-report of attention deficit and hyperactivity disorder in adolescents. *International Journal of Descriptive and Experimental Psychopathology, Phenomenology and Psychiatric Disorders, 32,* 81-92.

Davies, P. L., Segalowitz, S. J., Dywan, J., & Pailing, P. E. (2001). Error negativity and positivity as they relate to other ERP indices of attentional control and stimulus processing. *Biological Psychology, 56*, 191-206.

Davies, P. L., Se galowitz, S. J., & Gavin, W. J. (2004). Development of response-monitoring ERPs in 7- to 25-year-olds. *Developmental Neuropsychology, 25*, 355-376.

de Bruijn, E. R., Grootens, K. P., Verkes, R. J., Buchholz, V., Hummeln, J. W., & Hulstijn,W. (2006). Neural correlates of impulsive responding in borderline personality disorder: ERP evidence for reduced action monitoring. *Journal of Psychiatric Research, 40*, 428-437.

Derryberry, D., & Rothbart, M. K. (1988). Arousal, affect, and attention as components of temperament. *Journal of Personality and Social Psychology, 55*, 958-966.

Diehl, M., Semegon, A. B., & Schwarzer, R. (2006). Assessing attention control in goal pursuit: A component of dispositional self-regulation. *Journal of Personality Assessment, 86*, 306-317.

Dimoska, A., Johnstone, S. J., Barry, R. J., & Clarke, A. R. (2003). Inhibitory motor control in children with attention-deficit/hyperactivity disorder: Event-related potentials in the stop-signal paradigm. *Biological Psychiatry, 54*, 1340-1349.

Durston, S. (2003). A review of the biological bases of ADHD: What have we learned from imaging studies? *Mental Retardation and Developmental Disabilities Research Reviews, 9*, 184-195.

Eimer, E. (1994). An ERP study on visual-spatial priming with peripheral onsets. *Psychophysiology, 31*, 154-163.

Endler, N. S., & Kocovski, N. L. (2000). Self-regulation and distress in clinical psychology. In M. Boekaerts, P. R. Pintrich, & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 569-599). San Diego, CA: Academic Press.

Falkenstein, M., Hohnsbein, J., Hoorman, J., & Blanke, L. (1990). Effects of error in choice reaction time tasks on the ERP under focused and divided attention. In: Brunia, C. H. M., Gaillard, A. W. K., & Kok, A. (Eds.), *Psychophysiological Brain Research* (pp. 192-195). Tilberg University Press, Tilberg.

Falkenstein, M., Hoorman, J., Christ, S., & Hohnsbein, J. (2000). ERP components on reaction errors and their functional significance: A tutorial. *Biological Psychology 51*, 87-107.

Fan, J., McCandliss, B. D., Sommer, T., Raz, M., & Posner, M. I. (2002). Testing the efficiency and independence of attentional networks. *Journal of Cognitive Neuroscience, 340*, 340-347.

Faraone, S. C. (2004). Etiology and pathophysiology of adult attention deficit hyperactivity disorder. *Primary Psychiatry, 11*, 28-40.

Faraone, S. V., Biederman, J., Doyle, A., Murray, K., Petty, C., Adamson, J. J., et al. (2006). Neuropsychological studies of late onset and subthreshold diagnoses of adult attention-deficit/hyperactivity disorder. *Biological Psychiatry, 60*, 1081-1087.

Faraone, S. V., Sergeant, J., Gillberg, C., & Biederman, J. (2003). The worldwide prevalence of ADHD: Is it an American condition? *World Psychiatry, 2*, 104-113.

Fayyad, J., DeGraaf, R., Kessler, R., Alonso, J., Angermeyer, M., Demyttenaere K., et al. (2007). Cross-national prevalence and correlates of adult attention-deficit/hyperactivity disorder. *British Journal of Psychiatry, 190*, 402-409.

Fernandez-Duque, D., Baird, J. A., & Posner, M. I. (2000). Executive attention and metacognitive regulation. *Consciousness and Cognition, 9*, 288-307.

Gehring, W. J. Gross, B., Coles, M. G. H., Meyer, D. E., & Donchin, E. (1993). A neural system for error detection and compensation. *Psychological Science, 4*, 385-390.

Harris, K. R., Reid, R. R., & Graham, S. (2004). Self-regulation among students with LD and ADHD. In B. Y. L. Wong (3rd Ed.), *Learning about learning disabilities* (pp. 167-195). San Diego, CA: Elsevier Academic Press.

Hays, J. R., Reas, D. L., Shaw, J. B. (2002). Concurrent validity of the Wechsler abbreviated scale of intelligence and the Kaufman brief intelligence test among psychiatric inpatients. *Psychological Reports, 90*, 355-359.

Herrmann, M. J., Rommler, J., Ehlis, A. C., Heidrich, A., & Fallgatter, A. J. (2004). Source localization (LORETA) of the error-related-negativity (ERN/Ne) and positivity (Pe). *Cognitive Brain Research, 20*, 294–299.

Hervey, A. S., Epstein, J. N., & Curry, J. F. (2004). Neuropsychology of adults with attention-deficit/hyperactivity disorder: A meta-analytic review. *Neuropsychology, 18*, 485-503.

Hester, R., Foxe, J. J., Molholm, S., Shpaner, M., & Garavan, H. (2005). Neural mechanisms involved in error processing: A comparison of errors made with and without awareness. *NeuroImage*, *27*, 602–608.

Hogan, A. M., Vargha-Khadem, F., Kirkham, F. J., & Baldeweg, T. (2005). Maturation of action monitoring from adolescence to adulthood: An ERP study. *Developmental Science*, *8*, 525-534.

Holroyd, C. B., & Coles, M. G. (2002). The neural basis of human error processing: Reinforcement learning, dopamine, and the error-related negativity. *Psychological Review 109*, 679-709.

Hopfinger, J. B., & Mangun, G. R. (1998). Reflexive attention modulates processing of visual stimuli in human extrastriate cortex. *Psychological Science, 9*, 441-447.

Hull, J. G., & Slone, L. B. (2004). Alcohol and self-regulation. In R. F. Baumeister, & K. D. Uohs (Eds.), *Handbook of self-regulation: Research, theory, and applications* (pp. 466-491). New York, NY: The Guilford Press.

Ingersoll, B. (1988). *Your hyperactive child.* New York: Doubleday.

Jodo, E., & Kayama, Y. (1992). Relation of a negative ERP component to response inhibition in a go/nogo task. *Electroencephalography & Clinical Neurophysiology, 28,* 477-482.

Johnston, C. (2002). The impact of attention deficit hyperactivity disorder on social and vocational functioning in adults. In P. S. Jensen & J. R. Cooper (Eds.), *Attention deficit hyperactivity disorder: State of the science and best practices* (Chapter 6, pp. 1-21). Kingston, NJ: Civic Research Institute.

Jones, L. B., Rothbart, M. K., & Posner, M. I. (2003). Development of executive attention in preschool children. *Developmental Science, 6,* 498-504.

Jonkman, L. M., Lansbergen, M., & Stauder, J. E. A. (2003). Developmental differences in behavioral and event-related brain responses associated with response preparation and inhibition in a go/nogo task. *Psychophysiology, 40,* 752-761.

Jonkman, L. M., van Melis, J. J. M., Kemner, C., & Markus, C. R. (2007). Methylphenidate improves deficient error evaluation in children with ADHD: An event-related brain potential study. *Biological Psychology, 76,* 217-229.

Kardash, C. M., & Amlund, J. T. (1991). Self-reported learning strategies and learning from expository text. Contemporary Educational Psychology, 16, 117-138.

Karoly, P. (1993). Mechanisms of self-regulation: A systems view. *Annual Review of Psychology, 44,* 23-52.

Kessler, R. C., Adler, L., Barkley, R., Biederman, J., Conners C. K., Demler, O., et al. (2006). The prevalence and correlates of adult ADHD in the United States: Results from the National Comorbidity Survey Republican. *American Journal of Psychiatry, 163,* 716-723.

Kieling, C., Goncalves, R. R. F., Tannock, R., & Castellanos, F. X. (2008). Neurobiology of attention deficit hyperactivity disorder. *Child and Adolescent Psychiatric Clinics of North America, 17,* 285-307.

Leth-Steensen, C., Elbaz, Z. K., & Douglas, V. I. (2000). Mean response times, variability, and skew in the responding of ADHD children: A response time distributional approach. *Acta Psychologica, 104,* 167-190.

Liotti, M., Pliszka, S. R., Perez, R., Kothmann, D., & Woldorff, M. G. (2005). Abnormal brain activity related to performance monitoring and error detection in children with ADHD. *Cortex, 41*, 377-388.

Luck, S. J. (1995). Multiple mechanisms of visual-spatial attention: Recent evidence from human electrophysiology. *Behavioural Brain Research, 71*, 113-123.

Luszczynska, A., Diehl, M., Gutiérrez-Doña, B., Kuusinen, P., & Schwarzer, R. (2004). Measuring one component of dispositional self-regulation: Attentional control in goal pursuit. *Personality and Individual Differences, 37*, 555-566.

Luu, P., Collins, P., Tucker, D.M., 2000. Mood, personality, and self-monitoring: Negative affect and emotionality in relation to frontal lobe mechanisms of error monitoring. *Journal of Experimental Psychology and Genetics, 129*, 43-60.

Luu, P., Tucker, D. M., Derryberry, D., Reed, M., & Poulsen, C. (2003). Electrophysiological responses to errors and feedback in the process of action regulation. *Psychological Science, 14*, 47-53.

MacLaren, V. V., Taukulis, H. K., & Best, L. A. (2007). Inhibitions in adults with attention-deficit/hyperactivity disorder: Event-related potentials in the stop task. *Applied Psychophysiology and Biofeedback, 32*, 155-162.

Maes, S., & Gebhardt, W. (2000). Self-regulation and health behavior: The health behavior goal model. In M. Boekaerts, P. R. Pintrich, & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 343-348). San Diego, CA: Academic Press.

McPherson, D. L., & Salamat, M. T. (2004). Interactions among variables in the P300 response to a continuous performance task in normal and ADHD adults. *Journal of the American Academy of Audiology, 15*, 666-677.

Malloy-Diniz, L., Fuentes, D., Lette, B. W., Correa, H., & Bechara, A. (2007). Impulsive behavior in adults with attention deficit/hyperactivity disorder: Characterization of attentional, motor and cognitive impulsiveness. *Journal of the International Neuropsychological Society, 13*, 693-698.

Mahone, E.M., Cirino, P.T., Cutting, L.E., Cerrone, P.M., Haelthorn, K.M., Hiemenz, J.R., et al. (2002). Validity of the behavior rating inventory of executive function of ADHD and/or Tourette's syndrome. *Clinical Neuropsychology, 17,* 644-662.

Mangun, G. R., & Hillyard, S. A. (1990). Allocation of visual-attention to spatial locations: Tradeoff functions for event-related brain potentials and detection performance. *Perception & Psychophysics, 47*, 532-550.

Mannuzza, S., Klein, R. G., Bessler, A., Malloy, P., & LaPadula, M. (1993). Adult outcome of hyperactive boys: Educational achievement, occupational rank, and psychiatric status. *Archives of General Psychiatry, 50*, 577-584.

Mather, N., Schrank, F. A., & Woodcock, R. W. (2007). Examiner's Manual. *Woodcock-Johnson III Tests of Achievement Form C/Brief Battery*. Rolling Meadows, IL: Riverside Publishing.

Mather, N., & Woodcock, R. W. (2001). *Examiner's manual: Woodcock-Johnson III test of achievement*. Itasca, IL: Riverside Publishing.

Mathewson, K., Dywan, J., & Segalowitz, S. J. (2005). Brain bases of error-related ERPs as influenced by age and task. *Biological Psychology, 70*, 88-104.

Matthew, G., Schwean, V. L., Campbell, S. E., Saklofske, D. H., Mohamed, A. A. R. (2000). Personality, self-regulation, and adaptation: A cognitive-social framework. In M. Boekaerts, P. R. Pintrich, & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 171-207). San Diego, CA: Academic Press.

McCallum, W. C. (1988). Potentials related to expectancy, preparation and motor activity. In T. W. Picton (Ed). *Human Event-Related Potentials, EEG Handbook* (revised series, vol. 3, pp. 427-534). Amsterdam: Elsevier Science.

Müller, B., W., Gimbel, K., Keller-Plieβnig, A., Sartory, G., Gastpar, M., & Davids, E. (2007). Neuropsychological assessment of adult patients with attention-deficit/hyperactivity disorder. *European Archives of Psychiatry and Clinical Neuroscience, 257*, 112-119.

National Institute of Health. (1998). *Diagnosis and treatment of attention-deficit/hyperactivity disorder*. NIH Consensus Statement, 16(2). Washington, DC: US Government Printing Office.

Nieuwenhuis, S., Ridderinkhof, K. R., Blom, J., Band, G. P., & Kok, A. (2001). Error-related brain potentials are differentially related to awareness of response errors: Evidence from an antisaccade task. *Psychophysiology, 38*, 752-760.

Nigg, J. T. (2005). Neuropsychological theory and findings in attention-deficit/hyperactivity disorder: The state of the field and salient challenges for the coming decade. *Biological Psychiatry, 57*, 1424-1435.

Nigg, J. T., Stavro, G., Ettenhofer, M., Hambrick, D. Z., Miller, T., & Henderson, J. M. (2005). Executive functions and ADHD in adults: Evidence for selective effects on ADHD symptom domains. *Journal of Abnormal Psychology, 114*, 706-717.

O'Connell, R. G., Dockree, P. M., Bellgrove, M. A., Kelly, S. P., Hester, R., Garavan, H., et al. (2007). The role of cingulate cortex in the detection of errors with and without awareness: A high-density electrical mapping study. *European Journal of Neuroscience, 25*, 2571-2579.

Otten, L. J., & Rugg, M. D. (2005). Interpreting even-related brain potentials. In T. C. Handy (Eds.), *Event-related potentials: A methods handbook* (pp.3-16). Cambridge, MA: The MIT Press.

Overbeek, T. J. M., Nieuwenhuis, S., Ridderinkhof, K. R. (2005). Dissociable components of error processing. *Journal of Psychophysiology, 19*, 319-329.

Overtoom, C. C. E., Kenemans, J. L., Verbaten, M. N., Kemner, C., van der Molen, M. W., van Engeland, H., et al. (2002). Inhibition in children with attention-deficit/hyperactivity disorder: A psychophysiological study of the stop task. *Biological Psychiatry, 51*, 668-676.

Pailing, P. E., & Segalowitz, S. J. (2004). The effects of uncertainty in error monitoring on associated ERPs. *Brain and Cognition, 56*, 215-233.

Perchet, C., & Garcia-Larrea, L. (2005). Learning to react: Anticipatory mechanisms in children and adults during a visuospatial attention task. *Clinical Neurophysiology, 116*, 1906-1917.

Perchet, C., Revol, O., Fourneret, P., Mauguière, F., & Garcia-Larrea, L. (2001). Attention shifts and anticipatory mechanisms in hyperactive children: An ERP study using the Posner paradigm. *Biological Psychiatry, 50*, 44-57.

Picton, T. W. (1992). The P300 wave of the human event-related potential. *Journal of Clinical Neurophysiology, 9*, 456-479.

Pintrich, P. R. (2000a). Issues in self-regulation theory and research. *The Journal of Mind and Behavior, 21*, 213-220.

Pintrich, P. R. (2000b). The role of goal orientation in self-regulated learning. In M. Boekaerts, P. R. Pintrich, & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 451-502). San Diego, CA: Academic Press.

Pintrich, P. R. (2003). A motivational science perspective on the role of student motivation in learning and teaching contexts. *Journal of Educational Psychology, 95*, 668-686.

Pintrich, P. R., Smith, D. A. F., Garcia, T., & McKeachie, W. J. (1991). *A manual for the use of the motivated strategies learning questionnaire (MSLQ)*. Ann Arbor, MI: University of Michigan, National Center for Research to Improve Postsecondary Teaching and Learning.

Polich, J. (1993). Cognitive brain potentials. *Current directions in Psychological Science: A Journal of the American Psychological Society 2,* 175-179.

Posner, M. I., & Cohen, Y. (1984). Components of visual orienting. In Bouma, H. and Bouwhuis, D.G. (Eds), *Attention and performance X* (pp. 531-556). Hillsdale, NJ: Lawrence Erlbaum and Associates.

Rabbitt, P. M. (1966). Errors and error correction in choice-response tasks. *Journal of Experimental Psychology, 71*, 264-272.

Rabin, L.A., Roth, R.M., Isquith, P.K., Wishart, H.A., Nutter-Upham, K.E., Pare, N., et al., (2006). Self- and informant reports of executive function on the BRIEF-A in MCI and older adults with cognitive complaints. *Clinical Neuropsychology, 21*, 721-732.

Richards, J. E. (2005). Attention. In B. Hopkins with R. G. Barr, G. F. Michel, & P. Rochat (Eds.), *The Cambridge encyclopedia of child development* (pp. 282-286). New York: Cambridge University Press.

Roderiguez, P. D., & Baylis, G. C. (2007). Activation of brain attention systems in individuals with symptoms of ADHD. *Behavioural Neurology, 18*, 115-130.

Roth, R.M., Isquith, P.K., & Gioia, G.A. (2005). *BRIEF-A: Behavior Rating Inventory of Executive Functions-Adult Version.* Lutz, FL: Psychological Assessment Resources.

Rothbart, M. K., Ahadi, S. A., & Evans, D. E. (2000). Temperament and personality: Origins and outcomes. *Journal of Personality and Social Psychology, 78*, 122-135.

Rothbart, M. K., Ellis, L. K., & Posner, M. I. (2004). Temperament and self-regulation. In R. F. Baumeister, & K. D. Uohs (Eds.), *Handbook of self-regulation: Research, theory, and applications* (pp. 357-370). New York, NY: The Guilford Press.

Ruchsow, M., Spitzer, M., Gron, G., Grothe, J., & Kiefer, M. (2005). Error processing and impulsiveness in normals: Evidence from event-related potentials. *Cognitive Brain Research, 24*, 317-325.

Ruchsow, M., Walter, H., Buchheim, A., Martius, P., Spitzer, M., Kachele, H., et al., (2006). Electrophysiological correlates of error processing in borderline personality disorder. *Biological Psychology, 72*, 133-140.

Rueda, M. R., Posner, M. I., & Rothbart, M. K. (2005). The development of executive attention: Contributions to the emergence of self-regulation. *Developmental Neuropsychology, 28*, 573-594.

Sanders, A. F. (1983). Towards a model of stress and human performance. *Acta Psychologica, 53*, 61–97.

Santesso, D. L., & Segalowitz, S. J. (2008). Development of rrror-related ERPs in middle to late adolescent males. *Developmental Psychology, 44*, 205-217.

Scahill, L., & Schwab-Stone, M. (2000). Epidemiology of ADHD in school-age children. *Child and Adolescent Psychiatric Clinics of North America, 9*, 541-555.

Schachar, R. J., Chen, S., Logan, G. D., Ornstein, T. J., Crosbie, J., Ickowicz, A., & Pakulak, A. (2004). Evidence for an error monitoring deficit in attention deficit hyperactivity disorder. *Journal of Abnormal Child Psychology, 32*, 285-293.

Schoechlin, C., & Engel, R. R. (2005). Neuropsychological performance in adult attention-deficit hyperactivity disorder: Meta-analysis of empirical data. *Archives of Clinical Neuropsychology, 20*, 727-744.

Schrank, F. A., & Woodcock, R. W. (2007). Woodcock-Johnson III Normative Update Compuscore and Profiles Program (Version 3.0) [Computer software]. *Woodcock-Johnson III Normative Update*. Rolling Meadows, IL: Riverside Publishing.

Schraw, G., & Dennison, R. S. (1994). Assessing metacognitive awareness. *Contemporary Educational Psychology, 19*, 460-475.

Schunk, D. H., & Zimmerman, B. J. (Eds.). (1998). *Self-regulated learning: From teaching to self-reflective practice*. New York, NY: The Guilford Press.

Schunk, D. H., & Zimmerman, B. J. (2003). Self-regulation and learning. In W. M. Reynolds & G. E. Miller (Eds.), *Handbook of psychology, Vol. 7* (pp. 59-78). Hoboken, NJ: John Wiley and Sons.

Schwarzer, R., Diehl, M., & Schmitz, G. S. (1999). *Self-Regulation Scale*. From http://www.fu-berlin.de/gesund/skalen

Seidman, L. J., Valera, E. M., Makris, N., Monuteaux, M. C., Boriel, D. L., Kelkar, K., et al. (2006). Dorsolateral prefrontal and anterior cingulate cortex volumetric abnormalities in adults with attention-deficit/hyperactivity disorder identified by magnetic resonance imaging. *Biological Psychiatry, 60*, 1071-1080.

Sergeant, J. A., Geurts, H., Huijbregts, S., Scheres, A., & Oosterlaan, J. (2003). The top and the bottom of ADHD: A neuropsychological perspective. *Neuroscience and Behavioral Reviews, 27*, 583-592.

Sergeant, J. A., Geurts, H., & Oosterlaan, J. (2002). How specific is a deficit of executive functioning for attention-deficit/hyperactivity disorder? *Behavioural Brain Research, 130*, 3-28.

Smith, J. L., Johnstone, S. J., & Barry, R. J. (2003). Aiding diagnosis of attention-deficit/hyperactivity disorder and its subtypes: Discriminant function analysis of event-related potential data. *Journal of Child Psychology and Psychiatry, 44*, 1067-1075.

Sobanski, E., Brüggemann, D., Alm, B., Kern, S., Deschner, M., Schubert, T., et al. (2007). Psychiatric comorbidity and functional impairment in a clinically referred sample of adults with attention-deficit/hyperactivity disorder (ADHD). *European Archives of Psychiatry and Clinical Neuroscience, 257*, 371-377.

Sobanski, E., Brüggemann, D., Alm, B., Kern, S., Philipsen, A., Schmalzried, H., et al. (2008). Subtype differences in adults with attention-deficit/hyperactivity disorder (ADHD) with regard to ADHD-symptoms, psychiatric comorbidity and psychosocial adjustment. *European Psychiatry, 23*, 142-149.

Sparks, R., L., Javorsky, J., & Philips, L. (2004). College students classified with ADHD and the foreign language requirement. *Journal of Learning Disabilities, 37*, 169-178.

Spencer, K. M. (2005). Averaging, detection, and classification of single-trial ERPs. In T. C. Handy (Eds.), *Event-related potentials: A methods handbook* (pp.209-227). Cambridge, MA: The MIT Press.

Spencer, T., Biederman, J., Wilens, T., Doyle, R., Surman, C., Rrince, J., et al. (2005) A large, double-blind, randomized clinical trial of methylphenidate in the treatment of adults with attention-deficit/hyperactivity disorder. *Biological Psychiatry, 57*, 456-463.

Stavro, G. M., Ettenhofer, M. L., & Nigg, J. T. (2007). Executive functions and adaptive functioning in young adult attention-deficit/hyperactivity disorder. *Journal of the International Neuropsychological Society, 13*, 324-334.

Tecce, J. J. (1972). Contingent negative variation (CNV) and psychological processes in man. *Psychological Bulletin, 77*, 73– 108.

Turner, D. C., Clark, L., Dowson, J., Robbins, T. W., & Sahakian, B. J. (2004). Modafinil improves cognition and response inhibition in adult attention-deficit/hyperactivity disorder. *Biological Psychiatry, 55*, 1031-1040.

van Boxtel, G. J. M., van der Molen, M.W., & Jennings, J. R. (2005). Differential involvement of the anterior cingulate cortex in performance monitoring during a stop-signal task. *Journal of Psychophysiology, 19*, 1-10.

van Meel, C. S., Heslenfeld, D. J., Oosterlaan, J., & Sergeant, J. A. (2007). Adaptive control deficits in attention-deficit/hyperactivity disorder (ADHD): The role of error processing. *Psychiatry Research, 151*, 211-220.

van Veen, V., & Carter, C. S. (2002). The timing of action-monitoring processes in the anterior cingulate cortex. *Journal of Cognitive Neuroscience, 14*, 593-602.

Vidal, F., Hasbroucq, T., Grapperon, J., & Bonnet, M. (2000). Is the 'error negativity' specific to errors? *Biological Psychology, 51*, 109-128.

Vogel, E. K., & Luck, S. J. (2000). The visual N1 component as an index of a discrimination process. *Psychophysiology,37*,190-203 .

Vohs, K. D., & Baumeister, R. F. (2004). Understanding self-regulation: An introduction. In R. F. Baumeister, & K. D. Uohs (Eds.), *Handbook of self-regulation: Research, theory, and applications* (pp. 1-9). New York, NY: The Guilford Press.

Wechsler, D. (1999). *Manual for the Wechsler Abbreviated Scale of Intelligence*. San Antonio, TX: The Psychological Corporation.

Weiss, G., Hechtman, L., Milroy, T., & Perlman, T. (1985). The Wender Utah rating scale: An aid in the retrospective diagnosis of childhood attention deficit hyperactivity disorder. *American Journal of Psychiatry, 150*, 885-890.

Weiss, M., & Murray, C. (2003). Assessment and management of attention-deficit hyperactivity disorder in adults. *Canadian Medical Association Journal, 168*, 715-722.

Weyandt, L. L., & DuPaul, G. (2006). ADHD in college students. *Journal of Attention Disorders, 10*, 9-19.

Wiersema, R., van der Meere, J., Antrop, I., & Roeyers, H. (2006). State regulation in adult ADHD: An event-related potential study. *Journal of Clinical and Experimental Neuropsychology, 28*, 1113-1126.

Wiersema, R., van der Meere, J., & Roeyers, H. (2005). ERP correlates of impaired error monitoring in children with ADHD. *Journal of Neural Transmission, 112*, 1417–1430.

Willcutt, E. G., Doyle, A. E., Nigg, J. T., Faraone, S. V., & Pennington, B. F. (2005). Validity of the executive function theory of attention-deficit/hyperactivity disorder: A meta-analytic review. *Biological Psychiatry, 57*, 1336-1346.

Willcutt, E. G., Betjemann, R. S., Pennington, B. F., Olson, R. K., DeFries, J. C., & Wadsworth, S. J. (2007). Longitudinal study of reading disability and attention-deficit/hyperactivity disorder: Implications for education. *Mind, Brain, and Education, 1*, 181-192.

Woodcock, R. W., Schrank, F. A., Mather, N., & McGrew, K. S. (2007). *Woodcock-Johnson III Tests of Achievement Form C/Brief Battery*. Rolling Meadows, IL: Riverside Publishing.

Yong-Liang, G., Robaey, P., Karayanidis, F., Bourassa, M., Pelletier, G., & Geoffroy, G. (2000). ERPs and behavioral inhibition in a go/no-go task in children with attention-deficit hyperactivity disorder. *Brain and Cognition, 43*, 215-220.

Yordanova, J., Falkenstein, M., Hohnsbein, J., & Kolev, V. (2004). Parallel systems of error processing in the brain. *NeuroImage, 22*, 590-602.

Zimmerman, B. J., & Martinez-Pons, M. (1988). Construct validation of a strategy model

of student self-regulated learning. *Journal of Educational Psychology, 80,* 284-290.
Zimmerman, B. J. (2000). Attaining self-regulation: A social cognitive perspective. In M. Boekaerts, P. R. Pintrich, & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 13-39). San Diego, CA: Academic Press.

Zimmerman, B. J., & Schunk, D. H. (Eds.). (2001). *Self-regulated learning and academic achievement: Theoretical perspectives* (2nd Ed.). Mahwah, NJ: Erlbaum.

APPENDIX A: Informed Consent

Informed Consent to Participate in a Research Study
Colorado State University

TITLE OF STUDY: The Relationship of Self-Regulation and Academic Achievement in College Students with and without Attention-Deficit/Hyperactivity Disorder: A Brain-Behavior Perspective

PRINCIPAL INVESTIGATOR: Patricia Davies, PhD, OTR, Associate Professor
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CO-PRINCIPAL INVESTIGATOR: Wen-Pin Chang, MS, OTR, PhD Candidate
School of Education
(970) 492-9130

WHY AM I BEING INVITED TO TAKE PART IN THIS RESEARCH? You are being invited to participate in this study because you are either healthy student with no known psychiatric or neurological disorders or student with attention-deficit/hyperactivity disorder (ADHD) in the appropriate age range and literate in English.

WHO IS DOING THE STUDY? This study is a PhD dissertation project led by Dr. Patricia L. Davies and Dr. George A. Morgan.

WHAT IS THE PURPOSE OF THIS STUDY? This is a research study to examine if inhibition abilities (how well a person suppresses unnecessary information or stops from making an unwanted response), attention abilities (how well a person can focus on a particular activity) and monitoring abilities (how well a person acknowledges their task performance or is aware of their mistakes) relate to a person's learning in classroom. Most people use these abilities to monitor or change their behaviors based on how well they did on that activity, something that we call self-regulation. We are trying to determine if a person's ability or inability to self-regulate in daily life activities relates to the capacity to learn. This study is designed to investigate the relationship between ability to self-regulate and learning capabilities in college students with and without ADHD. The results of this study will assist us to better understand learning difficulties that are observed in college students with ADHD and possibly develop intervention strategies.

WHERE IS THE STUDY GOING TO TAKE PLACE AND HOW LONG WILL IT LAST? This study will take place in the Human Development Lab in the Gifford Building at Colorado State University and will last around 2.5 – 3 hours. This will occur during either one or two visits to the lab. The visits will be scheduled at times that are maximally convenient for you.

WHAT WILL I BE ASKED TO DO? We will record your brain activity, an electroencephalogram (EEG), while you participate in some computer tasks. A cap, similar to a bathing cap with EEG sensors will be placed on your head. The sensors rest on the scalp and record the brain activity. In order for the sensors to record brain activity, a gel is placed between the sensor and your scalp. The gel is water based and will wash out easily. The EEG portion will last about 1 hour long, 5 minutes for explanation, about 15 minutes for placing the sensors, about 35 minutes for three computer tasks, and about 5 minutes for removing the sensors. During the EEG

recording, there will be 3 computer tasks involving in button-pressing when a correct visual stimulus is presented on the computer screen. Following the EEG data collection, the cap will be removed.

The second portion of this study will involve two pencil and paper assessments that are designed to measure your thinking and academic learning abilities and several questionnaires that are designed to measure your self-regulation abilities. The pencil and paper tasks for measuring your thinking abilities will be about 20 minutes, while for academic learning skills will last about 40 minutes. You will be asked to fill out six questionnaires which will tell us about your ability to self-regulate during daily life activities and report about behaviors that may be symptoms of ADHD or other neuropsychiatric behaviors and this will take about 30 ~ 45 minutes total. In addition, we will ask some questions about personal information such as your birth date, gender, ethnic background, and education level.

ARE THERE REASONS WHY I SHOULD NOT TAKE PART IN THIS STUDY? The only reason that you should not take part in this study is if you are not in the age range of 18-30 years of age or have any psychiatric or neurological disorders other than ADHD.

WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS? This research should not cause any physical harm to you. The EEG recordings and behavioral testing are performed according to standard practices. In placing scalp or other skin-surface sensors it is possible that you may experience slight tenderness in the spot where the skin surface was cleaned prior to placing the sensor, especially if you have very sensitive skin, however, this soon disappears. Please inform us if you have a history of fainting in the doctor's office or other location when excited or if you suffer from a sodium or nutritional deficiency. It is not possible to identify all possible risks in research activities, but the investigators have taken reasonable safeguards to minimize any known and possible, but unknown, risks.

ARE THERE ANY BENEFITS FROM TAKING PART IN THIS STUDY? There are no direct benefits for participants. However, we find that participants typically find seeing their brain activity displayed on the screen an interesting experience. The results from this research will help us understand brain functions and behavior performance associated with self-regulation and learning in adults with and without ADHD.

DO I HAVE TO TAKE PART IN THE STUDY? Your participation in this research is voluntary. If you decide to participate in the study, you may withdraw your consent and stop participating at any time without penalty or loss of benefits to which you are otherwise entitled.

WHAT WILL IT COST ME TO PARTICIPATE? There are no direct costs for your participation other than the time you spend participating in the research study.

WHO WILL SEE THE INFORMATION THAT I GIVE?
We will keep private all research records that identify you, to the extent allowed by law. Your information will be combined with information from other people taking part in the study. When we write about the study to share it with other researchers, we will write about the combined information we have gathered. You will not be identified in these written materials. We may publish the results of this study; however, we will keep you name and other identifying information private. All data will be only identified by a

participant code and not by name or any other personal information in the computer or written forms. An example of the code that will be used is SR001 (SR=self-regulation project and 001=represents the number of this participant). We will make every effort to prevent anyone who is not on the research team from knowing that you gave us information, or what that information is. For example, your name will be kept separate from your research records and these two things will be stored in different places under lock and key. You should know, however, that there are some circumstances in which we may have to show your information to other people. For example, the law may require us to show your information to a court.

CAN MY TAKING PART IN THE STUDY END EARLY? You may be removed from the study if you do not meet the criteria for participation or do not finish all of the tests.

WILL I RECEIVE ANY COMPENSATION FOR TAKING PART IN THIS STUDY? You will receive a T-shirt, mug, or 10 dollars for participating in this study.

WHAT HAPPENS IF I AM INJURED BECAUSE OF THE RESEARCH? The Colorado Governmental Immunity Act determines and may limit Colorado State University's legal responsibility if an injury happens because of this study. Claims against the University must be filed within 180 days of the injury.

WHAT IF I HAVE QUESTIONS? Before you decide whether to accept this invitation to take part in the study, please ask any questions that might come to mind now. Later, if you have questions about the study, you can contact the investigator, Patti Davies at 970-491-7294. If you have any questions about your rights as a volunteer in this research, contact Janell Barker, Human Research Administrator at 970-491-1655. We will give you a copy of this consent form to take with you.

WHAT ELSE DO I NEED TO KNOW? Your participation in this research is voluntary. If you decide to participate in the study, you may withhold your consent and you may stop participating at any time without penalty or loss of benefits to which you are otherwise entitled. Your signature acknowledges that you have read the information stated and willingly sign this consent form. Your signature also acknowledges that you have received, on the date signed, a copy of this document containing 3 pages.

__________________________________ ________________
Signature of person agreeing to take part in the study Date

____
Printed name of person agreeing to take part in the study

__________________________________ ________________
Name of person providing information to participant Date

____
Signature of Research Staff

APPENDIX B: Adult Demographic Questionnaire

Adult Demographic Screening Questionnaire

Today's Date: ____________ Age: __________ Date of birth: __________

Please check your gender: _____ Male _____ Female

Your current educational level ______ Are you a first generation college student? __Yes___No

Your parents' educational level: Father______________ Mother______________

The following questions provide us with some information on your learning abilities.
Please answer YES (Y) or NO (N) or Don't Know (D) to the questions.

1. Have you ever been diagnosed by a professional (doctor, psychologist, diagnostician) as having a problem with any of the following?
   a) Reading Disability __________
   b) Learning Problem __________
   c) Depression ______________
   d) Delayed Speech ______________
   e) Stuttering _____________
   f) Other Speech and Language Impairments _____________
   g) Attention Deficit Disorder or Hyperactivity _______________
   h) Sensory Processing Difficulties _____________________
2. Have you ever experienced a head injury or concussion? ____________
   If yes, were you unconscious at the time? __________
   If yes, for how long approximately? __________
   Were you hospitalized at the time for the injury? __________
3. Have you ever had a fainting episode? _____
   If yes, please explain. ____
4. Have you ever been diagnosed with a neurological or psychiatric disorder such as seizures, epilepsy, or depression? ________ Or family history of any of these?________
   If yes, please explain. ____
5. Are you on any prescription medication? ___________
   If so, please write the type of medication that you take. __________________
   Frequency of the medication _______________
   When was the last time you took the medication _______________

Please answer the following questions about hand preference.

6. Are you right or left handed? _____________
7. Which hand do you write with? _______________
8. Do you use one hand for some activities and the other of other activities? ______

What is your ethnic and racial background? Please check the all that apply.
Note: This information is required for reporting to our funding agencies.

9. Ethnicity: _______ Hispanic or Latino _______ Not Hispanic or Latino

10. Race: _____ American Indian/Alaska Native _____ Asian
    _____ Native Hawaiian/other Pacific Islander _____ Black/African American
    _____ White _____ Other, please specify_______

APPENDIX C: Adult Temperament Questionnaire

ADULT TEMPERAMENT QUESTIONNAIRE – LONG FORM EFFORTFUL CONTROL DIMENSION

Subject ID: ________________

Directions

On the following pages you will find a series of statements that individuals can use to describe themselves. There are no correct or incorrect responses. All people are unique and different, and it is these differences which we are trying to learn about. Please read each statement carefully and give your best estimate of how well it describes you. Circle the appropriate number below to indicate how well a given statement describes you.

circle #:	if the statement is:
1	extremely untrue of you
2	quite untrue of you
3	slightly untrue of you
4	neither true nor false of you
5	slightly true of you
6	quite true of you
7	extremely true of you

If one of the statements does not apply to you (for example, if it involves driving a car and you don't drive), then circle "X" (not applicable). Check to make sure that you have answered every item.

1. If I want to, it is usually easy for me to keep a secret.
   1 2 3 4 5 6 7 X

2. It is easy for me to hold back my laughter in a situation when laughter wouldn't be appropriate.
   1 2 3 4 5 6 7 X

3. When I see an attractive item in a store, it's usually very hard for me to resist buying it.
   1 2 3 4 5 6 7 X

4. I can easily resist talking out of turn, even when I'm excited and want to express an idea.
   1 2 3 4 5 6 7 X

5. When I decide to quit a habitual behavioral pattern that I believe to be undesirable, I am usually successful.
   1 2 3 4 5 6 7 X

6. When I'm excited about something, it's usually hard for me to resist jumping right into it before I've considered the possible consequences.
1 2 3 4 5 6 7 X

7. Even when I feel energized, I can usually sit still without much trouble if it's necessary.
1 2 3 4 5 6 7 X

8. I often avoid taking care of responsibilities by indulging in pleasurable activities.
1 2 3 4 5 6 7 X

9. At times, it seems the more I try to restrain a pleasurable impulse (e.g., eating candy), the more likely I am to act on it.
1 2 3 4 5 6 7 X

10. I usually have trouble resisting my cravings for food drink, etc.
1 2 3 4 5 6 7 X

11. It is easy for me to inhibit fun behavior that would be inappropriate.
1 2 3 4 5 6 7 X

12. I usually finish doing things before they are actually due (e.g., paying bills, finishing homework, etc.).
1 2 3 4 5 6 7 X

13. I am often late for appointments.
1 2 3 4 5 6 7 X

14. I often make plans that I do not follow through with.
1 2 3 4 5 6 7 X

15. As soon as I have decided upon a difficult plan of action, I begin to carry it out.
1 2 3 4 5 6 7 X

16. If I think of something that needs to be done, I usually get right to work on it.
1 2 3 4 5 6 7 X

17. I can make myself work on a difficult task even when I don't feel like trying.
1 2 3 4 5 6 7 X

18. Even when I have enough time to complete an activity today, I often tell myself that I will do it tomorrow.
1 2 3 4 5 6 7 X

19. If I notice I need to clean or wash something (e.g., car, apartment, laundry, etc.), I often put it off until tomorrow.

1 2 3 4 5 6 7 X

20. I hardly ever finish things on time

1 2 3 4 5 6 7 X

21. I usually get my responsibilities taken care of as soon as possible.

1 2 3 4 5 6 7 X

22. When I am afraid of how a situation might turn out, I usually avoid dealing with it.

1 2 3 4 5 6 7 X

23. I can keep performing a task even when I would rather not do it.

1 2 3 4 5 6 7 X

24. When I am sad about something, it is hard for me to keep my attention focused on a task.

1 2 3 4 5 6 7 X

25. When I am anxious about the outcome of something, I have a hard time keeping my attention focused on a task.

1 2 3 4 5 6 7 X

26. It is very hard for me to focus my attention when I am distressed.

1 2 3 4 5 6 7 X

27. When I am happy and excited about an upcoming event, I have a hard time focusing my attention on tasks that require concentration.

1 2 3 4 5 6 7 X

28. When I am especially happy, I sometimes have a hard time concentrating on tasks that require me to keep track of several things at once.

1 2 3 4 5 6 7 X

29. When I hear good news, my ability to concentrate on taking care of my responsibilities goes out the window.

1 2 3 4 5 6 7 X

30. When I am trying to focus my attention, I am easily distracted.

1 2 3 4 5 6 7 X

31. When trying to focus my attention on something, I have difficulty blocking out distracting thoughts.

1 2 3 4 5 6 7 X

32. When trying to study something, I have difficulty tuning out background noise and concentrating.

1 2 3 4 5 6 7 X

33. When interrupted or distracted, I usually can easily shift my attention back to whatever I was doing before.

1 2 3 4 5 6 7 X

34. I am usually pretty good at keeping track of several things that are happening around me.

1 2 3 4 5 6 7 X

35. It's often hard for me to alternate between two different tasks.

1 2 3 4 5 6 7 X

APPENDIX D: Self-Regulation Scale

Self-Regulation Scale

Subject ID: ________________

Please rate the following questions based on the scale.

1. I can concentrate on one activity for a long time, if necessary.

1	2	3	4
Not at all true	Barely true	Somewhat true	Completely true

2. If I am distracted from an activity, I don't have any problem coming back to the topic quickly.

1	2	3	4
Not at all true	Barely true	Somewhat true	Completely true

3. If an activity arouses my feelings too much, I can calm myself down so that I can continue with the activity soon.

1	2	3	4
Not at all true	Barely true	Somewhat true	Completely true

4. If an activity requires a problem-oriented attitude, I can control my feelings.

1	2	3	4
Not at all true	Barely true	Somewhat true	Completely true

5. It is difficult for me to suppress thoughts that interfere with what I need to do. (–)

1	2	3	4
Not at all true	Barely true	Somewhat true	Completely true

6. I can control my thoughts from distracting me from the task at hand.

1	2	3	4
Not at all true	Barely true	Somewhat true	Completely true

7. When I worry about something, I cannot concentrate on an activity. (–)

1	2	3	4
Not at all true	Barely true	Somewhat true	Completely true

8. After an interruption, I don't have any problem resuming my concentrated style of working.

1	2	3	4
Not at all true	Barely true	Somewhat true	Completely true

9. I usually have a whole bunch of thoughts and feelings that interfere with my ability to work in a focused way. (–)

1	2	3	4
Not at all true	Barely true	Somewhat true	Completely true

10. I stay focused on my goal and don't allow anything to distract me from my plan of action.

1	2	3	4
Not at all true	Barely true	Somewhat true	Completely true

APPENDIX E: Motivated Strategies for Learning Questionnaire

Motivated Strategies for Learning Questionnaire (MSLQ)

Subject ID: ________________

Please rate the following questions based on the scale.

Not at all true of me			Neutral			Very true of me
1	2	3	4	5	6	7

1. During class time I often miss important points because I'm thinking of other things.
   1 2 3 4 5 6 7

2. When reading for this course, I make up questions to help focus my reading.
   1 2 3 4 5 6 7

3. I often feel so lazy or bored when I study for this class that I quit before I finish what I planned to do.
   1 2 3 4 5 6 7

4. When I become confused about something I'm reading for this class, I go back and try to figure it out.
   1 2 3 4 5 6 7

5. If course readings are difficult to understand, I change the way I read the material.
   1 2 3 4 5 6 7

6. I work hard to do well in this class even if I don't like what we are doing.
   1 2 3 4 5 6 7

7. Before I study new course material thoroughly, I often skim it to see how it is organized.
   1 2 3 4 5 6 7

8. I ask myself questions to make sure I understand the material I have been studying in this class.
   1 2 3 4 5 6 7

9. I try to change the way I study in order to fit the course requirements and the instructor's teaching style.
   1 2 3 4 5 6 7

10. I often find that I have been reading for this class but don't know what it was all about.
    1 2 3 4 5 6 7

11. When course work is difficult, I either give up or only study the easy parts.
    1 2 3 4 5 6 7

12. I try to think through a topic and decide what I am supposed to learn from it rather than just reading it over when studying.
    1 2 3 4 5 6 7

13. Even when course materials are dull and uninteresting, I manage to keep working until I finish.
    1 2 3 4 5 6 7

14. When studying for this course I try to determine which concepts I don't understand well.
    1 2 3 4 5 6 7

15. When I study for this class, I set goals for myself in order to direct my activities in each study period.
    1 2 3 4 5 6 7

16. If I get confused taking notes in class, I make sure I sort it out afterwards.
    1 2 3 4 5 6 7

APPENDIX F: Correlation Results

Relationships of Inhibition Components and Behavioral Indicators of Self-regulation

Relationship in Control Students

Behavioral rating inventory of executive function – adult version (BRIEF-A) inhibit. Pearson product-moment two-tailed correlation analysis revealed that two components, Pz go N2 amplitude: $r = -.435, p = .014$, and Pz no-go N2 latency: $r = -.402, p = .025$, were significantly related to BRIEF-A inhibit.

BRIEF-A shift. The result revealed that two components, Cz go P3 amplitude: $r = -.357, p = .048$, and Fz no-go P3 amplitude: $r = -.381, p = .034$, were significantly related to BRIEF-A shift.

BRIEF-A initiate. The result revealed that only Pz Go N2 amplitude: $r = -.459, p = .009$, was significantly related to BRIEF-A initiate.

BRIEF-A working memory. The result revealed that three components, Cz go N2 latency: $r = -.359, p = .047$, FCz go N2/P3 peak-to-peak amplitude: $r = -.362, p = .045$, and Fz go N2/P3 peak-to-peak amplitude: $r = -.392, p = .029$, were significantly related to BRIEF-A working memory.

BRIEF-A task monitor. The result revealed that two components were significantly related to BRIEF-A task monitor, which were Pz go P3 amplitude: $r = -.504, p = .004$, and Pz no-go P3 amplitude: $r = -.429, p = .016$.

BRIEF-A organization of materials, BRIEF-A metacognition index (MI), and BRIEF-A global executive composite (GEC). The Pz go N2 amplitude was the only component related to these three behavioral indicators (organization of materials: $r = -.373, p = .039$, MI: $r = -.461, p = .009$, GEC: $r = -.455, p = .010$).

Adult temperament questionnaire (ATQ) activation control. The result revealed that two components were significantly related to ATQ activation control, which were Pz go P3 amplitude: $r = .476, p = .007$, and Pz no-go P3 amplitude: $r = .415, p = .020$.

Self-regulation scale (SRS). The result revealed that two components were significantly related to SRS, which were Pz go N2 latency: $r = .453, p = .010$, and Pz go N2 amplitude: $r = .489, p = .005$.

Motivated strategies for learning questionnaire (MSLQ) metacognitive self-regulation. The result revealed that three components were significantly related to this behavioral indicator, which were FCz no-go N2 amplitude: $r = .355, p = .050$, FCz go P3 amplitude: $r =.362, p = .042$, and Fz go P3 amplitude: $r = .382, p = .034$.

Relationship in Students with ADHD

BRIEF-A inhibit. The Pearson product-moment two-tailed correlation analysis only revealed that Cz go N2 latency was significantly related to BRIEF-A inhibit, $r = -.396, p = .017$.

BRIEF-A emotional control. The result only revealed that FCz go P3 amplitude was significantly related to BRIEF-A emotional control, $r = -.362, p = .030$.

BRIEF-A self-monitor. The result revealed that Cz go N2 latency: $r = -.462, p = .005$, Fz go P3 amplitude: $r = -.344, p = .040$, and FCz go P3 amplitude: $r = -.373, p = .025$, were significantly related to BRIEF-A self-monitor.

BRIEF-A BRI. The result revealed that Fz go P3 amplitude: $r = -.354, p = .034$, and FCz go P3 amplitude: $r = -.386, p = .020$, were significantly related to BRIEF-A BRI.

BRIEF-A initiate. The result revealed that four components, Cz go N2 latency: $r = -.468, p = .004$, FCz go N2 latency: $r = -.347, p = .038$, Pz go P3 latency: $r = -.337, p =$

.045, and Cz no-go N2/P3 peak-to-peak amplitude: $r = .341, p = .042$, were significantly related to BRIEF-A initiate.

BRIEF-A working memory. The result revealed that only Cz go N2 latency: $r = -.418, p = .011$, was significantly related to BRIEF-A working memory.

BRIEF-A task monitor. The result revealed that only Cz go N2 latency: $r = -.466, p = .004$, was significantly related to BRIEF-A task monitor.

BRIEF-A MI and BRIEF-A GEC. The result revealed that Cz go N2 latency was the only component related to these two indicators (BRIEF-A MI: $r = -.372, p = .025$, BRIEF-A GEC: $r = -.429, p = .009$).

ATQ inhibition control. The result revealed that only Pz go N2/P3 peak-to-peak amplitude was significantly related to ATQ inhibition control, $r = -.340, p = .042$.

SRS. The result revealed that two components were significantly related to SRS, which were Cz go N2 latency: $r = .364, p = .029$, and Pz go N2 amplitude: $r = .378, p = .023$.

MSLQ metacognitive self-regulation. The result revealed that two components were significantly related to this behavioral indicator, which were Fz go N2 latency: $r = .364, p = .029$, and FCz go N2 latency: $r = .389, p = .019$.

Relationship of Monitoring ERP Components and Behavioral Indicator of Self-regulation Relationship in Control Students

BRIEF-A self-monitor. Pearson product-moment two-tailed correlation analysis only revealed that FCz Pe amplitude was significantly related to BRIEF-A self-monitor, $r = -.389, p = .037$.

BRIEF-A plan/organization. The result only revealed that Pz Pe amplitude was significantly related to BRIEF-A plan/organization, $r = -.397$, $p = .033$.

BRIEF-A task monitor. The results revealed that two components were significantly related to BRIEF-A task monitor, which were Pz error-related negativity (ERN) amplitude: $r = -.420$, $p = .023$, and Pz Pe amplitude: $r = -.509$, $p = .005$.

BRIEF-A organization of materials. The results revealed that two components were significantly related to BRIEF-A organization of materials, which were Pz ERN amplitude: $r = -.384$, $p = .040$, and Pz Pe amplitude: $r = -.375$, $p = .045$.

BRIEF-A MI. The results revealed that two components were significantly related to BRIEF-A MI, which were Pz ERN amplitude: $r = -.396$, $p = .033$, and Pz Pe amplitude: $r = -.426$, $p = .021$.

SRS. The results revealed that Fz ERN latency: $r = .421$, $p = .023$, and FCz Ne latency: $r = .424$, $p = .022$, were significantly related to SRS.

MSLQ metacognitive self-regulation. The result revealed that three components were significantly related to this behavioral indicator, which were Fz ERN latency: $r = -.393$, $p = .035$, Cz ERN latency: $r = -.486$, $p = .007$, and FCz ERN latency: $r = -.544$, $p = .002$.

Relationship in Students with ADHD

BRIEF-A inhibit. The results revealed that two components were significantly related to BRIEF-A Inhibit, which were FCz ERN latency: $r = .424$, $p = .016$, and Fz Pe latency: $r = .361$, $p = .043$.

BRIEF-A emotional control. The results revealed that two components were significantly related to BRIEF-A emotional control, which were Pz Pe amplitude: $r = .352$, $p = .048$, and FCz Pe latency: $r = .393$, $p = .026$.

BRIEF-A self-monitor. The results revealed that two components were significantly related to BRIEF-A self-monitor, which were FCz Pe amplitude: $r = -.360$, $p = .043$, and FCz Pe latency: $r = .433$, $p = .013$.

BRIEF-A BRI. The results revealed that two components were significantly related to BRIEF-A BRI, which were Pz ERN amplitude: $r = .349$, $p = .050$, and FCz Pe latency: $r = .387$, $p = .029$

BRIEF-A initiate. The result only revealed that Pz Pe latency was significantly related to BRIEF-A initiate, $r = -.377$, $p = .033$.

BRIEF-A working memory. The result only revealed that FCz ERN latency was significantly related to BRIEF-A working memory, $r = .350$, $p = .050$.

MSLQ metacognitive self-regulation. The result only revealed that Pz Pe latency was significantly related to this behavioral indicator, $r = .357$, $p = .045$.

MSLQ effort regulation. The result only revealed that Cz ERN latency was significantly related to this behavioral indicator, $r = .392$, $p = .027$.

Relationship of Attention ERP Components and Behavioral Indicator of Self-regulation Relationship in Control Students

BRIEF-A inhibit. Pearson product-moment two-tailed correlation analysis revealed that three components were significantly related to BRIEF-A inhibit, which were Fz invalid cue target-P1 amplitude: $r = -.414$, $p = .026$, FCz no cue target-P1 amplitude: $r = .390$, $p = .036$, Pz valid cue target-P3 latency: $r = -.367$, $p = .050$.

BRIEF-A shift. The result showed that Cz no cue target-N1 latency: $r = .392, p = .035$, Oz valid cue cue-P3 latency: $r = -.475, p = .008$, Cz valid cue cue-P3 amplitude: $r = -.376, p = .041$, and Pz invalid cue cue-P3 latency: $r = -.379, p = .039$, were significantly related to BRIEF-A shift.

BRIEF-A emotional control. The result revealed that two components were significantly related to BRIEF-A emotional control, which were FCz invalid cue target-P1 latency: $r = .382, p = .041$, Fz no cue target-P1 latency: $r = .374, p = .046$.

BRIEF-A self-monitor. The result revealed that five components were significantly related to BRIEF-A self-monitor, which were Fz invalid cue target-P1 latency: $r = -.425, p = .022$, Oz no cue target-P1 amplitude: $r = -.448, p = .015$, Cz invalid cue target-N1 latency: $r = -.424, p = .022$, Oz invalid cue target-P3 amplitude: $r = -.444, p = .016$, and Oz invalid cue cue-P3: $r = -.416, p = .022$.

BRIEF-A initiate. The result indicated that four components were significantly related to BRIEF-A initiate, which were Pz valid cue target-P1 latency: $r = .417, p = .025$, Pz valid cue target-N1 latency: $r = .376, p = .045$, Fz invalid cue target-N1 latency: $r = -.439, p = .017$, and Cz no cue target-N1 latency: $r = .472, p = .010$.

BRIEF-A working memory. The result indicated that Fz no cue target-N1 latency: $r = .392, p = .035$, Cz no cue target-N1 latency: $r = .467, p = .011$, and Pz invalid cue cue-P3 latency: $r = -.372, p = .043$, were significantly related to BRIEF-A working memory.

BRIEF-A plan/organization. The result revealed that four components were significantly related to BRIEF-A plan/organization , which were Pz valid cue target-P1 latency: $r = .458, p = .012$, Fz invalid cue target-N1 latency: $r = -.369, p = .049$, Cz no

cue target-N1 latency: $r = .431, p = .020$, and Oz valid cue CNV/RP area amplitude: $r = -.375, p = .041$.

BRIEF-A task monitor. The result revealed that several components were significantly related to BRIEF-A task monitor, which were Pz valid cue target-P1 latency: $r = .408, p = .028$, Pz valid cue target-N1 latency: $r = .437, p = .018$, Pz valid cue target-N1 amplitude: $r = .377, p = .044$, Cz valid cue target-N1 amplitude: $r = .405, p = .029$, FCz invalid cue target-N1 amplitude: $r = .405, p = .029$, Fz no cue target-N1 latency: $r = .421, p = .023$, Cz no cue target-N1 amplitude: $r = .375, p = .045$, Pz invalid cue target-P3 amplitude: $r = -.441, p = .017$, Fz no cue target-P3 latency: $r = .392, p = .035$, Oz valid cue cue-P3 amplitude: $r = -.444, p = .014$, Pz valid cue cue-P3 amplitude: $r = -.380, p = .038$, Oz invalid cue cue-P3 amplitude: $r = -.400, p = .029$, and Pz invalid cue cue-P3 amplitude: $r = -.397, p = .030$.

BRIEF-A organization of materials. The result showed that five components were related to BRIEF-A organization of materials, which were Oz no cue target-P1 amplitude: $r = -.374, p = .046$, Fz no cue target-P1 latency: $r = .378, p = .043$, Fz valid cue target-P1 latency: $r = .400, p = .032$, Oz valid cue target-P3 latency: $r = -.391, p = .036$, and Oz invalid cue target-P3 amplitude: $r = -.450, p = .014$.

BRIEF-A MI. The result revealed that four components were significantly related to BRIEF-A MI, which were Pz valid cue target-N1 latency: $r = .374, p = .046$, Fz valid cue target-N1 latency: $r = -.478, p = .009$, Fz no cue target-N1 latency: $r = .376, p = .044$, and Cz no cue target-N1 latency: $r = .478, p = .009$.

BRIEF-A GEC. The result revealed that four components were significantly related to BRIEF-A GEC, which were Fz no cue target-N1 latency: $r = .392, p = .035$, Cz no cue

target-N1 latency: $r = .462, p = .012$, and Pz invalid cue target-P3 amplitude: $r = -.383, p = .040$.

ATQ inhibition control. The result revealed that four components were related to ATQ inhibition control, which were Pz invalid cue target-P1 amplitude: $r = .391, p = .036$, Oz no cue target-P1 latency: $r = .368, p = .050$, Pz valid cue target-P3 latency: $r = .401, p = .031$, and Oz valid cue target-P3 latency: $r = .394, p = .034$.

ATQ activation control. The result revealed that there were several components related to ATQ activation control, which were Pz valid cue target-P1 latency: $r = -.425, p = .021$, Oz valid cue target-P1 latency: $r = -.450, p = .014$, Cz invalid cue target-P1 latency: $r = -.374, p = .045$, Fz no cue target-P1 amplitude: $r = -.370, p = .048$, \Cz no cue target-P1 amplitude: $r = -.467, p = .011$, Oz invalid cue target-N1 latency: $r = .402, p = .031$, Fz no cue target-N1 latency: $r = -.422, p = .023$, Cz no cue target-N1 amplitude: $r = -.422, p = .023$, Fz no cue target-P3 amplitude: $r = -.438, p = .017$, Cz no cue target-P3 latency: $r = -.479, p = .009$, FCz no cue target-P3 latency: $r = -.389, p = .037$, and FCz no cue target-P3 amplitude: $r = -.393, p = .035$.

ATQ attention control. The result revealed that only Fz valid cue cue-P3 latency: $r = -0.374, p = 0.042$, and Pz invalid cue CNV/RP area amplitude: $r = -.416, p = .022$, were significantly related to ATQ attention control.

ATQ effortful control. The result only revealed that Pz valid cue target-P3 latency was significantly related to ATQ effortful control, $r = .397, p = .033$.

SRS. The result showed that only Fz invalid cue target-P3 latency was significantly related to SRS, $r = .389, p = .037$.

MSLQ metacognitive self-regulation. The result revealed that several components were significantly related to this behavioral indicator, which were Fz valid cue target-P1 amplitude: $r = .417, p = .024$, Oz invalid cue target-P1 amplitude: $r = -.388, p = .038$, FCz valid cue cue-P3 amplitude: $r = .457, p = .011$, Fz valid cue cue-P3 amplitude: $r = .503, p = .005$, Oz invalid cue target-N1 amplitude: $r = -.380, p = .042$, Pz valid cue target-P3 latency: $r = .462, p = .012$, Oz valid cue CNV/RP area amplitude: $r = -.424, p = .020$, and Fz valid cue CNV/RP area amplitude: $r = -.407, p = .026$

MSLQ effort regulation. The result showed that only Fz valid cue target-P1 amplitude: $r = .375, p = .045$, and Oz invalid cue target-P1 amplitude: $r = -.396, p = .034$, were significantly related to this behavioral indicator.

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BRIEF-A inhibit. The results revealed that several components were related to BRIEF-A inhibit, which were Pz valid cue target-P1 latency: $r = -.414, p = .019$, Pz valid cue target-P3 amplitude: $r = .373, p = .035$, Oz valid cue target-P3 amplitude: $r = .353, p = .047$, Cz valid cue target-P3 amplitude: $r = .375, p = .035$, Pz invalid cue target-P3 amplitude: $r = .426, p = .015$, Oz valid cue target-P3 amplitude: $r = .358, p = .044$, Oz valid cue target-P3 latency: $r = -.394, p = .026$, Fz no cue target-P3 latency: $r = -.363, p = .041$, FCz valid cue target-P3 latency: $r = -.354, p = .047$, and Cz invalid cue cue-P3 latency: $r = -.351, p = .042$.

BRIEF-A shift. The result revealed that three components were significantly related to BRIEF-A shift, which were Oz invalid cue target-P1 latency: $r = .563, p = .001$, Pz valid cue cue-P3 latency: $r = -.460, p = .006$, and Fz valid cue cue-P3 latency: $r = -.360, p = .037$.

BRIEF-A emotional control. The result revealed that several components were related to BRIEF-A emotional control, which were Oz no cue target-P1 latency: $r = .353$, $p = .047$, Pz valid cue target-P3 amplitude: $r = .395$, $p = .025$, Pz invalid cue target-P3 amplitude: $r = .403$, $p = .022$, Fz no cue target-P3 latency: $r = -.467$, $p = .007$, Cz no cue target-P3 latency: $r = -.350$, $p = .049$, FCz no cue target-P3 latency: $r = -.435$, $p = .013$, Fz valid cue cue-P3 latency: $r = -.361$, $p = .036$, and Oz invalid cue cue-P3 amplitude: $r = .383$, $p = .026$.

BRIEF-A self-monitor. The result indicated that Pz valid cue target-P1 latency: $r = -.436$, $p = .013$, Oz invalid cue target-N1 latency: $r = -.360$, $p = .043$, Oz invalid cue target-P3 latency: $r = -.418$, $p = .017$, and Fz no cue target-P3 latency: $r = -.375$, $p = .035$, were significantly related to BRIEF-A self-monitor.

BRIEF-A BRI. The result indicated that several components were related tto BRIEF-A BRI, which were Pz valid cue target-P3 amplitude: $r = .384$, $p = .030$, Oz valid cue target-P3 amplitude: $r = .367$, $p = .039$, Pz invalid cue target-P3 amplitude: $r = .406$, $p = .021$, Oz invalid cue target-P3 amplitude: $r = .350$, $p = .050$, Fz no cue target-P3 latency: $r = -.451$, $p = .010$, FCz no cue target-P3 latency: $r = -.412$, $p = .019$, Oz valid cue cue-P3 amplitude: $r = .386$, $p = .024$.

BRIEF-A initiate. The result revealed that three components were significantly related to BRIEF-A initiate, which were Oz no cue target-N1 amplitude: $r = -.458$, $p = .008$, Pz invalid cue target-P3 amplitude: $r = .365$, $p = .040$, and Oz invalid cue cue-P3 amplitude: $r = .360$, $p = .037$.

BRIEF-A working memory. The result showed that five components were significantly related to BRIEF-A working memory, which were Pz valid cue target-P1

latency: $r = -0.358, p = 0.044$, Fz no cue target-N1 amplitude: $r = -.357, p = .045$, Pz valid cue target-P3 amplitude: $r = .353, p = .047$, Oz valid cue target-P3 amplitude: $r = .426, p = .015$, and Oz invalid cue target-P3 amplitude: $r = .439, p = .012$.

BRIEF-A plan/organization. The result indicated that several components were related to BRIEF-A plan/organization, which were Fz no cue target-N1 amplitude: $r = -.472, p = .006$, Pz invalid cue target-P3 amplitude: $r = .432, p = .013$, Oz invalid cue target-P3 amplitude: $r = .380, p = .032$, Oz invalid cue target-P3 latency: $r = -.385, p = .029$, Oz valid cue cue-P3 amplitude: $r = .341, p = .048$, and Oz invalid cue cue-P3 amplitude: $r = .364, p = .034$.

BRIEF-A task monitor. The result revealed that two components were significantly related to BRIEF-A task monitor, which were Oz no cue target-N1 latency: $r = .361, p = .042$, and Fz invalid cue target-P3 latency: $r = -.412, p = .019$.

BRIEF-A organization of materials. The result revealed that three components were significantly related to BRIEF-A organization of materials, which were Pz invalid cue target-P3 amplitude: $r = .356, p = .045$, Oz invalid cue target-P3 latency: $r = -.515, p = .003$, and Fz invalid cue cue-P3 latency: $r = -.349, p = .043$.

BRIEF-A MI. The result revealed that four components were significantly related to BRIEF-A MI, which were Pz invalid cue target-P3 amplitude: $r = .436, p = .013$, Oz invalid cue target-P3 latency: $r = -.463, p = .008$, Oz invalid cue target-P3 amplitude: $r = .378, p = .033$, and Oz invalid cue cue-P3 amplitude: $r = .377, p = .028$,

BRIEF-A GEC. The result revealed that several components were related to BRIEF-A GEC, which were Pz valid cue target-P3 amplitude: $r = .368, p = .038$, Oz valid cue target-P3 amplitude: $r = .358, p = .044$, Pz invalid cue target-P3 amplitude: $r = .478, p =$

.006, Oz invalid cue target-P3 latency: $r = -.426, p = .015$, Oz invalid cue target-P3 amplitude: $r = .383, p = .025$, Pz invalid cue target-P3 amplitude: $r = .478, p = .006$, Fz no cue target-P3 latency: $r = -.393, p = .026$, FCz no cue target-P3 latency: $r = -.368, p = .039$, Oz valid cue cue-P3 amplitude: $r = .401, p = .019$, and Oz invalid cue cue-P3 amplitude: $r = .383, p = .025$.

ATQ inhibition control. The result revealed that several components were related to ATQ inhibition control, which were Oz invalid cue target-N1 latency: $r = .379, p = .032$, Oz invalid cue target-P3 latency: $r = .434, p = .013$, Oz invalid cue target-P3 amplitude: $r = -.349, p = .050$, Pz valid cue cue-P3 latency: $r = -.382, p = .026$, and Fz invalid cue cue-P3 latency: $r = .397, p = .020$.

ATQ activation control. The result revealed that two components were significantly related to ATQ activation control, which were Oz no cue target-N1 amplitude: $r = .370, p = .037$, and Pz invalid cue cue-P3 amplitude: $r = -.349, p = .043$.

ATQ attention control. The result indicated that several components were significantly related to ATQ attention control, which were Fz no cue target-N1 amplitude: $r = .420, p = .017$, Pz valid cue target-P3 amplitude: $r = -.423, p = .016$, Oz valid cue target-P3 amplitude: $r = -.435, p = .013$, Pz invalid cue target-P3 amplitude: $r = -.403, p = .022$, Oz invalid cue target-P3 amplitude: $r = -.349, p = .050$, Oz valid cue cue-P3 amplitude: $r = -.453, p = .007$, Pz valid cue cue-P3 amplitude: $r = -.362, p = .036$, and Oz invalid cue cue-P3 amplitude: $r = -.345, p = .046$.

ATQ effortful control. The result revealed that three components were significantly related to ATQ effortful control, which were Fz no cue target-N1 amplitude: $r = .376, p =$

.034, Pz invalid cue target-P3 amplitude: $r = -.406, p = .021$, and Oz valid cue cue-P3 amplitude: $r = -.382, p = .026$.

SRS. The result showed that Oz valid cue CNV/RP area amplitude: $r = .500, p = .003$, and Oz invalid cue CNV/RP area amplitude: $r = .385, p = .025$, were significantly related to SRS.

MSLQ metacognitive self-regulation. The result revealed that several components were significantly related to this behavioral indicator, which were Oz invalid cue target-N1 latency: $r = -.381, p = .031$, Cz valid cue target-N1 amplitude: $r = .385, p = .030$, Oz no cue target-N1 amplitude: $r = .477, p = .006$, Cz valid cue CNV/RP area amplitude: $r = -.372, p = .030$, and Oz invalid cue CNV/RP area amplitude: $r = .409, p = .016$

MSLQ effort regulation. The result showed that several components were significantly related to this behavioral indicator, which were Cz valid cue target-P1 amplitude: $r = .375, p = .035$, and FCz invalid cue target-P1 amplitude: $r = .372, p = .036$, FCz no cue target-P1 amplitude: $r = -.362, p = .042$, Cz valid cue target-N1 amplitude: $r = .367, p = .039$, FCz valid cue target-N1 amplitude: $r = .353, p = .047$, Oz no cue target-N1 latency: $r = -.370, p = .037$, Oz no cue target-N1 amplitude: $r = .376, p = .034$, Cz valid cue CNV/RP area amplitude: $r = -.395, p = .021$, and FCz valid cue CNV/RP area amplitude: $r = -.354, p = .040$.

APPENDIX G: Variables in Stepwise Discriminant Analyses

ERP components in the Go/No-go Task for Stepwise Discriminant Analysis

N2 Variables	Two groups Standardized canonical coefficients Function 1	P3 Variables	Two groups Standardized canonical coefficients Function 1
Cz go N2 latency	.741	FCz no-go P3 latency	1.000
Fz go N2 amplitude	.470	Cz no-go P3 latency[a]	.959
FCz go N2 latency[a]	.468	Fz no-go P3 latency[a]	.799
FCz go N2 amplitude[a]	.411	Pz no-go P3 latency[a]	.578
Cz no-go N2 latency[a]	.377	FCz go P3 latency[a]	.521
Cz go N2 amplitude[a]	.354	Cz go P3 latency[a]	.465
Pz go N2 amplitude[a]	.353	Fz go P3 latency[a]	.449
Pz no-go N2 latency[a]	.348	Pz go P3 latency[a]	.322
Pz go N2 latency[a]	.313	Fz no-go P3 amplitude[a]	-.291
Fz go N2 latency[a]	.296	Pz go P3 amplitude[a]	-.248
FCz no-go N2 latency[a]	.259	Fz go P3 amplitude[a]	-.248
Fz no-go N2 latency[a]	.246	FCz no-go P3 amplitude[a]	-.201
Fz no-go N2 amplitude[a]	.211	FCz go P3 amplitude[a]	-.189
Pz no-go N2 amplitude[a]	.185	Cz go P3 amplitude[a]	-.163
FCz no-go N2 amplitude[a]	.117	Cz no-go P3 amplitude[a]	-.056
Cz no-go N2 amplitude[a]	.073	Pz no-go P3 amplitude[a]	-.020

Note. a.This variable was not selected as accounting for a significant amount of variance in the analysis.

ERP Components in the Visual Letter Flanker Task for Stepwise Discriminant Analysis

	Two groups
	Standardized canonical coefficients
Variables	Function 1
Fz ERN amplitude	1.000
FCz ERN amplitude[a]	.801
Cz ERN amplitude[a]	.494
Fz ERN latency[a]	-.232
Cz ERN latency[a]	-.184
FCz ERN latency[a]	-.110
Pz ERN latency[a]	-.044
Pz ERN amplitude[a]	-.016

Note. a.This variable was not selected as accounting for a significant amount of variance in the analysis.

Target-P1 ERP Components in the Posner Task for Stepwise Discriminant Analysis

	Two sroups
	Standardized canonical coefficients
Variables	Function 1
Pz invalid cue target-P1 latency	.602
Oz invalid cue target-P1 latency[a]	.420
Cz invalid cue target-P1 latency[a]	.351
Fz invalid cue target-P1 latency[a]	.339
Oz valid cue target-P1 amplitude	.330
Fz valid cue target-P1 mplitude	-.305
FCz invalid cue target-P1 latency[a]	.297
Oz no cue target-P1 amplitude	-.261
Oz invalid cue target-P1 amplitude[a]	.254
FCz valid cue target-P1 amplitude[a]	-.222
Pz invalid cue target-P1 amplitude[a]	.218
Fz invalid cue target-P1 amplitude[a]	-.206
Cz valid cue target-P1 amplitude[a]	-.204
Pz valid cue target-P1 amplitude[a]	.200
Oz valid cue target-P1 latency[a]	.199
FCz valid cue target-P1 latency[a]	.192
Cz invalid cue target-P1 amplitude[a]	-.174
FCz no cue target-P1 amplitude[a]	-.172
Cz no cue target-P1 latency[a]	.171
Cz valid cue target-P1 latency[a]	.134
FCz invalid cue target-P1 amplitude[a]	-.089
Oz no cue target-P1 latency[a]	-.088
Pz no cue target-P1 latency[a]	.082
Fz no cue target-P1 amplitude[a]	-.075
Fz valid cue target-P1 latency[a]	-.060
Cz no cue target-P1 amplitude[a]	-.051
FCz no cue target-P1 latency[a]	-.031
Pz no cue target-P1 amplitude[a]	-.026
Fz no cue target-P1 latency[a]	-.024
Pz valid cue target-P1 latency[a]	.012

Note. a.This variable was not selected as accounting for a significant amount of variance in the analysis.

Target-N1 ERP Components in the Posner Task for Stepwise Discriminant Analysis

Variables	Two groups
	Standardized canonical coefficients
	Function 1
Pz invalid cue target-N1 latency	.599
FCz valid cue target-N1 amplitude	-.482
Fz valid cue target-N1 amplitude[a]	-.481
Cz valid cue target-N1 amplitude[a]	-.442
Cz invalid cue target-N1 latency[a]	.425
Oz invalid cue target-N1 latency[a]	.423
Oz valid cue target-N1 amplitude	.336
FCz invalid cue target-N1 latency[a]	.306
Fz invalid cue target-N1 latency[a]	.250
Cz no cue target-N1 latency[a]	.219
Oz no cue target-N1 amplitude[a]	.173
Cz invalid cue target-N1 amplitude[a]	-.165
Pz no cue target-N1 latency[a]	.153
Fz invalid cue target-N1 amplitude[a]	-.128
FCz invalid cue target-N1 amplitude[a]	-.128
Oz valid cue target-N1 latency[a]	-.112
Pz no cue target-N1 amplitude[a]	.106
FCz no cue target-N1 amplitude[a]	-.096
Cz valid cue target-N1 latency[a]	.087
FCz no cue target-N1 latency[a]	.068
Cz no cue target-N1 amplitude[a]	-.064
Oz invalid cue target-N1 amplitude[a]	.056
Fz valid cue target-N1 latency[a]	-.045
Fz no cue target-N1 amplitude[a]	.044
Pz valid cue target-N1 amplitude[a]	.038
Pz valid cue target-N1 latency[a]	-.030
Oz no cue target-N1 latency[a]	-.022
Fz no cue target-N1 latency[a]	.020
Pz invalid cue target-N1 amplitude[a]	-.012
FCz valid cue target-N1 latency[a]	.000

Note. a.This variable was not selected as accounting for a significant amount of variance in the analysis.

Target-P3 ERP Components in the Posner Task for Stepwise Discriminant Analysis

Variables	Two groups Standardized canonical coefficients Function 1
Oz no cue target-P3 amplitude	-.586
FCz no cue target-P3 latency	.524
Cz no cue target-P3 latency [a]	.507
Cz invalid cue target-P3 latency [a]	.466
Fz no cue target-P3 latency [a]	.427
Pz invalid cue target-P3 latency [a]	.337
Cz valid cue target-P3 amplitude[a]	.325
Oz invalid cue target-P3 amplitude[a]	-.211
FCz valid cue target-P3 amplitude[a]	.204
Pz valid cue target-P3 amplitude	.191
Oz valid cue target-P3 amplitude[a]	-.190
Oz invalid cue target-P3 latency [a]	.189
FCz invalid cue target-P3 latency [a]	.187
Cz no cue target-P3 amplitude[a]	.137
Fz invalid cue target-P3 amplitude[a]	.136
Fz invalid cue target-P3 latency [a]	.101
Oz valid cue target-P3 latency [a]	.079
Pz no cue target-P3 amplitude[a]	-.070
FCz no cue target-P3 amplitude[a]	-.069
Cz valid cue target-P3 latency [a]	.067
Pz no cue target-P3 latency [a]	.065
Fz no cue target-P3 amplitude[a]	-.057
Fz valid cue target-P3 amplitude[a]	.055
FCz valid cue target-P3 latency [a]	-.049
FCz invalid cue target-P3 amplitude[a]	.032
Pz valid cue target-P3 latency [a]	.026
Pz invalid cue target-P3 amplitude[a]	.025
Oz no cue target-P3 latency [a]	.023
Fz valid cue target-P3 latency [a]	.018
Cz invalid cue target-P3 amplitude[a]	.013

Note. a.This variable was not selected as accounting for a significant amount of variance in the analysis.

Behavioral Indictors of Self-Regulation for Stepwise Discriminant Analysis

Variables	Two groups Standardized Canonical Coefficients Function 1
SRS	.894
BRIEF-A working memory	-.863
ATQ attention control[a]	.793
BRIEF-A GEC[a]	-.786
ATQ effortful control[a]	.757
BRIEF-A inhibit[a]	-.727
BRIEF-A MI[a]	-.714
BRIEF-A plan/organize[a]	-.669
BRIEF-A BRI[a]	-.604
BRIEF-A initiate[a]	-.594
BRIEF-A task monitor[a]	-.587
BRIEF-A self-monitor[a]	-.541
ATQ activation control[a]	.530
ATQ inhibition control[a]	.505
BRIEF-A organization of materials[a]	-.488
BRIEF-A emotional control[a]	-.341
BRIEF-A shift[a]	-.314
MSLQ effort regulation[a]	.285
MSLQ metacognitive self-regulation[a]	.122

Note. a.This variable was not selected as accounting for a significant amount of variance in the analysis.