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Evaluation of Attention and Executive Control within a Model of Gf-Gc Cognitive Functioning

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EVALUATION OF ATTENTION AND EXECUTIVE CONTROL WITHIN A MODEL OF G_f-G_c COGNITIVE FUNCTIONING

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By

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ABSTRACT

EVALUATION OF ATTENTION AND EXECUTIVE CONTROL WITHIN A MODEL OF G_f-G_c COGNITIVE FUNCTIONING

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The G_f-G_c model (McGrew, 2003; McGrew & Flanagan, 1998) guided the development of most contemporary cognitive ability tests (Kaufman & Kaufman, 2004; Wechsler, 2003), as it enumerates general cognitive ability through the evaluation of its multiple components. This study involved an investigation of the G_f-G_c domains including added attention and executive control domains, which was measured by the Wechsler Intelligence Scale for Children, 4th Edition (WISC-IV) and Conners' Continuous Performance Test, 2nd Edition (CPT-II). These domains were compared via factor analysis of the WISC-IV and CPT-II.

In addition, Structural Equation Modeling was used to test the structure of the Dean-Woodcock Neuropsychology Model (Dean et al., 2003), particularly the primacy of attention and the interaction of executive control with other cognitive skills. The current

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study provided support for the addition of separate attention (G_{at}) executive control (G_{ec}) components within a G_f-G_c cognitive model. In addition, a significant interaction was found between attention and processing speed, which supports attention as a primary cognitive skill.

DEDICATION

This dissertation is dedicated to my family, particularly my wife Jocelyn, mother Maria, grandparents Nonna and Nonno Lisandrelli, and Mike and Paula Mattingly. Without all of your guidance and support completion of this dissertation would never have been possible. This journey has proven to be a long road paved with both successes and disappointments. I share this success with all of you and thank you from the bottom of my heart.

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CHAPTER 1

INTRODUCTION

1.1 Significance of the Problem

The empirical evaluation of human cognitive functioning has intrigued our species for decades. Dating back to the 1800's, Francis Galton initiated the revolution of measuring human ability, including the ability to complete tasks that require intricate thinking skills (Plucker, 2003). Throughout history the theories and methods for human cognitive evaluation have been developed and revised to include newer and more accurate components. Currently, the G_f-G_c model (McGrew, 2003; McGrew & Flanagan, 1998) guides the theory behind most cognitive ability tests (Kaufman & Kaufman, 2004; Wechsler, 2003), as it enumerates general ability through the evaluation of its multiple components.

The main purpose of this study is to continue investigation of cognitive assessment, and in particular G_f-G_c theory. While largely comprehensive, including 16 stratum II (broad) and 99 stratum I (narrow) skills, the G_f-G_c theory does not account for a person's ability to control subsystems, skills, and behaviors, or the ability of a person to attend to tasks. The inclusion of executive control and attention components to this theory will further broaden the scope and thus improve the validity of contemporary cognitive assessment.

Several contemporary studies (Duff, Schoenberg, Scott, & Adams, 2005; Floyd, Bergeron, & Hamilton, 2005; Keith, Goldenring Fine, Taub, Reynolds, & Kranzler, 2006; Naglieri, Goldstein, Delauder, & Schwebach, 2005; Wechsler, 2003) have analyzed the relationship between cognitive assessment, attention, and executive abilities, but none have attempted to explore the possibility of a higher order processing relationship between cognitive skills that includes all of the current G_f-G_c components, as well as executive control and attention. This study will attempt such an analysis in order to add to the vast lineage of human ability analysis.

1.2 Processing

Throughout his career A.R. Luria (1966, 1973, & 1980) investigated the brain's involvement in complex behavior. He explained human cognition within three functional systems. These systems are associated with different anatomical regions in the brain. The first system controls arousal or cortical tone, which allows us to focus attention (Luria, 1973). Luria associated the first system with the brain stem, diencephalon, and medial regions. The second system controls analysis, management, and storage of data input from the external world (Luria, 1966; Kaufman & Kaufman, 2004). The second system involves occipital, parietal, and temporal lobe regulation. Finally, the third system necessitates the planning and organization of behavior through hypothesis generation, planning, and self-monitoring (Das, Naglieri, & Kirby, 1994; Kaufman & Kaufman, 2004; Luria, 1973). The third system is associated with frontal lobe regulation (Das et al., 1994).

Luria's (1973) model of executive functioning (EF) is explained as a cognitive processing approach that follows a hierarchical organization of dominance within cognitive systems. Based on Luria's (1966, 1970, 1973, & 1980) EF model, contemporary researchers have validated and extended the processing approach to cognition (Das, Naglieri, & Kirby, 1994; Kaufman & Kaufman, 2004; Naglieri, 1999; Reitan, 1988). Also, the importance of a reciprocal interaction, i.e. a "joint operation"

(Luria, 1970, pg 68.), between the first, second, and third cognitive systems has been highlighted (Das, Naglieri, & Kirby, 1994; Kaufman & Kaufman, 2004; Naglieri, 1999; Reitan, 1988). In addition to the processing approach to cognition, another contribution of this cognitive processing approach is the supposition that attention to task takes primacy to other cognitive systems (Luria, 1973).

On a similar token to Luria's (1973) model of cognitive processing, Dean, Woodcock, Decker, and Schrank (2003) describe the Dean-Woodcock Neuropsychology Model. The Dean-Woodcock model explains human cognitive abilities as a process between higher and lower cognitive functions. The different levels of processing, from lower to higher, described in the Dean-Woodcock model are distinguished as reflexive, automatic, and thinking. Each of these levels function in a reciprocal interaction with each other, which represents a cycle of sensory input, processing, and output (Dean et al., 2003). Although similar to Luria's (1973) processing approach, Dean and colleagues (2003) provide a more detailed rationale for a hierarchy of skills. By introducing their theory of hierarchical processing, the Dean-Woodcock model sets the stage for the inclusion of executive functions and attention within a hierarchical cycle of higher and lower human functions.

1.3 Executive Functioning

The concept of executive functioning (EF) is a topic of continuing debate and revision. The debate does not exist to reject the existence of a higher-order human cognitive control system. Rather, research is focused upon what constitutes executive functioning and how to measure its component features. The neuroanatomical theory posed by Andrewes (2001) provides an overarching summary of skills completed within a hierarchy of cognitive functions. The cognitive functions include: control, organization, concept formation, and problem solving, as well as attentional ability and certain qualities of personality.

Andrewes' (2001) neuroanatomical theory continues to include attention as an executive function. The theory proposed in this study eliminates attention as an executive function, and instead explains attention as a stand alone system under executive control (Baddeley, 2003; Meyer & Kieras, 1997) and having an intimate relationship between other cognitive systems (Luria, 1973).

Naglieri, Goldstein, Delauder, and Schwebach (2005) completed a study investigating the correlation between a child's attention (Conner's Continuous Performance Test: CPT) and their performance on measures of intelligence (Wechsler Intelligence Test for Children, 3rd ed.: WISC-III; and Cognitive Assessment System: CAS). They found few significant correlations between the CPT and WISC-III, which suggests measures of attention and cognitive ability each hold unique variance. The Naglieri et al. (2005) study supports the analysis of attention as a separate factor affecting cognitive ability.

Through this current study attention and the executive control mechanism regulating attention will be examined to determine their relationship with other predefined G_f-G_c cognitive components (McGrew & Flanagan, 1998; McGrew, 2003). As will be further explained in Chapter 2, the discussion of working memory will help advance the proposed theory of executive control and attention as separate, but functioning in a complex relationship of hierarchical processing (Baddeley, 2003; Dean et. al., 2003).

Along with supporting theory for the separation of EF and attention, EF development in children is considered here in order to explain an EF hierarchy phenomenon. That is, EF develops in children with basic functions such as executive control first, followed by more complex higher order functions such as concept formation and problem solving (Anderson, 2002; Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001; Goldberg & Bilder, 1987; Klenberg, Korkman, & Lahti-Nuuttila, 2001). For example, motor/impulse control is the first skill fully developed in children (Gioia, Isquith, Guy, & Kenworthy, 2000). As will be described further in Chapter 2, control is the necessary ability for all other executive functions to develop. It lays the basis for development of the higher-order skills (Barkley, 1997, 1999) such as concept formation and problem solving, and it is necessary for the proper regulation of attention (Posner & Peterson 1990).

A hierarchy of cognition (Das, Naglieri, & Kirby, 1994) can be conceptualized with each higher-order skill dependent upon the efficient performance of the previously developed prerequisite skills. A hierarchical processing model conceptually holds executive control as a necessary, but not sufficient skill for the performance of higher order executive functions, such as concept formation, problem solving, and the executive control of attention.

Support for a hierarchy involving concept formation and control was provided in a factor analytic study conducted by Minshew, Meyer, and Goldstein (2002), in which concept formation and concept identification were investigated in children with Autism. The authors demonstrated that the skill of identifying concepts was separate from abstract reasoning in children with Autism. They also found that cognitive flexibility (control) was an intermediate ability between identification and concept formation (Minshew et. al., 2002). Their study supports the notion of control as a precursor to concept formation.

Duff, Schoenberg, Scott, and Adams (2005) determined that EF interacts with both immediate and delayed recall in a hierarchical relationship. Duff et al. (2005) conducted a canonical analysis of measures of executive functions and memory and found that EF and memory share 55-60% of variance. As a sidebar to their study, Duff et al. (2005) noted that despite a relationship being evidenced, directionality could not be determined. Their study supports the interrelatedness and reciprocal processing of EF and memory, which raises the question of the relationship between EF and all other cognitive systems. The lack of causality may support the postulation that EF and other cognitive functions act within an interrelated global system.

Busch, Booth, McBride, Vanderploeg, Curtiss, and Duchnick (2005) completed a t-test analysis of the severity of executive dysfunction and performance on tasks of memory in subjects with head injury. They determined that memory was less related to executive dysfunction than overall cognitive dysfunction. However, when severity of cognitive dysfunction was controlled, memory and executive deficits were related based on the fluidity of the task. This finding indicates that tasks requiring executive cognitive fluidity were related to executive functions.

Neuroscience examinations of EF reveal frontal lobe involvement in higher-order cognition (Davies & Rose, 1999; Filley, Young, Reardon, & Wilkening, 1999; Goldberg, Podell, & Lovell, 1994; Goldman-Rakic, 1987; Luria, 1973; Rosenweig, Breedlove, & Leiman, 2002; Stuss & Benson, 1984). The frontal lobe of the human brain has been associated with the execution of EF and modulation of other brain systems, such as attention (Stuss & Gow, 1992). A neurological disease such as Huntington's Disease may offer a picture of what executive dysfunction involves. The frontal lobe atrophy caused by this disorder leads to deficits of executive functioning (Andrewes, 2001; adapted from Alexander, Crutcher and Delong, 1990; and Cummings and Coffey, 2000) such as disinhibition, dysfluency, and difficulty planning (Andrewes, 2001).

Barkley (1997), in his description of executive function, identifies behavioral inhibition as the mediator for the competent performance of four executive abilities: working memory, internalization of speech, self-regulation of affect/motivation/arousal, and reconstitution (which explains goal directed behaviors of the motor system). Barkley's model of Attention-Deficit/Hyperactivity Disorder provides support for the argument of a hierarchy of EF investigated in this study, with control being necessary but not sufficient for higher executive skills.

Another important executive system theory that supports a hierarchical cognitive process is called the Supervisory Attentional System (SAS) (Norman & Shallice, 1986). In this theory, the SAS acts as a mediator of sensory information and preexisting schemas when behavior is not automatic (Andrewes, 2001). Automaticity of behavior determines whether or not the SAS becomes involved. The SAS takes over behavioral control when (1) no preexisting schema is available for the stimuli, (2) two or more schemas are appropriate, (3) the strongest schema associated is inappropriate for the situation, or (4) the consequences of the wrong schema selection are dangerous. By defining the Supervisory Attentional System in this manner, which in itself is a key component to the executive attention system described by Andrewes (2001), Norman and Shallice (1986) provide support for the separation of EF and attention. The complex relationship between EF and attention will be investigated further in the literature review of this study.

The separation of control, concept formation, problem solving, and executive attention as distinct skills is supported by Luria's (1973) description of executive functioning as the performance of goal directed behaviors, which can be viewed as a domain of possible outcomes from the control, planning, organization, and integration roles of more basic cognitive functions. Recall Luria's (1973) model of executive functioning, which follows a cognitive processing approach and assumes the hierarchical dominance of cognitive modulation systems. Luria's processing approach will be a foundational key in this research by supporting the interconnectedness of EF, attention, and other cognitive processes.

A single domain score does not provide a valid account of EF because of the separation and distinction between skills that make up the construct (Messick, 1995). For example, although interrelated, concept formation and problem solving make up two different skills that are also measured differently (Delis, Kaplan, & Kramer, 2001). Often the measurement of a construct that includes several component skills is reported through an index or composite score. For example, the Wechsler Intelligence Scale for Children, 4^{th} ed. (WISC-IV) (Wechsler, 2003) reports an index named perceptual reasoning (PRI). The perceptual reasoning index is a composite of separate and distinct skills such as visual motor, visual concept formation, and visual discrimination. In contrast to viewing executive functioning as a single construct, research has indicated that the components of an EF domain reflect fundamental separate resources (Denkla, 1996; Boone, Ponton, Gorsuch, Gonzalez, & Miller, 1998).

1.4 Cattell-Horn-Carroll (current model) – Transformation into current theory

Contemporary G_f-G_c theory (McGrew, 2003; McGrew & Flanagan, 1998) accounts for fundamental cognitive domain skills in its definition of the broad stratum II. Based on the Cattell-Horn-Carroll (CHC; name, 1993) integrated G_f-G_c model, McGrew (2003) explains a working definition of the CHC theory, which categorizes abilities into 16 separate domains of functioning, called Broad (stratum II) domains. These broad definitions are further broken down into 99 Narrow (stratum I) definitions that account for comprehensive investigations of the factors that are included in stratum II domains. G_f-G_c theory explains cognition based on a comprehensive evaluation of multiple abilities (McGrew, 2003).

A discussion describing the comprehensive CHC theory of cognition is relevant to this study for the purpose of providing a framework for subsequent data analysis. The CHC theory has been couched as an all encompassing evaluation of human cognitive ability. Current intelligence tests for children base most of their measures on these broad and narrow CHC facets of cognition (Kaufman & Kaufman, 2004; Keith et al., 2006; Wechsler, 2003).

McGrew (2003) is further investigating stratum II and stratum I in G_f-G_c cognitive ability through a working model, which is updated as relevant research is completed. Recent empirical evidence validates the broad abilities G_f, G_c, G_v, G_{sm}, G_{lr}, G_s, G_q (quantitative knowledge), and G_{rw} (reading/writing) as structural components of the model (McGrew, 2003). The presence of G_q and G_{rw} reflects the integration of achievement into the CHC model.

In addition, Keith et al. (2006) completed a higher order confirmatory factor analysis of the Wechsler Intelligence Scale for Children-Fourth Edition (Wechsler, 2003). Keith et al. (2006) challenged the WISC-IV (Wechsler, 2003) factor structure of verbal comprehension, perceptual reasoning, working memory, and processing speed by validating a factor model that resembles CHC cognitive structure. Their study further validates the model in this investigation of the WISC-IV's measurement of cognitive components.

1.5 Where it's going

The application of the processing approach (Luria 1966a, 1966b, 1973, & 1980) within the component cognitive G_f-G_c model (McGrew, 2003) has been validated (Kaufman & Kaufman, 2004) and a hierarchical processing organization of cognition has been postulated (Dean et al., 2003); however, a cognitive organization that includes attention and EF (Goldberg, 1987) within that system has not been fully explored. Floyd, Bergeron, and Hamilton (2005) completed a joint exploratory factor analysis of subtests from the Delis-Kaplan Executive Function System and the Woodcock-Johnson III Tests of Cognitive Abilities to determine the relationship between executive functions and G_f-G_c cognitive components. Their study determined that both EF and cognitive ability tasks measure the same general construct. However, their explanation lacked a clear definition of EF skills, as well as an organization of each EF skill within an integrated model. Also, the analysis of this study did not take into account the processing relationship between cognitive systems (Dean et al., 2003) or the primacy of attention within the system (Luria, 1973).

1.6 Problem Statement

The purpose of this study is to continue investigation of the G_f-G_c theory and expand the Keith et al. (2006) validation of G_f-G_c measurement by the WISC-IV. A hierarchical processing organization, which may accurately explain the relationship between executive functions, should be applied to the inclusion of a new executive control (G_{ec}) component and a separate attention component (G_{at}) within the G_f-G_c theory. We propose the necessary inclusion of executive control (G_{ec}) and a separate attention factor (G_{at}), within a factorial organization of G_f-G_c cognitive measurement.

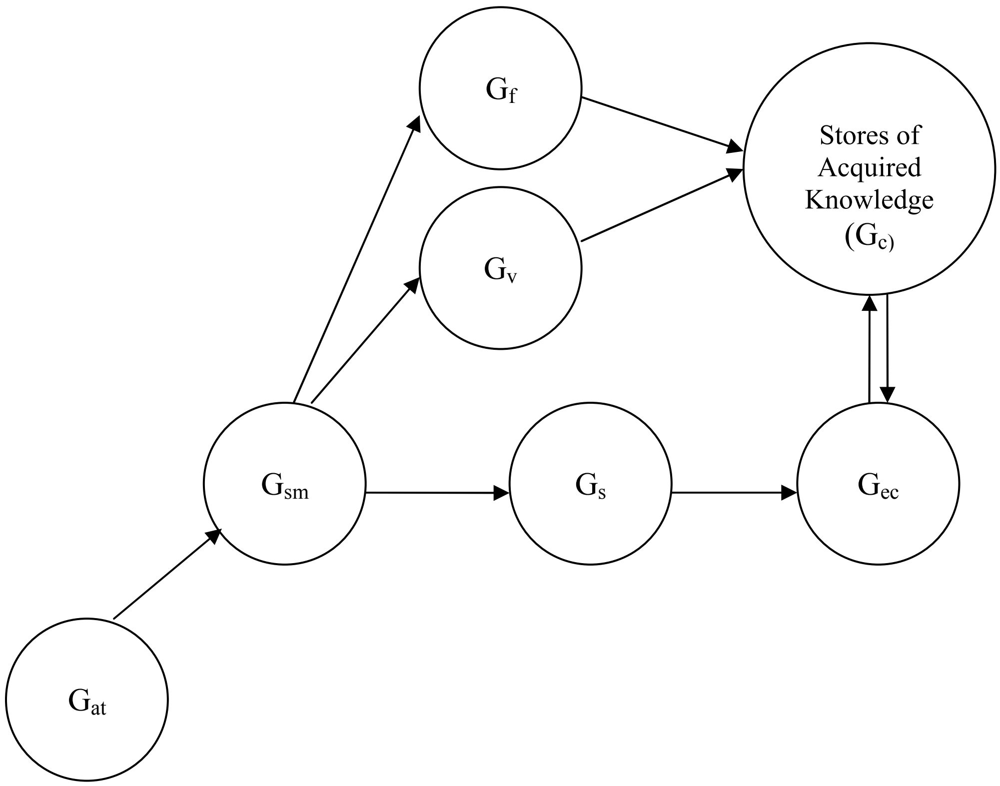
This study involves an investigation of the G_f-G_c domains measured by Wechsler Intelligence Scale for Children, 4th Edition (WISC-IV) and Conners' Continuous Performance Test, 2nd Edition (CPT-II). These domains will be compared via factor analysis of the WISC-IV and CPT-II. The WISC-IV, which measures G_f-G_c cognitive components (Keith et al., 2006; Wechsler, 2003), proposes the measurement of novel problem solving and concept formation; however, there is evidence that traditional intelligence testing does not appropriately evaluate executive functions, including executive control (Ardila, Pineda, & Rosselli, 2000).

Also, the relationship of these cognitive components remains in question. The hierarchical processing theory is supported by McGrew's (2003) WJ III CHC Information Processing Model. In this model McGrew (2003) identifies processing speed and working memory as constructs that function separately and above or predictive of Spearman's g (1927) and other stratum II cognitive components. The CHC Information Processing Model (McGrew, 2003) also provides support of a process between cognitive components in the G_f-G_c theory.

The second main purpose of this research is to test the structure of the Dean-Woodcock Neuropsychology Model (Dean et al., 2003). Given the fundamentals of cognitive processing proposed by contemporary research, questions arise as to the structural integrity of the Dean-Woodcock model. In particular, Luria (1966, 1973, & 1980) explained human cognition as the process between three systems, with primacy given to attention (Luria, 1973). Also, working memory has since been validated as a process between short term memory, long term memory, and executive control (Baddeley, 2003), which is not accounted for by the Dean et al. (2003) model. Therefore, the inclusion of G_{ec} and G_{at} components questions the primacy of each component within the Dean-Woodcock (2003) model. Analysis of the cognitive domains measured by the WISC-IV, and attention and executive control, as measured by the CPT-II, will shed light on the relationship between executive control, attention, and measures of cognitive ability in children.

Below (Figure 1.1) is a preview of the modified Dean Woodcock Neuropsychology model, with attention added as a primary component, to be tested in this study. This model guides the second step of this research study by providing a framework for analyzing the relationship between cognitive components. The model will be further explained in Chapter 3, Variables and Models.

Figure 1.1 Modified Dean Woodcock Neuropsychology model, with attention added as a primary component



G_{ec}= Executive Control
G_s= Processing Speed
G_{at}= Attention
G_{sm}= Short Term Memory/Conscious Awareness
G_f= Fluid Intelligence
G_v= Visual Spatial Ability
G_c= Crystallized Intelligence

1.7 Research Questions

1. Are there additional components, in addition to G_f-G_c, that further explain cognitive functioning and processes? Confirming data would include the components G_f, G_c, G_s, G_v, and G_{sm} delineated in the Keith et al. (2006) literature, with the addition of attention (G_{at}) and executive control (G_{ec}).
    a. Does executive control constitute a separate construct than is accounted for and measured by cognitive tests of G_f-G_c theory?

b. Does attention constitute a separate construct than is accounted for and measured by cognitive tests of G_f-G_c theory?

2. What is the structure of the relationship between attention, executive control, and CHC stratum II components measured by the WISC-IV? This model will be dependent first on verification of the presence of attention and executive control in research question #1. The second step of this question is dependent on the hypothesis that the components fit a model that is represented by Figure 1.1, with respect to G_f-G_c, and attention and executive control.

    a. Does the Dean Woodcock Neuropsychology Model (Dean et al, 2003) accurately represent the relationship between cognitive components?

CHAPTER 2

LITERATURE REVIEW

2.1 Processing Theory

Luria explained cognitive functioning as a process between cognitive systems (1966, 1973, & 1980). The concept of processing between systems differs from the basic G_f-G_c (McGrew & Flanagan, 1998; McGrew, 2003) method, which analyzes separate abilities. Luria's seminal works investigated the brain's involvement in complex behavior. He explained cognitive processing within three functional systems that can be associated with separate anatomical brain regions.

Luria's (1973) first system includes the ability to sustain attention. The first system is the basis for the cognitive processing model. Attention is necessary for the performance of information acquisition and processing (Das, Naglieri, & Kirby, 1994). This system is associated with the brain stem, diencephalon, and medial regions. These brain regions are responsible for arousal and cortical tone, which affect the adequate maintenance of attention (Stuss & Benson, 1984).

The second cognitive system is responsible for the integration of sensory input and complex planning/organizational skills (Kaufman & Kaufman, 2004; Reitan, 1988). This system accounts for cognitive memory functions, in that it is this system that controls the analysis, management, and storage of data input from the external world (Luria, 1966; Kaufman & Kaufman, 2004). The data integration and storage system is associated with temporal, frontal, cerebellar, hippocampal, and occipital lobe regulation (Rosenzweig, Breedlove, Leiman, 2002).

The final system involves the planning and organization of behavior, based on the data integrated and stored through the second system. This organized behavior occurs through hypothesis generation, planning, and self-monitoring (Das et al, 1994; Kaufman & Kaufman, 2004; Luria, 1973). The third system is associated with frontal lobe regulation (Das et al., 1994; Reitan, 1988; Stuss & Benson, 1984). This executive functioning system also follows a cognitive processing approach, which conforms to a hierarchical organization of dominance within cognitive systems (Luria 1966, 1973, & 1980).

The processing approach to cognition (Das et al, 1994; Kaufman & Kaufman, 2004; Naglieri, 1999; Reitan, 1988) is supported by current test construction, such as the KABC-II (Kaufman & Kaufman, 2004), and cognitive theory, such as the Dean-Woodcock Neuropsychology model (Dean, Woodcock, Decker, & Schrank, 2003). The KABC-II and Dean-Woodcock theory are similar to Luria's (1966, 1973, & 1980) model of cognitive processing, which identifies the importance of a reciprocal interaction between the first, second, and third cognitive systems (Das, Naglieri, & Kirby, 1994; Kaufman & Kaufman, 2004; Luria, 1970; Naglieri, 1999; Reitan, 1988).

The Dean-Woodcock Neuropsychology Model (Dean et al., 2003), explains human cognitive abilities as a process between higher and lower cognitive functions. The Dean-Woodcock model discriminates from lower to higher skills as reflexive, automatic, and thinking. The skills function in a reciprocal interaction similar to Luria's (1966, 1973, & 1980) explanation of the first, second, and third cognitive systems. The Dean et al. (2003) model represents a cycle of sensory input, processing, and output. Although similar to Luria's (1973) processing approach, Dean and colleagues (2003) provide a more detailed rationale for a hierarchy of skills.

Dean et al. (2003) advocate for a hierarchy of skills within an information-processing model. While sensory and motor functions are analyzed at input and output levels (reflexive), they set the stage for the effective performance of "thinking" level skills. The Dean-Woodcock Neuropsychology model explains that novel reasoning cannot occur without first activation of the sensory register, and then conscious awareness. Following conscious awareness, the analysis of stimuli occurs (through tactile-kinesthetic thinking, visual-spatial processing, and/or auditory processing). The long-term storage-retrieval ability is then stimulated prior to active transformation of stimuli to an output answer, also known as novel reasoning. This process is differentiated from "automatic," for which no active thinking is necessary. Examples of "automatic" processes are those over-learned skills with which we are fluent.

Dean et al. (2003) note that cognitive performance, motor output, and conscious awareness of stimuli cannot occur without passing through an executive control system. The executive control system includes motivation/volition, cognitive style/temperament, and emotional state. The executive control system acts as a gatekeeper directing the path of automatic versus non-automatic/novel processes. This system is also responsible for allocation of attention and monitoring of performance. Dean et al. (2003) include executive control in their model of cognitive processing, but they explain EF as solely a control mechanism with personality features. This model is similar to Barkley's (1997 & 1999) explanation of the behavioral and cognitive dyscontrol found in children with

ADHD. The construct of executive control will be investigated further in the Executive Functioning section of this chapter.

Kaufman and Kaufman (2004) developed The Kaufman Assessment Battery for Children, Second Edition (KABC-II) as a contemporary cognitive battery that begins to explore the union of Luria's (1966, 1973, 1980) processing theory and the G_f-G_c model of human cognition (McGrew & Flangan, 1998). The theoretical approach to developing the KABC-II is consistent with the focus of this study. The KABC-II provides a piece of evidence for cognitive processing within a field of study that lacks such investigation. While the application of the processing approach (Luria 1966a, 1966b, 1973, & 1980) within the component cognitive G_f-G_c model (McGrew, 2003) has been validated (Kaufman & Kaufman, 2004), a hierarchical organization of EF (Goldberg, 1987) within that system has not been fully explored.

2.2 Executive Functioning

A neuroanatomical perspective of Executive Functioning (EF) explains a system including five sub-domains: (1) control; (2) organization, synthesis, judgment (OSJ); (3) attention; (4) planning, sequencing, monitoring (PSM); and (5) personality (Andrewes, 2001). This five dimension definition of EF incorporates multiple founding theories in the area. This neuroanatomical definition will be a key theory for understanding EF this research study, because it includes and explains the fundamental variables being studied. Andrewes (2001) definition of EF is differentiated from the Dean et al. (2003) explanation of executive control, and Barkley's (1997, 1999) model of behavioral and cognitive dyscontrol, because it includes problem solving and concept formation as component skills instead of viewing them as separate constructs.

Control, OSJ, PSM, Attention, and Personality are dependent on each other and function based on a hierarchical processing system. Theories of hierarchical cognitive functions have been postulated (Duff, Schoenberg, Scott, & Adams, 2005), which assume frontal lobe executive control is critically involved in the hierarchical model (Goldberg & Bilder, 1987; Stuss & Benson, 1987). The study conducted by Duff et al. (2005) completed a canonical correlation of executive functions and memory, and determined that EF and memory share 55-60% of variance. A limitation noted by Duff et al. (2005) is that despite a relationship being evidenced, directionality could not be determined. This lack of causality may further support the postulation that EF and cognitive functions act within an interrelated global system.

Investigators have attempted to refute a hierarchical EF model (Varney & Stewart, 2004); however, their relationship did not include executive control as a foundational component. Rather, Varney and Stewart (2004) defined EF as planning and problem solving of verbal and nonverbal tasks. Their research did, however, support the definition of EF as a multi-component system as opposed to a single domain score.

As posed in this study, control is the necessary function for the performance of other "higher level" skills, such as concept formation, problem solving, and insight. One must possess the ability to control cognitive, attention, motor, and limbic systems in order to execute dependent skills properly (Barkley 1997, 1999). Goldberg and Bilder (1987) explain that the hypothesis of hierarchical cognitive control assumes two requirements. First, sequential organization allows for a dependent relationship between any operation and the output of the prior operation; and second, previous stages of the cognitive skill include more general types of the desired skill. Within the hierarchical processing model of EF, the base begins with control, followed by concept formation and problem solving, and ending with features of personality. The ability to form concepts and problem solve are dependent on the necessary performance of executive cognitive control. While social organization and motivational components are subsumed as an executive skill, this study focuses on cognitive skill rather than personality. For the purposes of this research study personality features will not be included; however, application of a hierarchical processing analysis between cognitive EF, personality EF, and component cognitive skills may be an important area of future research.

A hierarchical processing model can provide explanation for common executive deficits found in children with ADHD. Barkley (1997 & 1999) describes ADHD as a disorder marked by global dyscontrol. If a child with ADHD is lacking basic cognitive and behavioral control, then it would serve logical that their higher order executive functions would be negatively affected. To find support for this theory, one may look to the common measures used for the evaluation of ADHD in children. Measures of verbal learning, self-regulation, sequencing, mental flexibility, response/behavioral inhibition, planning, organization, attention, and working memory (Antshel & Waisbren, 2003; Barkley, 1997; de Jong & Das-Smaal, 1995; Seidman et. al., 2001; Wecker et. al., 2000) have been employed in batteries used to assess Attention Deficit Hyperactivity Disorders (ADHD) in children (Antshel & Waisbren, 2003; de Jong & Das-Smaal, 1995; Seidman et. al., 2001; Wecker et. al., 2000). The assessment of ADHD is important in the understanding of EF, because ADHD is characterized by categorical executive dysfunction (Mattson et at, 1999).

2.2.1 Sub-domains of Executive Functioning

2.2.1.1 Control (Flexibility)

Control refers to a person's ability to vary inhibition of multiple system functions, including cognition, emotion, language, attention, motor movements, and memory (Andrewes, 2001; Stuss & Benson, 1987). Flexibility of control is a subset of inhibition, and therefore is subsumed under control (Andrewes, 2001). The concept of control over novel situations, of which there is no preexisting schema, is a fundamental function of the prefrontal cortex (Goldberg, Podell, & Lovell, 1994). Flexible control describes how a person inhibits or disinhibits perceptual, cognitive, and response elements (Lezak, 1995), based on information from a feedback loop (Andrewes, 2001). The feedback loop is an automatic self-monitoring system that determines whether or not the amount and type of control resulted in the desired outcome. This loop is based on sensory feedback from the environment or mechanisms such as biofeedback. Deficit in executive flexibility results in perseverative and dysfunctional cognition, perception, or response (Lezak, 1995). Studies have also shown that intact flexibility is positively related to increased internalization of attributions for desired or positive situations (Garcia, Torrecillas, de Arcos, & Garcia, 2005).

A distinction can be made between control that is voluntary (effortful) versus control that is less than voluntary or reactive (Eisenberg, Spinrad, Fabes, Reiser, Cumberland, Shepard, Valiente, Losoya, Guthrie, & Thompson, 2004). Linked to anterior cingulate gyrus involvement (Posner & Rothbart, 1998), effortful control explains voluntary and flexible modulation of attention and activation or inhibition of behavior. Eisenberg et al. (2004) demonstrated the direct positive relationship between effortful control and impulsivity with externalizing behavior, and the indirect relationship with internalizing problems; however, their research noted the distinct impact of effortful control and impulsivity to outcomes. Conclusions form the Eisenberg et al. (2004) study note that children with low impulsivity do not spontaneously attempt new problem regulatory strategies; and children with low effortful control may not be able to manage negative emotional states. Thus, it can be predicted that children with low levels of either effortful control or impulsivity will have low levels of resiliency, possibly increasing the risk of internalizing problems (Eisenberg et. al., 2004). The addition of effortful control to the explanation of EF is important to better detail the impact of control on human behavior, cognition, and emotion.

2.2.1.2 Organization, Synthesis, Judgment (Concept Formation)

Andrewes' (2001) OSJ describes the function of a person's concept formation. Concept formation is the ability to categorize and compare current information and/or experience with previous learning or experience (Andrewes, 2001). In short it explains a person's capacity for abstracting universal or rational concepts (Wang, 1987). Concept formation is also responsible for a person's ability to make socially acceptable or situation based judgments. One must address new information in relation to their knowledge base (Murphy & Allopenna, 1994) and determine how it fits with their preexisting schemas (Andrewes, 2001). For example, concept formation deficits in children with Autistic Disorder have been examined (Minshew, Meyer, & Goldstein, 2002), which account for their difficulty generalizing learned social skills to novel social situations.

The skill of concept formation is believed to be housed in the frontal lobes (Wang, 1987). It is not affected by level of education, and it follows a specific developmental pattern (Wang, 1987). Development of concept formation skills in will be discussed further in the development section of this chapter.

2.2.1.3 Planning, Sequencing, Monitoring (Problem Solving)

Inherent in executive functioning is optimal performance of goal directed behaviors (Luria, 1973). The neuroanatomical perspective describes planning, sequencing, and monitoring as necessary for a person's ability to problem solve (Andrewes, 2001). It is the ability to plan goal oriented behavior, and self monitor the problem solving process. This skill is necessary for the identification and organization of the process and components necessary to achieve a goal (Lezak, 1995). A person can self monitor via a cognitive and sensory feedback loop. From this feedback a person must determine if their course is appropriate for the task and modify accordingly (Andrewes, 2001). Deficit in self-correction and self-monitoring may result from an inability to perceive mistakes, or inaction to correct such mistakes (Lezak, 1995).

Newman, Carpenter, Varma, and Just (2003) explain that the prefrontal cortex is involved in the function of problem solving. They go on to explain that while there is bi-hemispheric involvement in planning, a necessary component of problem solving (Andrewes, 2001), the left and right prefrontal cortices are involved in different stages of planning. Newman et al. (2003) conclude that the right prefrontal cortex may be more involved with the generation of a plan, and the left prefrontal cortex may be more involved in the execution of a plan. As will be described further in the biological basis section of this chapter, the Newman et al. (2003) conclusion mirrors the novelty-routinization approach to frontal lobe functions (Goldberg, Podell, & Lovell, 1994), which indicates that novel problem solving is a right frontal lobe function.

2.2.1.4 Personality

The executive manifestation of personality is comprised of drive, social skills, and insight (Andrewes, 2001). Drive refers to initiation to undertake a task. Persons with frontal lobe damage can exhibit decreased drive, which can result in an inability to initiate activities or carry through on a task (Andrewes, 2001; Lezak, 1995).

Impaired social skills can also occur following severe focal frontal lobe damage. This deficit presents as a person being socially inappropriate, not being able to form social strategies, and not being able to synthesize social feedback (Andrewes, 2001). A deficit in social competence can present as crude behavior, or a lack of understanding and recognition of social norms and mores. Impaired social awareness may result in extreme forms of politeness (Lezak, 1995).

Insight relates with the ability to compare one's characteristics, emotions and social adaptation, to those of others, and in turn modulate one's behavior and adapt socially (Andrewes, 2001; Prigatano, 1991). This capacity of self-awareness includes both the awareness of physical status and the awareness of situational and environmental contexts (Lezak, 1995).

2.3 Attention

Attention refers to a person's ability to distribute their focus, also called divided attention, to different tasks, while simultaneously avoiding situational intrusions (Andrewes, 2001). The attention component has been left out of the hierarchical processing model of executive functioning, because attention doesn't follow conceptually with the idea of executive skill. However, attention does include an executive component and components of attention are included in the cognitive processing model proposed in this research. For example, Posner and Peterson (1990) described the executive control system as including control functions of attention such as divided attention, selective attention, sustained attention, and alertness. Therefore all facets of attention are not controlled by executive functioning; rather the overarching concept of attention is modulated by EF. Attention is an important feature of this research and it will be investigated as existing in a relationship (Luria, 1973) with executive control (Posner & Peterson, 1990; Meyer & Kieras, 1997) and G_f-G_c (McGrew & Flanagan, 1998; McGrew, 2003) cognitive components.

Support for the separation of attention and G_f-G_c cognitive components was provided by studies showing need for the focused assessment of attention (Naglieri, Goldstein, Delauder, & Schwebach, 2005; Manly, Anderson, Nimmo-Smith, Turner, Watson, & Robertson, 2001). In the Naglieri et al. (2005) study, attention, as measured by the Conners' Continuous Performance Test (CPT), and cognitive ability, as measured by the Wechsler Intelligence Test for Children-3rd ed. (WISC-III), were found not to share significant variance. The lack of significant correlations between the CPT and WISC-III suggests unique variance for each measure. Similarly, Manly et al. (2001) found that sustained attention, selective attention, and attentional control are not directly measured by WISC-III prorated IQ or the vocabulary, similarities, block design, or object assembly subtests. These studies support the investigation of EF, G_f-G_c cognitive components, and attention as separate constructs.

2.3.1. Andrewes' Theory of Executive Attention

Andrewes (2001) explains four systems of attention: the arousal system, orienting system, perceptual system, and executive attention system (Posner & Peterson, 1990). Each of these four systems is responsible for different functions related to attention. The arousal system is broken down into two types: tonic arousal and phasic arousal. Arousal is directly influenced by the ascending reticular activating system (ARAS) with sensory information being passed through the thalamus. The thalamus is responsible for regulation of sensory information available to brain systems (Andrewes, 2001).

Tonic arousal refers to arousal involved in the daily cycles of sleep and wakefulness, and the ability to be awakened and maintain wakefulness (Andrewes, 2001; Stuss & Benson, 1984). Tonic arousal is influenced by the suprachiasmic nucleus (SCN). The SCN is situated above the optic chiasm with neuronal projections stemming from the optic nerve. The SCN has access to information regarding environmental light. The SCN has a direct role in regulating circadian rhythm, and thus the varying levels of arousal throughout the day (Andrewes, 2001). Severe pathology of tonic arousal is akinetic mutism. This disorder is characterized by an intact sleep-wake cycle, but little cognitive function (Stuss & Benson, 1984). The other end of the spectrum describes "drifting attention". In this case, attention can be given to a stimulus, but is quickly reverted back to a lethargic or sleepy state (Stuss & Benson, 1984).

Phasic arousal is considered more variable than tonic arousal because it is determined by environmental events (Stuss & Benson, 1984). "Fight or flight" is a metaphor used to describe the physiological attention response to dangerous environmental stimuli. Phasic arousal is affected by hypothalamic influence. The hypothalamus is responsible for the mediation of emotion and drive, or hunger, in relation to environmental events. When dangerous stimuli are identified, one becomes alerted by hormones released through the adrenal glands, or ARAS. A disorder in which tonic arousal is intact, but thalamic (phasic) functions are deficient is characterized by alertness and cooperation with an inability to suppress external stimuli (Stuss & Benson, 1984). In this case, external stimuli are easily distracting.

The orienting reflex response is the attentional component of phasic arousal. This is seen as simply changing attention to a stimulus of appeal. The orienting reflex is in response to novel stimuli (Andrewes, 2001). It is a curiosity for unfamiliar events or objects. The reflexive structured control of eye movements in response to stimuli is accounted for by the orienting system. Eye movements are oriented to stimuli via a pathway involving the superior colliculus (SC). The SC acts as a mediator of sensory information, sensory eye fields, motor systems, executive control, and the eye in order to orient attention to a specific novel stimulus (Andrewes, 2001). Habituation occurs when a stimulus is no longer novel, and doesn't elicit the orienting reflex.

The perceptual attention system is responsible for selective attention based on preferential concentration to stimuli of relative importance (Andrewes, 2001). A common example of the function of this system is the cocktail party phenomenon. If a person is at a cocktail party and they are engrossed in a conversation that demands their attention, then they may not hear a person across the room calling their name. If that same person is involved in a boring or uninteresting conversation, their name or other words of interest spoken across the room may get their attention. The perceptual attention system allows a person to perceive important stimuli despite attending to something else (Andrewes, 2001).

Andrewes (2001) describes the executive attention system as having specific control of the inhibition of the reflexive orienting response. Forms of attention mediated by the executive attention system include focused attention, sustained attention, divided attention, and attention shifting. Focus involves capacity for attention and the ability to attend selectively to stimuli. Sustained attention specifically involves vigilance to task. Sustaining attention and remaining alert affect the ability to complete a task effectively. Divided attention refers to the simultaneous use of information, which allows for the manipulation and integration of multiple sets of stimuli. Attention shifting involves the cognitive control of the attentional system. Divided attention is most affected by acute frontal lobe injury or diffuse brain injury affecting the frontal-brainstem control pathway (Stuss & Gow, 1992). Cognitive flexibility allows attention to be shifted between sets based on feedback or changing classification requirements (Andrewes, 2001).

The Andrewes (2001) model of attention follows true to cognitive processing theory. Each attention component functions in an interdependent relationship of cause-effect-modulation. For example, sustained attention is a task associated with the executive attention system. However, the processing of the attention system (Das, Naglieri, Kirby, 1994) indicates that for the proper execution of sustained attention the arousing, orientating, and perceptive systems must function properly. Cognitive processing and the hierarchical model of cognition are common themes in this research. Andrewes (2001) supported this process approach through evidence of the cause-effect-mediation relationship of attention.

2.3.2. Posner and Peterson Three Factor Theory of Attention

In a seminal work on the attention system, Posner and Peterson (1990) delineated three basic characteristics of human attention. First, the attention system can be identified as separate from other cognitive systems in the brain. Second, attention functions within a network, as opposed to a single center or a general brain function. Third, within the attention system, different regions perform different functions. Posner and Peterson (1990) explain the three functions as orientation, signal detection, and vigilance.

In a contemporary examination of attention in children, Manly et al. (2001) provided support for Posner and Peterson's (1990) explanation of three functions within the attention system. Manly et al. (2001) applied the Structural Equation Modeling (SEM) approach to data from a child sample that was given a contemporary attention battery (Test of Everyday Attention for Children) executive functioning measures, and a measure of cognitive ability. The SEM indicated the best fit for a model of attention in children including selective attention, attentional control/switching, and sustained attention. In addition to Manly et al. (2001) providing support for Posner and Peterson's (1990) three separate attention functions, the nonsignificant relationships they found between attention factors and other cognitive tasks provide support for attention components as additional skills separate from typical G_f-G_c cognitive components.

2.3.3. Norman and Shallice Theory of Attention

Norman and Shallice (1986) explain the difference between routine behavior and behavior requiring executive involvement. Routine behavior involves three steps: sensory activation of schemas; the selection of appropriate, or "best match", schemas given the stimuli; and ending with the execution of a behavior program. The Norman and Shallice (1986) model is investigated to provide a basis for the fractionation of attention and EF.

Routine behavior is considered automatic and not in need of executive involvement. Behavior can be considered automatic following a number of different criteria. Hasher and Zacks (1984) list six criteria for automaticity: encoding without deliberate effort; incidental encoding; no effects of training or practice; small individual differences; small to no age differences between children, adults, and elderly; and information is not disrupted by simultaneous attention-demanding tasks. The model of behavioral control (Norman & Shallice, 1986) involves the use of a contention scheduler to associate stimuli with appropriate schemas.

The Supervisory Attentional System (SAS) explains the function of the control of cognitive functions in order to navigate a new task. If the contention scheduler cannot find a preexisting schema, there is more than one appropriate schema available, the strongest schema is inappropriate given the situation, or the consequences of a wrong schema selection are dangerous, then the SAS becomes involved to adapt and integrate components of previously learned information and the novel task (Norman & Shallice, 1986).

The explanation of the executive attentional system bares resemblance to the Norman and Shallice (1986) model of executive functioning. The executive attentional system allocates resources to specific functions depending on the need of an organism. The SAS defines it as non-automatic behavior, but this can be translated into behavior that is novel or requires additional cognitive resources. The SAS model provides support for the disconnection of EF and attention, and further explains the executive modulation of attention.

2.4 Executive Memory (Working Memory)

The cognitive component of memory is inclusive of sensory, working, and long term memory. Executive functions serve as a modulator between the three types of memory, but neither is independent of the other three. A model of multiple theoretical views describes working memory as a function of the phonological loop (composed of the phonological store and articulatory loop), central executive, visuo-spatial sketchpad (composed of the visual cache and inner scribe), and episodic long term memory buffer (Baddeley & Hitch, 1974; Baddeley, 2003). The central executive in this model refers to executive modulation of attention (Baddeley & Hitch, 1994) and accounts for the "working" component of working memory.

A comparison has been made between the current working memory model and multi-component cognitive G_f-G_c theory (Baddeley, 2003). An individual's episodic long-term memory, acquired language, and visual semantics account for crystallized skills that are referenced to provide the foundation for novel problem solving. The visuo-spatial sketchpad, episodic buffer, and phonological loop are fluid systems of G_f related abilities. The central executive is a separate regulatory system that controls cognition and behavior based non-automatic cognitions or behaviors (Baddeley, 2003).

Baddeley (2003) makes the comparison of G_f-G_c with the fluid and crystallized systems of working memory, with central executive functions apparent as a separate collaboration. The correlation of working memory and G_f-G_c components is clear, with executive functioning as a separate additional component (Baddeley, 2003). Additionally, Duff, Schoenberg, Scott, and Adams (2005) found that working memory shares more variance with learning and memory than with executive functions. This study provided support for the separation of executive functions and working memory. A comprehensive psychometric analysis, which includes the neuroanatomical executive functioning components as separate skills from the basic G_f-G_c broad domains, provides productive foundation for the relationship between cognition and the hierarchy of executive functions (Baddeley, 2003).

2.4.1. Theories of Working Memory

Baddeley and Hitch (1974) pioneered a model of working memory in terms of the central executive modulation and integration of various slave systems. The model of working memory has undergone significant development since Baddeley and Hitch proposed the model of central executive modulation of various slave systems and long term memory in 1974. The slave systems involved in working memory are the visuo-spatial scratch pad and the phonological loop. The phonological loop is responsible for processing auditory information and maintaining it to allow for mental manipulation. The visuo-spatial is comparably responsible for visual and nonverbal information. Each of these systems is dependent on a person's memory capacity. As information/data is being maintained in each of these slave systems, the central executive coordinates the processes of integrating and correlating the information with episodic long-term memory and regulates attention resources (Baddeley & Hitch, 1994). Components of information being addressed in working memory require continued reference to the long term memory, and the episodic buffer performs this task.

A progressive model of working memory breaks the phonological loop into phonological store and articulatory loop. The phonological store accounts for auditory memory span, and the articulatory loop controls the rehearsal and maintenance of the memory. This model also breaks the visuo-spatial sketchpad into the visual cache and inner scribe. The visual cache controls the passive storage of visual memories, and the inner scribe is an active system that controls a person's memories for spatial positioning and movements. The central executive in this model is responsible for the allocation of resources/attention (Baddeley & Hitch, 1994) to each of these slave systems and the meditation of stimuli with visual and language episodic long-term memory.

The exact definition of executive functioning is a somewhat elusive topic. The debate is partially due to the poly-connectivity of brain systems and the possible directionality of control. Many brain systems are dependent or related in function to each other. It is because of this interdependent relationship that the pathway of control has not been solidified.

2.5. Development of Executive Functioning in Children

Children experience three major "growth spurts" in executive function between the ages of 0-5 years, 7-9 years, and 11-13 years (Anderson, 2002). Children as young as 12 months exhibit goal directed problem solving behavior, and as young as 18 months exhibit self control to maintain an action or inhibit a behavior (Gioia, Isquith, Guy, & Kenworthy, 2000). Skills emerging from 0-5 years may include the ability to inhibit certain behaviors and shift to a new response, the ability to voluntarily modulate attention (Luria, 1973), the ability to inhibit instinct behaviors (Klenberg, Korkman, & Lahti-Nuuttila, 2001), the emergence of simple advanced planning skills, the emergence of simple conceptual reasoning and generation of new concepts, the ability to rapidly switch between simple response sets, and an increase in response speed and verbal fluency (Anderson, 2002). Motor inhibition and impulse control are seen as the skills first fully developed, approximately by age 6 years (Klenberg, Korkman, & Lahti-Nuuttila, 2001).

Although attentional control begins to develop around 2 years of age, a child's behavior continues to be highly perseverative until the third and fourth years of age (Posner & Rothbart, 1998). Also between 3 and 4 years old, the accuracy of a child's responses to tasks that require inhibition of a prepotent response increases dramatically (Posner & Rothbart, 1998), with continued improvement of inhibition into adulthood (Durston, Thomas, Yang, Ulug, Zimmerman, & Casey, 2002). This increase in accuracy for selective inhibition tasks marks the development of effortful control in children (Eisenberg et. al., 2004; Posner & Rothbart, 1998).

While younger children can make decisions, their decisions tend to require more time and are not as sophisticated as those made by older children and adolescents. Also, a child begins to acquire the ability to learn from their mistakes and develop alternate strategies, with mastery of this skill by 8 years of age (Anderson, 2002). Children as young as 8 years old can perform tasks of frontal lobe functioning at some level (Davies & Rose, 1999).

Between the ages of 7 to 9 years children increase their ability to deal with multi-dimensional switching tasks, planning and organization skills rapidly develop (between 7 and 10 years), and strategic and reasoning behaviors become more efficient (between 7 and 11 years). A significant burst in processing speed also becomes apparent from approximately 9 years until 10 years old (Anderson, 2002).

During the development from 11 until 12 years old, a child's processing speed experiences another significant increase. Also at this time, self-regulation and strategic decision making abilities change. There can be seen a regression from the use of conceptual strategies to utilization of more conservative and cautious "piecemeal" approaches. A child's information processing, cognitive flexibility, and goal setting are basically mature by 12 years old. Also, at 12 years the neuroelectric activity in the dorsolateral prefrontal area is fully mature (Davies & Rose, 1999). A person's EF development does not end with the critical period of 13 years old, but continues to emerge the refinement of strategies, improved decision-making, increased efficiency and fluency (Anderson, 2002), and concept formation (Wang, 1987).

It has been suggested that a person's frontal lobe develops on a different timeline than other brain regions. Davies and Rose (1999) found that versus parietal lobe development, cognitive performance skills that are dependent on frontal lobe activity take longer and are more significant when they develop. As can be noted from the developmental progress of executive functions, EF develops in spurts rather than a linear progression (Anderson, 2002; Gnys & Willis, 1991).

Anderson et al. (2001) studied the development of executive functions in adolescence. They employed neuropsychological tests of several EF sub-domains in order to determine developmental progression of these skills. This study assumed attentional control, cognitive flexibility, and goal setting as separate components of EF. The developmental progression of EF skills is relatively flat during this time, as compared to the significant spikes or spurts (Anderson, 2002) evident during early and middle childhood. Attentional control undergoes another significant increase around 15 years of age, accounting for an increase in attentional capacity and processing speed (Anderson et al., 2001). This study found that cognitive flexibility is likely already mature by the time a child reaches adolescence. They found no significant increases in this EF component during adolescence. Goal setting, which subsumes initiating, planning, problem solving, and strategic behaviors, steadily improves until 12 years of age and is likely fully developed by this time. Despite improvements in attentional control and planning, adolescence does not offer hallmark changes in EF (Anderson et al., 2001).

Wang (1987) describes concept formation as “last to appear, first to disappear” (pg 10). He explains that concept formation begins to develop in puberty and continues throughout adulthood. Concept formation progressively matures through most of adulthood, but may begin to show decline as early as 40 years of age (Wang, 1987).

2.6. Biological Basis of Executive Functioning

Structural damage to the dorsolateral frontal lobe regions of the brain has been implicated in executive functioning deficits. This brain region has been implicated in mediating executive functions in children as young as 8 years old. Children with damage to the dorsolateral frontal region have demonstrated more EF impairment than did children with damage to either the medial or orbital frontal regions (Filley et al., 1999). However, the frontal connectivity to other brain systems is well documented (Stuss & Benson, 1984), and these systems are thereby regulated by a person’s executive functions. The pathways between these systems, or the systems of interest, are also implicated in executive functioning deficits (Gioia, Isquith, Guy, & Kenworthy, 2000).

Goldman-Rakic (1987) explained that a possible reason why children experience continued improvement in their cognitive abilities, into adulthood, may be because of the elimination of synapses, continued myelin formation, changes in the regulation of neurotransmitter receptor synthesis and maintenance, and modification in the biosynthesis of neurotransmitters and peptides. Davies and Rose (1999) attributed frontal lobe development to progressive maturational stages. In an analysis of variance for performance on tasks measuring frontal lobe (executive) functions versus tasks associated with parietal functions, Davies and Rose (1991) determined that performance on neuropsychological tasks of frontal lobe function showed more significant increases as a child progressed through maturational stages, than did performance on tasks associated with parietal lobe functioning.

Goldberg, Podell, and Lovell (1994) caution against the interpretation of lateral executive functions as verbal versus nonverbal. They describe the novelty-routinization approach as the differential between left and right frontal lobe functions. The right frontal cortex is responsible for the processing of novel or unfamiliar cognitive demands. They describe the left frontal cortex as involves the processing of routine or preexisting knowledge (Goldberg, Podell, & Lovell, 1994). This theory breaks down the verbal – nonverbal barrier in that it assumes right hemispheric involvement in the acquisition of language, a novel task in young children. Similarly, contemporary research describes plan generation as a right prefrontal function, while plan execution is largely a left prefrontal task (Newman et al., 2003).

Rosenweig, Breedlove, and Leiman (2002) describe dysexecutive, disinhibited, and apathetic type syndromes associated with prefrontal cortex injury. Dysexecutive type syndrome, associated with the dorsolateral region of the brain, results in diminished judgment, planning, insight, and temporal organization; cognitive impersistence; motor programming deficits; and diminished self care. A person with a disinhibited type syndrome, which is associated with dysfunction of the orbitofrontal region, may exhibit stimulus driven behavior, diminished social insight, and emotional lability. Finally, the apathetic type syndrome, resulting from damage to the mediofrontal region, includes diminished spontaneity, diminished verbal output, diminished motor behavior, urinary incontinence, lower extremity weakness and sensory loss, diminished spontaneous prosody, and increase response latency.

The dorsolateral region is responsible for the cognitive aspects of executive functioning. While the orbital and medial areas are related to the behavioral manifestations of executive function (Anderson, 2002).

One of the most visible systems affected by the frontal lobe executive control is the motor system. Deficits are apparent in following significant damage to the prefrontal convexity and orbital areas of the prefrontal lobes. Prefrontal convexity damage, otherwise known as hypokinesis, results in retarded motor movement that seems to lack initiative. Orbital damage, otherwise known as hyperkinesis, results in impulsivity and restlessness that may present itself as an inability to sit still and make effective motor movements (Stuss & Benson, 1984).

Luria (1973) also described motor deficits in terms of lesions localized to pre-motor areas, and massive damage to or pathology of the frontal motor areas. Pre-motor region damage/pathology results in an inability to stop the successive repetition of a motor action. This action is seen as a compulsive repetition of preinitiated actions (Stuss

& Benson, 1984). Pre-motor functions differ slightly from frontal motor functions, in that frontal motor damage can result in repetition of a motor action in the presence of different instructions (Stuss & Benson, 1984).

Another role Stuss and Benson (1984) explain as controlled by the frontal lobes is sensory-perceptual function. Unilateral sensory neglect and unilateral inattention phenomenon are characteristic of frontal lobe lesions. Unilateral sensory neglect is characterized by an inability to attend to a sensory field with damage to the opposite frontal lobe. This inability follows a spectrum of severity and can range from minimal neglect to severe sensory defect (Stuss & Benson, 1984). Unilateral inattention phenomenon is described as the inability to report bilateral stimuli in spite of being able to report separate unilateral stimuli in both visual fields (Stuss & Benson, 1984).

Subcortical structures for circuitry pathways in people with Huntington's and Parkinson's disease have been identified. Both disorders have significant executive dysfunction sequelae, and it is important to acknowledge these syndromes to form an understanding of EF. The first circuit is described as the Dorsolateral Circuit and is responsible for executive dysfunction in Huntington's and Parkinson's disorders. The circuit is as follows: convexity of the frontal lobe, dorsolateral head of the caudate nucleus, globus pallidus and substantia nigra, and then medial dorsal thalamic nuclei and ventral anterior. This pathway then circles back to the convexity of the frontal lobe (Andrewes, 2001; adapted from Alexander, Crutcher and Delong, 1990 and Cummings and Coffey, 2000).

The second circuit, named the orbitofrontal circuit, is responsible for emotional and social dysfunction in these disorders. The circuit begins with the inferior lateral prefrontal cortex, then the inferior caudate nucleus, the pallidum and substantia nigra, and finally the medial portions of the ventral anterior and medial dorsal thalamic nuclei, before returning to the inferior lateral prefrontal cortex (Andrewes, 2001; adapted from Alexander, Crutcher and Delong, 1990 and Cummings and Coffey, 2000).

The final circuit, anterior cingulated circuit, is responsible for akinetic mutism, apathy, lack of drive and focus of attention. This circuit begins in the cortex of the anterior cingulated gyrus (Brodmann's area 24), then to the ventral or limbic striatum, nucleus accumbens, ventomedial portions of the caudate and putamen, and finally the medial thalamic nuclei before returning to the cortex of the anterior cingulated gyrus (Andrewes, 2001; adapted from Alexander, Crutcher and Delong, 1990 and Cummings and Coffey, 2000).

2.7. Executive Functioning as it Relates to Attention-Deficit/Hyperactivity Disorder

The DSM-IV-TR (2001) defines Attention-Deficit/Hyperactivity Disorder (ADHD) as a childhood disorder that may include inattention, impulsive behavior, and/or hyperactive behavior. ADHD is broken down into three subtypes by the DSM: ADHD, Combined Type; ADHD, Predominantly Inattentive Type; and ADHD, Predominantly Hyperactive-Impulsive Type. ADHD is a behavioral disorder characterized by specific observable behavioral and social deficits. Even though ADHD is diagnosed through observable behaviors, specific cognitive deficits are hallmark.

Barkley (1999), a key researcher in the area of childhood ADHD, explains that children with ADHD exhibit a deficient ability to inhibit responses. Response inhibition involves three processes: inhibition of initial response prior to the event, stopping an ongoing response during an event, or controlling interference during an event to ensure proper completion. Excessive activity level, or hyperactivity, is due to a child's impulsiveness or inability to inhibit motor action (Barkley, 1999). Children with ADHD have significant trouble conforming to behavioral restriction despite specific instructions from their environment (Barkley, 1999). Inhibitory defect can also be seen as an inability to delay gratification, and an inability to resist temptations (Barkley, 1999).

Children with ADHD have demonstrated significantly lower performance on the Wisconsin Card Sorting Test, Verbal Fluency (F-A-S, animals, and fruits) and Picture Arrangement (WISC-R), which supports the theory that children with ADHD have deficits in executive functioning (Chelune & Baer, 1986; Pineda, Ardila, Rosselli, Cadavid, Mancheno, & Mejia, 1998). Children with ADHD have deficient performance on both the phonetic and categorical sections of verbal fluency tests, but they tend to display more significant deficit on the phonetic section (Pineda, Ardila, Rosselli, Cadavid, Mancheno, & Mejia, 1998).

Children with ADHD perform significantly worse than non-ADHD children on measures of executive function such as the Wisconsin Card Sorting Test, tests of Verbal Fluency, and the Picture Arrangement subtest of the Wechsler series of intelligence tests. This supports the idea that children with ADHD display executive dysfunction (Pineda, Ardila, Rosselli, Cadavid, Mancheno, & Mejia, 1998).

Children with ADHD have significantly more difficulty on cognitive tasks of flexibility and abstract categorization than do children without ADHD. Also, children with ADHD tend to make errors on tasks, such as Picture Arrangement, that are common in persons with frontal lobe damage (Pineda, Ardila, Rosselli, Cadavid, Mancheno, & Mejia, 1998).

ADHD has characteristics similar to prefrontal injury (Benton, 1991). Specifically, ADHD and hyperactivity involve dysfunction of the prefrontal cortex (Benton, 1991). A difference exists between prefrontal injury and ADHD in the functioning of visuo-perceptive and visuo-analytic capacity. These skills are largely intact with prefrontal injury, but can be dysfunctional in children with ADHD (Benton, 1991).

2.8. Executive Functioning Conclusion

In order to complete a proper analysis of the complex nature of EF, time must be spent describing its component parts, development, and biological causation. Through investigation of the neuroanatomical perspective of EF, several key components were identified: control, cognitive flexibility, problem solving, and personality characteristics such as drive, social skills, and insight. These components comprehensively explain the specific executive functions that are not directly related to the executive modulation of other brain systems.

Some contemporary theories of executive functioning include components that are dependent on the proper execution of other systems or skills. For example, the execution of attention and working memory is dependent on the proper functioning of several brain systems. Attention requires a person to have intact arousal system, orienting system, perceptual system, and executive attention system. Dysfunction in any one system will cause a person to experience symptoms of inattention. As well, working memory is dependent on the functioning phonological loop (composed of the phonological store and articulatory loop), central executive, visuo-spatial sketchpad (composed of the visual cache and inner scribe), and episodic long term memory buffer

(Baddeley & Hitch, 1974). As is the case with attention, dysfunction with any one component will affect a person's working memory ability.

The basic concept of EF development in humans explains the theory of hierarchical executive skill development. The first executive skill to develop in children is the ability to control impulses and motor movements (Klenberg, Korkman, & Lahti-Nuuttila, 2001). This control skill sets the groundwork for what proves to be a hierarchical processing order of executive functions. As control is the first to develop, some of the last EF skills mastered include planning, goal setting, concept formation, and judgment. Those skills that are the most complex and difficult to master prove to be those that are most severely affected by dysfunction at the lower levels of the hierarchy.

In conclusion to this executive functioning concept and research synthesis, EF assessment measures can prove to be useful tools for the understanding of what constitutes executive ability. The D-KEFS is an example of a contemporary assessment battery that employs a processing approach to EF, and attempts to account for all of the contributing factors to successful executive functioning. It breaks down the necessary skills for successful completion of a task and separates EF from brain systems that contribute to task completion. This process allows researchers and clinicians to remove the contribution that non-EF skills have on the EF performance. The result is a purer understanding of how executive abilities and other related systems contribute to a person's functioning levels across domains.

2.9. Cattell-Horn-Carroll Model of Cognitive Ability

According to McGrew (2003) the working definition of the Cattell-Horn-Carroll (CHC) theory of cognition categorizes abilities into 16 separate domains of functioning, called the Broad (stratum II) definitions. These broad definitions are further broken down into Narrow (stratum I) definitions that account for comprehensive investigations of the factors that are included in stratum II domains.

Fluid Intelligence/Reasoning (G_f) describes the ability to solve novel or non-mastered problems (McGrew, 2003; McGrew & Flanagan, 1998). The skills necessary for fluid reasoning often include processes such as problem solving, concept formation, and classification. Measured factors that load on this subcategory include general sequential reasoning, induction, quantitative reasoning, Piagetian reasoning, and speed of reasoning (McGrew, 2003).

Crystallized Intelligence/Knowledge (G_c) describes a person's acquired knowledge of the language and specific nuances of culture, and/or the application of this knowledge (McGrew, 2003). G_c is the store of verbal declarative and procedural knowledge. Variance contributing to G_c includes language development, lexical knowledge, listening ability, general information, information about culture, communication ability, oral production and fluency, grammatical sensitivity, foreign language proficiency, and foreign language aptitude (McGrew, 2003; McGrew & Flanagan, 1998).

General (or domain-specific) Knowledge (G_{kn}) describes the extent of a person's acquired knowledge in specialized domains (McGrew, 2003). G_{kn} typically does not represent experiences of a person's particular culture. Factors such as knowledge of English as a second language, knowledge of signing, skill in lip reading, geography achievement, general science information, mechanical knowledge, and knowledge of behavioral content are measures of the variance in G_{kn} (McGrew, 2003; McGrew & Flanagan, 1998).

Visual Spatial Abilities (G_v) describes the set of abilities that accounts for the different processes involved in the generation, storage, retrieval and transformation of visual stimuli. G_v tasks require the accurate perception and mental transformation of spatial orientation tasks. Measures that make up G_v include visualization, spatial relations, closure speed, flexibility of closure, visual memory, spatial scanning, serial perceptual integration, length estimation, perceptual illusions, perceptual alternations, and imagery.

G_a is the acronym for auditory processing. This subcategory explains an individual's ability to control the perception of auditory information (McGrew, 2003). It involves a variety of abilities necessary for the discrimination of sound, and the analysis, manipulation, comprehension, and synthesis of sound. Phonetic coding, speech sound discrimination, resistance to auditory stimulus distortion, memory for sound patterns, general sound discrimination, temporal tracking, musical discrimination and judgment, maintaining and judging rhythm, sound-intensity/duration discrimination, sound-frequency discrimination, hearing and speech threshold factors, absolute pitch, and sound localization are all factors included in G_a (McGrew, 2003).

G_{sm}, short-term memory, describes the ability to capture and maintain stimuli from the immediate situation (McGrew, 2003). CHC theorists (McGrew, 2003) generally explain Immediate as recall within one minute of exposure to stimulus. Memory span and working memory are included as factors of G_{sm}. Working memory is maintained in this interpretation of CHC theory despite being driven by theoretical development and not as an individual differences factor (McGrew & Flanagan, 1998). This is explained further in the section describing the theories of working memory.

Long-term storage and retrieval (G_{lr}) describes the ability to encode information with fluent post retrieval of the information. Two major types of G_{lr} include the ability to fluently retrieve information from long term storage over minutes or hours, which McGrew (2003) describes as intermediate memory, and fluency of retrieval with days, months, or years since encoding. A correlation has also been drawn between the G_f-G_c concept of G_{lr} and the long-term memory buffer explained in Baddeley and Hitch's (1974) theory of working memory (McGrew & Flanagen, 1998). G_{lr} differentiates between the ability to retrieve stored facts, reproductive process, and the ability to produce material from previously learned rules or information. G_{lr} includes twelve narrow factor definitions. Included are the ability to associate pairs of information, rapidly and fluently produce words based on phonemic or categorical clue (McGrew & Flanagan, 1998), and the ability to draw figures based on visual stimulus rapidly and fluently. G_{lr} does not dissociate between verbal and nonverbal tasks, but accounts for the appropriate consolidation of information and accurate manipulation of memory.

Cognitive processing speed (G_s) refers to the speed with which one can accurately perform tasks that are considered relatively routine or automatic. The G_s narrow definition includes speed of reading and writing, the speed with which one can take a test of routine tasks, visual perceptual and scanning speed, and the speed of accurate performance of basic numerical operations.

McGrew (2003) also describes the time needed to make a decision as a broad categorical definition (G_t). On a basic level G_t is the ability to make decisions quickly given simple stimuli (McGrew, 2003). G_t is explained by reaction to a single stimuli, the choice between two or more alternative stimuli, the processing of a decision that requires mental manipulation or comparison of characteristics, and the time it takes to identify changes or characteristics of stimuli based on limited exposure to that stimuli.

Rapid and fluent motor movements that are independent of cognitive control (G_{ps}) are accounted for by the CHC theory. A typical G_{ps} task involves goal directed hand, finger, or leg movements in the presence of a speed requirement.

Quantitative knowledge (G_q) accounts for the breadth and depth of learned quantitative knowledge (McGrew, 2003). Mathematical knowledge involves the storage of declarative and procedural math facts. Math facts are generally measured on tests of math achievement.

Similar to G_q, Reading and writing (G_{rw}) also accounts for the breadth and depth of declarative and procedural knowledge. G_{rw} describes reading and writing skills in terms of reading decoding, reading comprehension, verbal language comprehension, cloze ability, spelling ability, writing ability, English usage knowledge, and speeded reading and writing fluency. Reading speed is also loads on G_s, and writing speed on G_s and G_{ps}. G_q and G_{rw} reflect the integration of achievement into the G_f-G_c theory (McGrew & Flanagan, 1998).

The final broad stratum II definition is psychomotor ability (G_p). G_p is the ability to perform motor movements with precision, coordination, or strength (McGrew, 2003). Measures that load on this domain include static strength, multilimb coordination, finger and manual dexterity, arm-hand steadiness, control precision, aiming, and gross body equilibrium.

Olfactory abilities (G_o), Tactile abilities (G_h), and Kinesthetic abilities (G_k) are included in McGrew's (2003) working definition of the CHC model of cognitive ability, but they have not as of yet been thoroughly investigated. G_o refers to abilities that depend on olfactory sensory receptors. Each category describes sensory sensitivity in each area, with the inclusion of olfactory memory.

Table 2.1

Table of stratum I and II abilities incorporated in the CHC expansion of the G_f-G_c cognitive model. All sixteen stratum II abilities are subsumed under one stratum I ability, labeled as "g" (adapted from McGrew, 2003).

Stratum II	Stratum III
Fluid Intelligence (G_f)	General Sequential Reasoning Induction Quantitative Reasoning Piagetian Reasoning Speed of Reasoning
Crystallized Intelligence (G_c)	Language Development Lexical Knowledge Listening Ability General Information Information about Culture Communication Ability Oral Production and Fluency Grammatical Sensitivity Foreign Language Proficiency Foreign Language Aptitude
General Knowledge (G_{kn})	Knowledge of English as a second language Knowledge of signing Skill in Lip-reading Geography Achievement General Science Information Mechanical Knowledge Knowledge of Behavioral Content
Visual Spatial Abilities (G_v)	Visualization Spatial Relations Closure Speed Flexibility of Closure Visual Memory Spatial Scanning Serial Perceptual Integration Length Estimation Perceptual Illusions Perceptual Alternations Imagery

Auditory Processing (G_a)	Phonetic Coding Speech Sound Discrimination Resistance to Auditory Stimulus Distortion Memory for Sound Patterns General Sound Discrimination Temporal Tracking Musical Discrimination and Judgment Maintaining and Judging Rhythm Sound-Intensity/Duration Discrimination Sound-Frequency Discrimination Hearing and Speech Threshold Factors Absolute Pitch Sound Localization
Short-term Memory (G_{sm})	Memory Span Working Memory
Long-term Storage and Retrieval (G_{lr})	Associative Memory Meaningful Memory Free Recall Memory Ideational Fluency Associational Fluency Expressional Fluency Naming Facility Word Fluency Figural Fluency Figural Flexibility Sensitivity to Problems Originality/Creativity Learning Abilities
Cognitive Processing Speed (G_s)	Perceptual Speed Rate of Test Taking Number Facility Speed of Reasoning Reading Speed-fluency Writing Speed-fluency
Decision/Reaction Time or Speed (G_t)	Simple Reaction Time Choice Reaction Time Semantic Processing Speed Mental Comparison Speed Inspection Time
Psychomotor Speed (G_{ps})	Speed of Limb Movement Writing Speed-fluency Speed of Articulation Movement Time
Quantitative Knowledge (G_q)	Mathematical Knowledge Mathematical Achievement
Reading/Writing (G_{rw})	Reading Decoding Reading Comprehension Verbal-printed Language Comprehension Cloze Ability Spelling Ability Writing Ability English Usage Knowledge Reading Speed-fluency Writing Speed-fluency
Psychomotor Abilities (G_p)	Static Strength

	Multilimb Coordination Finger Dexterity Manual Dexterity Arm-hand Steadiness Control Precision Aiming Gross Body Equilibrium
Olfactory Abilities (G_o)	Olfactory Memory Olfactory Sensitivity
Tactile Abilities (G_h)	Tactile Sensitivity
Kinesthetic Abilities (G_k)	Kinesthetic Sensitivity

2.10. The Development of the CHC Model of Cognitive Ability

The CHC model underwent major developments during throughout its history leading to the contemporary version. A continuum of progress proposing significant theoretical, measurement and assessment developments is suggested by McGrew (2004).

The development of the CHC model began with Spearman's g/s factor theory. Spearman's two-factor theory poses a correlation between general intelligence (g) and specific factors (s). These two factors were thought to explain for the relationship between measures of sensory discrimination. It is fitting that the roots of a theory based on factor analysis begin with the g/s factor theory, because Spearman has been credited for introducing factor analysis to cognitive theory.

The British Tradition began by analyzing the g-factor and then grouping smaller factors based on breadth. This theory posed a hierarchical theory of g and its "subfactors" (McGrew, 2003). It suggested that most of the variance of intelligence was made up of g and to a lesser extent the small group factors.

The American Tradition does not readily identify a g-factor. This led to the formation of second order factors. Thurstone's Primary Mental Abilities (PMA) theory (1938) separated seven to nine abilities that were essentially independent of the factor g. This was the beginning of the differentiation between fluid (G_f) and Crystallized (G_c)

intelligence. Factor analysis of the first order definitions led to second order definitions explaining G_f and G_c. After this development, the WERCOF abilities were recognized, which suggested 60 possible cognitive abilities (McGrew, 2003).

Following early development of psychometric theory, specific research on the G_f-G_c theory provided an extension to the existing factors. Additional broad G-factors were included in the model. They were G_v (visuo-spatial abilities), G_{sm} (short-term memory), G_{lr} (long-term storage and retrieval), and G_s (cognitive processing speed). The additional G-factors were supported by factor analytic, developmental, genetic, neurocognitive, and outcome-criterion evidence research (McGrew, 2003). There was additional support for eight broad abilities and a hierarchical structural model of intelligence (Gustafasson, 1984). At the time that research was supporting the existence of these additional factors, there was no test battery that reflected the theory. This disparity is referred to as a theory-to-applied measurement practice gap. The hierarchical framework was based on the suggestions that G_f was equivalent to “g”, which essentially placed G_f at the top of the pyramid.

The WJ-R battery (Woodcock & Johnson, 1989) was the first clinical assessment of cognitive ability that was based on the G_f-G_c theory. This assessment specifically aimed at closing the theory-to-applied measurement practice gap. Through factor analysis of the WJ battery, independent researchers (Horn, Carroll, Woodcock, and McGrew) design the WJ-R, which measures nine broad abilities.

Following this major advancement in the assessment of cognitive ability, other well known intelligence batteries (DAS, DTLA-3, KABC, SB-IV, and WISC-

R/WAIS/WAIS-R) were classified at the broad G_f-G_c level. This cross-battery assessment further verified the construct evidence for the G_f-G_c theory.

Carroll's (1993) three tier hierarchical model of cognitive ability included an overarching g-factor, which was defined by breadth of generality. The developing model of ability included narrow, broad, and general levels. To this point Cattell and Horn's model differed from Carroll with respect to the presence of a g-factor. Empirical evidence from the use of WJ-R norm data supported the existence of Carroll's three levels of ability, and also the presence of intermediate abilities, which exist between the three levels.

Emerging empirical data lead to a merging of the theories and the classification of intelligence batteries into narrow and broad ability levels. It sparked investigations into the definitions of broad and narrow abilities. A formalized cross battery confirmatory factor analytic (CFA) approach was applied to major intelligence assessments for classification of abilities (Phelps, McGrew, Knopik, & Ford, 2005). The Phelps et al. (2005) CFA used the Wechsler Intelligence Scale for Children, 3rd edition (WISC-III) and the Woodcock Johnson Test of Cognitive Abilities, 3rd edition (WJ-III) to confirm G_f-G_c broad domains and narrow abilities. The WISC-III and WJ-III load heavily on five stratum II domains (G_c, G_q, G_s, G_{sm}, G_v), and additionally the G_a, G_f, and G_{lr} domains load only on the WJ-III assessment. Phelps et al. (2005) indicates that the fourth edition of the Wechsler intelligence series (WISC-IV; PsychCorp, 2004) may represent the addition of G_f, G_a, and G_{lr} domains.

As the investigations of this theory continue, empirical evidence validates the broad abilities G_f, G_c, G_v, G_{sm}, G_{lr}, G_s, G_q (quantitative knowledge), and G_{rw}

(reading/writing) as structural components of the CHC model. The presence of G_q and G_{rw} reflects the integration of achievement into this model. The continuing study of this theory can account for the validation of the sixteen broad level abilities. As this working model of cognitive ability continues to develop, stratum II and stratum I will continue to be refined through empirically validated psychometric evidence. The purpose of this research is to continue this investigation. The inclusion of executive functions and attention is relevant to the development of CHC cognitive theory.

2.11. Relationship between Executive Functioning and Cognitive Ability

Executive functioning, when defined as a skill describing responses to the inhibition of confounding variables for the integration, organization, and maintenance of attention and memory (Wecker et. al., 2000), has been linked to Global Fluid Intelligence (G_f) (de Jong & Das-Smaal, 1995), academic achievement, a child's placement in special classes, a child's need for tutoring assistance, and grade retention (Seidman et. al., 2001). Deficits in executive functioning for children aged 8-17 years with brain lesions, as measured by the Wisconsin Card Sorting Test (WCST), were found not to be related to general cognitive impairment as measured by the VIQ and FSIQ (Filley et al, 1999). However, in a population of normal children with above average to very superior IQs, performance on the WCST was found to vary based on IQ level (Arffa, Lovell, Podell, & Goldberg, 1998). Arffa et al. (1998) found that children with very superior IQs outperformed peers with above average to superior IQs on the WCST. This study suggests a link between "higher level conceptual functions" (pg. 718) in children and measures of IQ.

Generally, psychometric intelligence has been found to be intact following insult to the frontal lobes or pathology following disease (Benton, 1991). Specific skills measured by conventional intelligence tests are not included in the deficits found in the disabilities of frontal or pre-frontal injury (Benton, 1991). Mattson et al (1999) found that for children with fetal alcohol exposure, there is no significant correlation between intelligence and executive functioning; however they do note that this finding may have been due to the small sample size of their study. Low intelligence does not account for all of the deficit variance found in children with fetal alcohol syndrome and prenatal exposure to alcohol, because of their deficits in executive functioning (Mattson et al, 1999).

Scores on Word Context tests have been found to be correlated with intelligence, but deficits on Word Context measures may not be accounted for primarily by executive dysfunction (Mattson et al, 1999).

Research involving adult neurological patients has demonstrated that people with focal frontal lobe damage often perform normally on tests measuring IQ and other basic skills, such as reading and spelling tests (Delis, Kaplan, & Kramer, 2001). Tests measuring IQ have correlations between .20 and .40 with tests of higher-level EF tests (Ardila, Pineda, & Rosselli, 2000). This means that only about 4-16% of the variance for EF tests is accounted for by measures of IQ and basic level achievement (Delis, Kaplan, & Kramer, 2001). Ardila, Pineda, and Rosselli (2000) found that performance on the WCST, as a measure of concept formation and executive functions, is not highly correlated with performance on the WISC-R. Their conclusions support the postulation that IQ tests are not sensitive to executive control and planning. As well, Murji and

DeLuca (1998) found that FSIQ from the WISC-III was not a factor in overall performance on the Tower of London, as a task of planning and problem solving, for children aged 6 to 15 years with FSIQ greater than 80.

The relationship between ADHD, IQ, and executive functions has been analyzed by many previous studies (Barkley, 1990; Crinella & Yu, 2000; Duncan et al., 1995, 1996; Goldstein, 1987; Priftera & Dersh, 1993; Schwean, Saklofske, Yackulic, & Quinn, 1993; Swanson, 1997; Wechsler, 1991). The thought is that measures of fluid intelligence have a higher correlation to psychometric “g” than do conventional measures of general intelligence (Duncan et al., 1995, 1996), such as FSIQ (Wechsler, 2003) and global composite index. Frontal lobe lesions have been found to affect a person’s executive functions, but they may not affect fluid intelligence (Crinella & Yu, 2000). Regardless, most tasks that measure cognitive ability require some level of executive processing or control (Anderson, 2002).

Mahone, Hagelthorn, Cutting, Schuerholz, Pelletier, Rawlins, Singer, and Denkla (2002) investigated the correlation of EF measures and IQ in children with and without ADHD. Their findings suggest that children with ADHD demonstrate larger deficits on tasks of executive functioning than do normal children when IQ is in the average range. However, children with IQs in the high average or superior range, with/without ADHD, could not be discerned on EF task performance alone. The authors noted that a child’s IQ score accounted for more variance in EF than did the diagnosis of ADHD. This supports IQ as a moderator variable for children with ADHD (Mahone et al., 2002). It also further supports the complex interaction of executive functions and component cognitive abilities being analyzed in this study.

2.12. Literature Review Conclusion

In conclusion to this literature review, it is imperative to recognize the complexity and interrelatedness of cognitive systems. Cognitive processing theories explain the interrelated nature of brain systems (Luria, 1973), as well as their hierarchical nature (Dean et al., 2003). Previous factor analytic studies support additional separate EF factors (Boone et al., 1998) within a cognitive system; and correlational studies indicate that tests of intelligence for children are not sensitive to executive abilities (Ardila, Pineda, & Rosselli, 2000).

The joining of processing and skill based theories is proposed in this research study, based on an extensive review of current literature. Utilizing contemporary state of the art assessments for each component, the theory that executive control, attention, and component cognitive skills function within a reciprocal processing hierarchy will be tested. The procedure for this proposal will be enumerated in Chapter 3 of this study.

CHAPTER 3

METHOD

The methods chapter presents a description of the participants, instruments used, and procedure for statistical analysis involved in this study. This study utilizes an exploratory factor analytic design to evaluate executive control, attention, and the G_f-G_c cognitive components measured by contemporary measures of attention and cognitive abilities in children. Based on literature research analysis (refer to Chapter 2), prior studies identified Crystallized Intelligence (G_c), Fluid Reasoning/Concept Formation (G_f), Visual-Spatial Skills (G_v), Conscious Awareness/Short-term memory (G_{sm}), and Processing Speed (G_s) factors (Keith et al., 2006) as measured by the WISC-IV test of intelligence. This study proposes the addition of attention (proposed G_{at}) and Executive Control (proposed G_{ec}) into a child cognitive factor structure.

Also, in addition to the exploratory factor structure analysis, a structural equation model will be formed to test the relationship between factors. In particular, components of the Dean-Woodcock Neuropsychology Model (Dean et al., 2003) will be tested.

3.1 Participants

Data for this study were collected from an ongoing database of patients referred to the Allegheny General Hospital Department of Psychiatry for a neuropsychological evaluation. Subject data analyzed consisted of 225 children aged 6 to 16 years. Determination of the minimum required sample size for structural equation model analysis was completed prior to subject selection. Based on the Schumacker and Lomax (1996) proposal of 10 subjects per variable, the proposed sample of this study, 225 subjects for 15 observed variables, is adequate for analysis. The age range has been defined between 6 to 16 years in order to follow the age restrictions for the Wechsler Intelligence Scale for Children, 4th Edition (6 to 16 years) (Wechsler, 2003) and Conners' Continuous Performance Test-II (6 years and up) (Conners & MHS Staff, 2002).

Children can be referred for a neuropsychological assessment from a number of different sources including their Primary Care Physician/Pediatrician, School District, Psychiatrist, Mental Health Therapist, or through self-referral. To be included in the study each participant has a Full Scale IQ score in the borderline range or higher (FSIQ $\geq$ 70). Children receiving scores in the mental retardation range (FSIQ $\leq$ 69) were excluded from this study in order to control for skill dysfunction due to global cognitive deficit.

The majority of children referred for evaluation to the Allegheny General Hospital Department of Psychiatry are males. In part because of this disparity, gender differences were not investigated. Previous studies have found relatively few sex differences on measures of executive functioning (Davies & Rose, 1999), and it seems that both girls and boys develop executive functioning skills at similar rates (Anderson, 2002). Davies and Rose (1999) found that differences in executive functioning between males and females were related to some visual spatial tasks, but these differences depended on the type of visual spatial task administered.

3.2. Measures

Standardized assessments that were used for this study include the Wechsler Intelligence Scale for Children, Fourth Ed. (WISC-IV) and Conners' Continuous Performance Test (CPT-II). The study participants represented the norm group characteristics of each test in terms of age, gender, geographic location, and ethnic background. The tests were selected from a comprehensive battery of tests given to children referred for neuropsychological assessment to determine etiological factors. They are considered valid and reliable estimates of the corresponding abilities measured.

3.2.1. Conners' Continuous Performance Test, 2nd Ed. (CPT-II)

The CPT-II is a computer administered test measuring attention to task, vigilance (sustained attention), and the ability to inhibit motor response (Conners & MHS Staff, 2002). The test requires a respondent to press a space bar or mouse button when any letter appears except the letter "X". The inter-stimulus interval changes randomly through six time blocks based on a person's performance versus average response times. The test lasts for 14 minutes with no break. This assessment can be administered to individuals six years of age and older (Conners & MHS Staff, 2002).

Five scores from the CPT-II were analyzed in this study as observed variables of executive control and attention: Omission Errors, Commission Errors, Hit Reaction Time, Hit Reaction Time Standard Error, and Variability of Standard Error. Barkley, Edwards, Laneri, Fletcher, and Metevia (2001) completed a factor analysis of tasks of executive functioning, temporal reward discounting, and time estimation and reproduction. The factor solution identified these five variables as measuring inattention and inhibition (executive control), and provides support for the selection of CPT-II variables in this study.

The two scores used to analyze impulsive responding (executive control) are number of Commissions (# of Commissions) and Hit Reaction Time (Hit RT). Commissions are the number of times a respondent reacts to non-target stimuli. Hit

Reaction Time is the mean response time measured in milliseconds. Low T-scores for Hit Reaction Time indicate a fast response time. The response criterion and response speed of the individual taking the test affect their number of commissions. Slow response time, in the presence of a high number of omission and commission errors indicates inattention, while a high number of commission errors and a fast response time indicate an impulsive response style (Conners & MHS Staff, 2002).

The scores that used to measure attention are Omission Errors (# of omissions), Hit Reaction Time Standard Error (Hit RT SE), and Variability of Standard Error (Variability of SE). Omission errors are the number of times which an examinee did not respond to a target item and reflects inattention to stimuli (Barkley et al., 2001). Hit RT SE acts as a measure of consistency between response times. A high degree of variability between response times can indicate inattentiveness (Conners & MHS Staff, 2002). The measure Variability of SE also reflects variability of response times, but in contrast to Hit RT SE, Variability of SE indicates the inconsistency in response time with relation to an individual's standard error.

Below (Table 3.1) is a table of the Split-Half reliability coefficients from the CPT-II manual of the measures used in this study.

Table 3.1

CPT-II Split-Half reliability coefficients

Variable	Reliability
# of Commissions	r_{12}= .83
# of Omissions	r_{12}= .94
Hit RT	r_{12}= .95

Hit RT SE	r_{12}= .87
Variability of SE	r_{12}= .66

r_{12}=split-half reliability coefficients

Also, through validity studies conducted during standardization of the CPT-II, it was determined that the CPT-II test discriminates accurately between ADHD and non-ADHD groups (Conners & MHS Staff, 2002; Epstein, Erkanli, Conners, Klaric, Costello, & Angold, 2003). Discriminant validity is supported by the ability of the CPT-II to identify correctly between clinical versus non-clinical groups. Both the reliability and validity coefficients are considered within acceptable limits to account for true score and predictive values (Conners & MHS Staff, 2002).

3.2.2. Wechsler Intelligence Scale for Children, 4th Ed. (WISC-IV)

In 1944 Wechsler defined intelligence as "…capacity of the individual to act purposefully, to think rationally, and to deal effectively with his environment." The WISC-IV is the newest revision of the Wechsler Intelligence Scale for Children series that is used as a broad measure of intelligence for children aged 6 years to 16 years, 11 months. The WISC-IV is based on a model that states a child's estimate of global functioning (Full-Scale IQ) is determined by measures of Verbal Comprehension (VCI), Perceptual Reasoning (PRI), Working Memory (WMI), and Processing Speed (PSI).

The revision of the WISC brought many changes to the look and feel of the test. Five new subtests have been added, and four of the remaining subtests have been modified for improvement. The Verbal Comprehension Index subtests include: Similarities, Vocabulary, Comprehension, Information, and Word Reasoning. These subtests assess a child's verbal abilities related to reasoning, comprehension, and conceptualization.

The Perceptual Reasoning Index subtests include: Block Design, Picture Concepts, Matrix Reasoning, and Picture Completion. This index assesses perceptual reasoning and organization. The Perceptual Reasoning Index replaced the Performance Intelligence Quotient on previous versions of the WISC series, and reflects an increased emphasis on fluid intelligence, or the ability to manipulate novel information.

The Working Memory Index subtests include: Digit Span (forward and backward), Letter-Number Sequencing, and Arithmetic. This index assesses a child's attention, concentration, and working memory. It replaced the Freedom from Distractibility Index on previous versions of the WISC series.

The Processing Speed Index measures a child's speed of processing for mental and graphomotor tasks. The subtests for this index include: Coding, Symbol Search, and Cancellation.

The WISC-IV allows for a wide range of interpretation, from indices measuring a variety of a child's skills, such as the global Full Scale Intelligence Quotient; to the small detail provided though process analysis of individual responses. The WISC-IV also lowered test floors and raised test ceilings from previous versions. There has been the addition of both easier and more difficult items on all the subtests.

Several studies have analyzed the WISC-IV in order to better understand the constructs it measures (Keith, Goldenring Fine, Taub, Reynolds, & Kranzler, 2006; Wechsler, 2003). Wechsler (2003) compared the four WISC-IV factors (Verbal Comprehension, Perceptual Reasoning, Working Memory, and Processing Speed) to the 11 domains of functioning explained by the Cattell, Horn, and Carroll (1993) theory of cognitive abilities (McGrew, 2003). The G_f (Fluid Reasoning), G_c (Crystallized

Knowledge), G_s (Processing Speed), G_v (Visual Spatial Abilities), G_{sm} (Short-term Memory), and G_q (Quantitative Knowledge), broad band domains can be identified in measurements included in the recent WISC revision. However, Wechsler (2003) continues to delineate the WISC-IV factors as Verbal Comprehension (VC), Perceptual Reasoning (PR), Working Memory (WM), and Processing Speed (PS).

The study conducted by Keith et al. (2006) further explores Wechsler's (2003) analysis and challenges the current factor structure. By using a higher order confirmatory factor analysis Keith et al. (2006) identified a model defined by the factors G_c, G_v, G_f, G_{sm}, and G_s.

The following table (Table 3.2) lists the WISC-IV subtests, current index factor structure (Wechsler, 2003), and proposed cross-validated factor structure determined by Keith et al. (2006):

Table 3.2

WISC-IV current index factor structure

Subtest	**Index Score**	**CHC Domain(s)**
Similarities[2]	Verbal Comprehension Index (VCI)	G_c
Vocabulary[2]	VCI	G_c
Comprehension[2]	VCI	G_c
Information	VCI	G_c
Word Reasoning[1]	VCI	G_c
Block Design[2]	Perceptual Reasoning Index (PRI)	G_v
Picture Concepts[1,2]	PRI	G_f
Matrix Reasoning[2]	PRI	G_f, G_v
Picture Completion	PRI	G_v, G_c

Digit Span[2]	Working Memory Index (WMI)	G_{sm}
Letter-Number Sequencing[2]	WMI	G_{sm}
Arithmetic	WMI	G_f
Coding[2]	Processing Speed Index (PSI)	G_s
Symbol Search[2]	PSI	G_s, G_v
Cancellation[1]	PSI	G_s

[1]These subtests are new additions to the WISC testing series. The proposed G_f-G_c domains measured by these tests were determined from an analysis of similar tasks on other preexisting normed tests.
[2]These subtests are considered the core subtests, and necessary to determine the Full-Scale IQ score.

Scores that will be used for analysis include the scaled scores for each of the ten core subtests (Similarities, Vocabulary, Comprehension, Block Design, Picture Concepts, Matrix Reasoning, Digit Span, Letter-Number Sequencing, Coding, and Symbol Search). Supplemental WISC-IV subtests will not be included in this study, because they were not routinely administered as part of the sample subject assessment battery. Not including the supplemental subtests may be a limitation of this study. Keith et al. (2006) suggest using all WISC-IV subtests in order to fully understand the constructs measured.

Below is a table (Table 3.3) of the psychometric properties of the scores used from the WISC-IV, which reflects both a reliable and valid measure.

Table 3.3

WISC-IV reliability and validity coefficients

Variable	**Reliability**	**Validity**
Block Design	$r_1= .86$	$r_2= .77$[1]
Similarities	$r_1= .86$	$r_2= .76$[1]
Coding	$r_1= .85$	$r_2= .76$[1]
Vocabulary	$r_1= .89$	$r_2= .82$[1]

Picture Concepts	r_1= .82	r_2= .44[2]
Comprehension	r_1= .81	r_2= .62[1]
Digit Span	r_1= .87	r_2= .77[1]
Matrix Reasoning	r_1= .89	r_2= .69[2]
Letter-Number Seq.	r_1= .90	r_2= .69[3]
Symbol Search	r_1= .79	r_2= .67[1]

r_1= internal consistency coefficient (Wechsler, 2003)
r_2= corrected correlation coefficient (Wechsler, 2003)
[1]= correlated to WISC-III (Wechsler, 2003)
[2]= correlated to WPPSI-III (Wechsler, 2003)
[3]= correlated to WAIS-III (Wechsler, 2003)

3.3. Procedure

Children referred for a neuropsychological evaluation at Allegheny General Hospital Department of Psychiatry are routinely administered a comprehensive battery of neuropsychological tests, which generally includes the Wechsler Intelligence Scale for Children, 4th ed. and Conner's Continuous Performance Test-II.

Each child may also complete self report measures, including the Achenbach Youth Self Report, Revised Children's Manifest Anxiety Scale, and Children's Depression Inventory. In addition to individual assessments, one or both of the child's parents complete several parent report measures including the Behavior Rating Inventory of Executive Functioning, the Achenbach Child Behavior Checklist, and a Neurodevelopmental History form. Each of these instruments contributes valuable variance when evaluating the strengths and weaknesses of children. Test choice for each assessment remains fluid, and may eliminate or add to the above list of tests.

The assessment procedures for each of the cases in the database were administered by either a board certified neuropsychologist, psychometrist, pre- or post-doctoral psychology intern, or psychology student trained in the administration of neuropsychological measures with the direct supervision of a board certified neuropsychologist. All diagnostic determinations were made by a board certified neuropsychologist.

3.4. Data Analysis

This study utilizes an exploratory factor analytic design evaluating a factor structure proposed from 15 indicator variables. The purpose of an exploratory factor analysis method is to reduce a set of variables, i.e. scores on tests, to smaller number of latent variables (Garson, 2005). Latent variables, or factors, are those occurrences that cannot be directly observed (Byrne, 1998). The latent variables hypothesized by this study were indicated by prior research. They include G_c, G_f, G_v, G_{sm}, G_s, G_{at}, and G_{ec}.

This analysis is exploratory, as opposed to confirmatory, because even though separate studies (Barkley, 2001; Keith et al., 2006) validate the separate G_f-G_c and attention factors, combining the two within one model adds method variance that cannot be explained as confirmatory. Factor analysis utilizes observed variables as indicators of the latent G_f-G_c expanded variables (Byrne, 1998) proposed in this research. Specifically, the SPSS computer program will be used to run the initial exploratory factor analysis. The initial factor analysis will set the stage for the second step of this study, which is the cognitive model verification. Validation of the proposed G_c, G_f, G_v, G_{sm}, G_s, G_{at}, and G_{ec} constructs is needed to fully evaluate the modified Dean Woodcock Neuropsychology model (Dean et al., 2003) outlined in Figure 1.1.

The structural equation modeling (SEM) approach to factor analysis will be used in this study to evaluate the relationship between proposed cognitive constructs. The AMOS computer program was used to evaluate this study's SEM factor structure. The SEM method evaluates the variance, as well as covariance, between variables (Garson, 2005). The link between observed variables and the underlying latent factors is fundamental, with regression path strengths between the variables and factors being used to help define the causal relationship (Byrne, 1998). Structural Equation Modeling utilizes both a measurement model and structural model to understanding the relationships between observed variables and factors, as well as between each factor. The measurement model represents the relationship between observed and latent variables, and the structural model illustrates the relationship between each of the latent variables. A full model combines both the structural and measurement models and provides an estimation of the inter- and intra-relationships between unobserved and observed variables (Byrne, 1998).

The focus of the SEM approach is to determine the goodness of fit between the sample data and the proposed model. Byrne (1998) describes the process of fitting the data into the model as: **Data = Model + Residual**. In this case residual represents the discrepancy between the observed data and proposed model.

Given that the hypothesis includes adding new G_{at} and G_{ec} factors into the already established G_f-G_c cognitive model, the framework for testing the structural equation models in this study will follow the most common type of SEM called the model generating approach (Byrne, 1998). The model generating approach allows this study to propose a model based on standing theory, either reject or accept the model based on goodness of fit, and modify the rejected model in a way that represents a better fit to the data.

Several goodness of fit statistics will be used to analyze both the G_f-G_c expanded model and modified Dean Woodcock Neuropsychology model, including Chi square (χ^2), Root Mean Square Error of Approximation (RMSEA), Parsimony Comparative Fit Index (PCFI), and Comparative Fit Index (CFI). The Chi square statistic is a measure of the fit of the covariance matrix to the restricted covariance matrix (Byrne, 1998). Relative to the degrees of freedom, a small χ^2 indicates a good fit and a large χ^2 indicates a poor fit (Jöreskog & Sörbom, 1993). RMSEA is a fit statistic sensitive to the complexity of the model being tested. Guidelines for the RMSEA are values nearing zero; however, values between .05-.08 indicate good fit (Byrne, 1998). The PCFI accounts for the number of estimated parameters (52 in this study) when measuring the overall fit of the hypothesized model. The PCFI represents the goodness of fit of the model and the parsimony of the model through one statistic (Byrne, 1998). Finally, the CFI statistics range from 0.0 to 1.0, with values >0.90 indicating good fit (Bentler, 1992; Byrne, 1998). Selection of these statistics was based on prior analytic research in the areas of cognition (Holland et al., 2004; Keith et al., 2006).

3.4.1 Evaluation of Assumptions

There are several assumptions that will be tested during the course of the SEM statistical procedure. Sample size and missing data will be assessed. For this study there are 225 subjects and 15 observed variables. The sample size of 225 individuals exceeds the Schumacker and Lomax (1996) proposal of 10 subjects per variable. Given this sample will be pulled from an already existing database, and therefore subject selection can be more restricted, missing data is not predicted to impact this study.

A test of normality and linearity will be conducted to determine skewness and kurtosis. The skewness and kurtosis statistics are used to evaluate distribution of scores.

Ideally these statistics will be as close to zero as possible (Holland et al., 2004), however statistics between 0 and 1.0 can be considered acceptable (Huck & Cormier, 1996).

An additional assumption is that the constructs in this study previously held up across age ranges (Conners & MHS Staff, 2002; Wechsler, 2003). This study will evaluate whether this remains true for the current sample by measuring age continuously. A continuous correlations test will be done to investigate developmental implications of construct measurement.

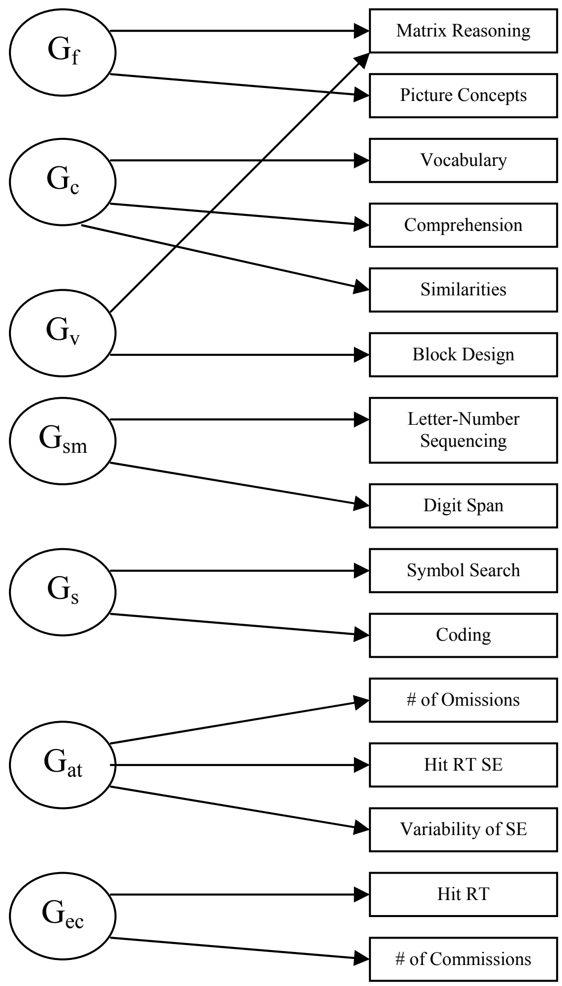
3.4.2 Variables and Models

This study's hypothesis identifies two separate models: the first is a seven factor model reflecting the inclusion of G_{at} and G_{ec} into the G_f-G_c cognitive structure; and the second model fits the seven factors into a reciprocal processing hierarchy to test the relationship between factors.

The hypothesized seven factor model (Figure 3.1) identifies G_f (matrix reasoning and picture concepts as indicators), G_c (similarities, vocabulary, and comprehension as indicators), G_v (matrix reasoning and block design as indicators), G_{sm} (letter-number sequencing and digit span as indicators), G_s (Coding and symbol search as indicators), G_{at} (# of Omissions, Hit RT SE, and Variability of SE), and G_{ec} (# of commissions and Hit RT as indicators) as factors measured by the 15 variables. This model being presented questions whether a seven factor model fits the data.

Each separate construct will be measured by the specified measurement variables. The model represents an organization of cognitive constructs that are measured by subtest scores on the WISC-IV and CPT-II. Note the arrows from each construct (circle) pointing to corresponding measurement variables (box). The arrow represents variance. This proposed model has each construct measured by at least 2 variables. Also, with the exception of Matrix Reasoning loading on both G_f and G_v, each variable loads on one construct.

Figure 3.1 Hypothesized seven factor model including G_f-G_c components, G_{at}, and G_{ec}



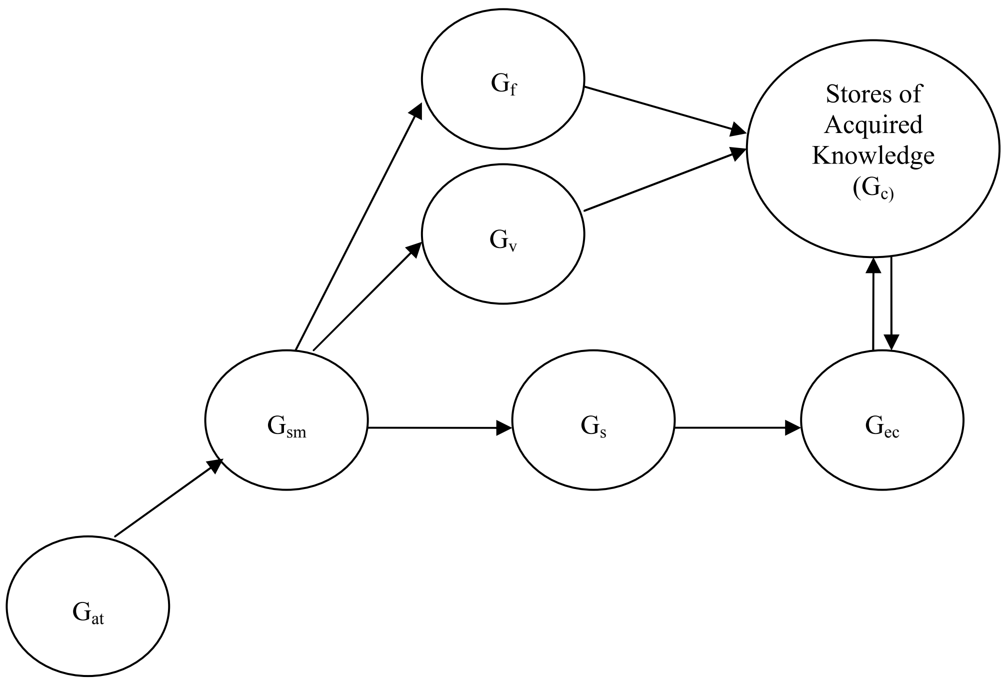
A check of identifiability (Tabachnick & Fidell, 2001) indicates that the seven factor G_f-G_c expanded model proposed in this study is over-identified, and therefore able to be solved uniquely (Stevens, 2002). There are 120 identified data points (with 15 variables, 15(15+1)/2=120 data points). The model hypothesized includes 52 parameters to be estimated (15 regression coefficients, 21 covariances, and 16 variances). Therefore, with 68 degrees of freedom (120-52) the model is over-identified (Tabachnick & Fidell, 2001).

The second model (Figure 3.2) reflects a modified version of the Dean et al. (2003) representation of the Dean-Woodcock Neuropsychology Model. This model proposes a process between attention, conscious awareness/short term memory, fluid reasoning, visual spatial ability, crystallized intelligence, processing speed, and executive control.

Recall the explanation of the Dean et al. (2003) model posed in Chapter 2. Dean et al. (2003) advocate for a hierarchy of skills within an information processing model. The executive control system acts as a gatekeeper directing the path of automatic versus non-automatic/novel processes. This system is also responsible for allocation of attention and monitoring of performance. The addition of attention as a separate factor in the modified model shown below (Figure 3.2) reflects Luria's (1973) contention that an attention system must first be on-line in order for subsequent mental processes to occur. The arrows in this diagram reflect how well one factor predicts another (Holland et al., 2004), which inherently helps determine the relationship between the constructs.

Figure 3.2 illustrates a cognitive structure explained by a process between component skills. Attention directly affects short term memory, which in turn affects the ability to complete tasks requiring processing speed, fluid reasoning, and visual-spatial skills. Fluid skills and visual spatial skills affect the processing of stored knowledge, which processes simultaneously through executive control. The executive control component is affected by how quickly information can be processed. Figure 3.2 explains task completion and skill delivery from beginning (primary skill) to completion (product).

Figure 3.2 Modified Dean Woodcock Neuropsychology model, with attention added as a primary component.



G_{ec}= Executive Control
G_s= Processing Speed
G_{at}= Attention
G_{sm}= Short Term Memory/Conscious Awareness
G_f= Fluid Intelligence
G_v= Visual Spatial Ability
G_c= Crystallized Intelligence

3.4.3. Research Questions

1. Are there additional components, in addition to G_f-G_c, that further explain cognitive functioning and processes? Confirming data would include the components Gf, Gc, Gs, Gv, and Gsm delineated in the Keith et al (2006) literature, with the addition of attention (Gat) and executive control (Gec).

a. Does executive control constitute a separate construct than is accounted for and measured by cognitive tests of G_f-G_c theory?

b. Does attention constitute a separate construct than is accounted for and measured by cognitive tests of G_f-G_c theory?

2. What is the structure of the relationship between attention, executive control, and CHC stratum II components measured by the WISC-IV? This model will be dependent first on verification of the presence of attention and executive control in research question #1. The second step of this question is dependent on the hypothesis that the components fit a model that is represented by Figure 3.2, with respect to G_f-G_c, and attention and executive control.

    a. Does the Dean Woodcock Neuropsychology Model (Dean et al, 2003) accurately represent the relationship between cognitive components?

CHAPTER 4

RESULTS

The main objective of the current study is to explore the possibility of a higher order processing relationship between cognitive skills that includes G_f-G_c Components Processing Speed, Short Term Memory/Conscious Awareness, Fluid Intelligence, Visual Spatial Ability, and Crystallized Intelligence, as well as executive control and attention. A description of the study's variables will first be presented, followed by summarization of research questions and the corresponding results. Factor analytic and structural equation modeling procedures will be reviewed as they answer each of the research questions.

4.1. Descriptive Statistics

The statistics describing the study sample are presented in Table 4.1. A majority of the respondents were male (71.6%) and were Caucasian (86.2%). Age in months of children tested ranged from 74 to 208. The mean age of children tested was 130.16 months (SD = 33.74).

The means and standard deviations for the fifteen indicator variables are presented in Table 4.2. The skewness and kurtosis of the distribution of these variables are also presented in Table 4.2. As referred to in this table, the WISC-IV Letter Number Sequencing had a high kurtosis value. The CPT-II Number of Omissions variable had very high skew and kurtosis values. All other variables had acceptable skew and kurtosis values.

Table 4.1

Descriptive Statistics of Study Sample (N = 225)

Variables	Frequency	Percentage
Sex		
Male	161	71.6
Female	64	28.4
Ethnicity		
Caucasian	194	86.2
Other	31	13.8

The correlations between the indicator variables are presented in Table 4.3. The WISC-IV subtests were generally correlated with each other. Only the Similarities and Vocabulary subtests were not significantly correlated with the Coding subtest. The WISC-IV subtests were correlated with four of the five the CPT-II measures. The WISC-IV subtests were generally not significantly related to the Number of Commissions.

Correlations between Age and the indicator variables were completed in order to investigate the stability of the constructs across age. Since age was not presented categorically, meaning in set age ranges, a continuous test was performed. Pearson correlations were conducted. If variable 1 is measured on an interval/ratio scale and variable 2 is measured on an interval/ratio scale – as age and the IQ tests were, then the Pearson r procedure is used (Garson, 2008). A continuous test measures the correlations of each test repeatedly cross ages, thus giving an indication as to developmental stability. The results are presented in Table 4.4.

Table 4.4 shows correlational significance across age for Vocabulary, Letter-Number Sequencing, Number of Omissions, Hit RT, Hit RT SE, and Variability of SE. The directionality and strength of the correlations between age and indicator variables in this situation indicate that older children tended to have better developed abilities on those tests. Of note, based on these findings attention seems to improve with age, which corresponds to contemporary understanding of the development of attention (Conners & MHS Staff, 2002; Lezak, 1995). As age increases, the number of omissions and inconsistency in response time decrease in this sample. Given that decreases in both of these scores indicate better attention (Conners & MHS Staff, 2002); this finding reflects an improvement in attention that occurs developmentally as age increases.

Table 4.2

Descriptive Statistics for Indicator Variables, Part One (N = 225)

Variable	Range	Mean	SD	Skewness Statistic	Skewness Std. Error	Kurtosis Statistic	Kurtosis Std. Error
WISC-IV							
Similarities	1 to 18	9.88	2.89	-.16	.16	-.01	.32
Vocabulary	3 to 16	9.26	2.58	.13	.16	-.35	.32
Comprehension	1 to 15	8.86	2.73	-.19	.16	-.03	.32
Block design	1 to 19	9.45	2.90	.09	.16	.11	.32
Picture concepts	1 to 18	10.56	2.78	-.37	.16	.80	.32
Matrix reasoning	2 to 18	9.57	2.70	.07	.16	.08	.32
Digit span	2 to 16	8.85	2.76	.18	.16	-.39	.32
Letter-number sequencing	1 to 19	9.01	2.78	-.37	.16	1.54	.32
Coding	1 to 17	7.93	2.94	.09	.16	-.22	.32
Symbol search	1 to 15	8.96	2.89	-.50	.16	.31	.32
CPT-II							
Number of omissions	34 to 117	51.48	11.59	2.14	.16	6.18	.32
Number of commissions	23 to 72	52.54	9.95	-.54	.16	-.28	.32
Hit RT	21 to 79	46.89	11.49	.51	.16	.00	.32
Hit RT SE	25 to 82	51.25	10.70	-.04	.16	-.44	.32
Variability of SE	24 to 72	51.09	10.45	-.19	.16	-.77	.32

Table 4.3

Correlations between Indicator Variables

Variable	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14
W Similarities (V1)														
W Vocabulary (V2)	.64**													
W Comprehension (V3)	.53**	.63**												
W Block (V4)	.35**	.35**	.20**											
W Picture (V5)	.39**	.39**	.30**	.25**										
W Matrix (V6)	.35**	.41**	.27**	.41**	.36**									
W Digit (V7)	.36**	.33**	.32**	.16*	.32**	.27**								
W Letter (V8)	.33**	.35**	.34**	.20**	.27**	.26**	.29**							
W Coding (V9)	.11	.13	.17*	.27**	.21**	.09	.11	.21**						
W Symbol (V10)	.26**	.22**	.23**	.33**	.16*	.16*	.14*	.25**	.55**					
CPT Omissions (V11)	-.27**	-.22**	-.19**	-.12	-.29**	-.29**	-.25**	-.25**	-.08	-.11				
CPT Commissions (V12)	.05	-.06	-.09	-.11	-.09	-.16*	-.11	-.05	-.14*	-.07	.05			
CPT Hit (V13)	-.22**	-.22**	-.16*	-.09	-.16*	-.15*	-.15*	-.19**	-.17*	-.21**	.40**	-.41**		
CPT HitSE (V14)	-.22**	-.29**	-.28**	-.10	-.20**	-.28**	-.22**	-.25**	-.16*	-.17**	.60**	.09	.71**	
CPT Variability (V15)	-.21**	-.27**	-.30**	-.08	-.19**	-.31**	-.23**	-.20**	-.15*	-.15*	.59**	.19**	.52**	.94**

* Significant at .05
** Significant at .01
W = WISC-IV
CPT = CPT-II

Table 4.4

Correlations between Age and Indicator Variables (N = 225)

Indicator Variable	Age
WISC Similarities	.095
WISC Vocabulary	.145*
WISC Comprehension	.065
WISC Block Design	.038
WISC Picture Concepts	.125
WISC Matrix Reasoning	.118
WISC Digit Span	-.029
WISC Letter-Number	.181**
WISC Coding	-.121
WISC Symbol Search	-.029
CPT # of Omissions	-.288**
CPT # of Commissions	.024
CPT Hit RT	-.387**
CPT Hit RT SE	-.368**
CPT Variability of SE	-.283**

* Significant at .05
** Significant at .01

4.2. Research Question 1

1. Are there additional components, in addition to G_f-G_c, that further explain cognitive functioning and processes? Confirming data would include the

components G_f, G_c, G_s, G_v, and G_{sm} delineated in the Keith et al (2006) literature, with the addition of attention (G_{at}) and executive control (G_{ec}).

a. Does executive control constitute a separate construct than is accounted for and measured by cognitive tests of G_f-G_c theory?

b. Does attention constitute a separate construct than is accounted for and measured by cognitive tests of G_f-G_c theory?

4.3. Exploratory Factor Analysis

An exploratory factor analytic procedure was conducted to test whether the WISC-IV subtests and the CPT-II measures would yield the 7 hypothesized components shown in Figure 3.1. The extraction method specified was principal components analysis (PCA) and the rotation method requested was an orthogonal Varimax rotation. Principle components analysis was used because it assumes unique variance of components, versus elimination of unique variance as in procedures such as Principal axis factor analysis (PAF) (Fabrigar, Wegener, MacCallum, & Strahan, 1999; Tabachnick & Fidell, 2001). Due to the nature of the separation of cognitive skills outlined in the literature (Keith et al., 2006; Meyer & Kieras, 1997; Naglieri, Goldstein, Delauder, & Schwebach, 2005; Norman & Shallice, 1986; Phelps et al., 2005), exclusion of unique variance was thought to be a shortcoming of the PAF procedure for use in this study; therefore, PCA was chosen as a more appropriate factor analysis method.

Orthogonal Varimax rotation was selected because it assumes that the variables are uncorrelated and maximizes large loadings (Tabachnick & Fidell, 2001). Varimax indicates that each component has a few large loadings and more loadings of zero. This simplifies interpretation because after Varimax each original variable tends to be associated with one (or small #) of components, and each components represents only a small # of variables (Abdi, 2003; Tabachnick & Fidell, 2001). Literature review for this study supports orthogonal rotation because of the distinct separation of cognitive components (Keith et al., 2006; Phelps et al., 2005), executive control, and attention (Meyer & Kieras, 1997; Naglieri, Goldstein, Delauder, & Schwebach, 2005; Norman & Shallice, 1986).

The PCA analysis yielded four components, accounting for 62.99% of the variance. The eigenvalues and the variance explained by each of the components are presented in Table 4.5. The components and their corresponding variables are presented in Table 4.6. The criterion for eigenvalue selection was set at the default value of 1.

Table 4.5

Variance Explained by Resulting Components

Component	Eigenvalue	Eigenvalue % of Variance
1	4.68	31.22
2	2.03	13.50
3	1.42	9.46
4	1.32	8.81

As can be seen in Table 4.6, the first component consists primarily of the WISC-IV subtests. The Similarities, Vocabulary, and Comprehension subtests loaded highly onto the first component. The Picture Concepts, Matrix Reasoning, Digit Span, and Letter Number Sequencing subtests loaded moderately onto the first component.

Accordingly, this component could be labeled as a combined G_f-G_c, including both Fluid and Crystallized abilities.

Table 4.6

Indicator Variable Loadings (Rotated Matrix)

Variable	Component			
	1	2	3	4
WISC Similarities	**.80**	-.06	.09	.19
WISC Vocabulary	**.82**	-.11	.07	.07
WISC Comprehension	**.71**	-.13	.08	.03
WISC Block Design	*.45*	.05	*.45*	-.10
WISC Picture Concepts	**.58**	-.14	.12	-.08
WISC Matrix Reasoning	**.57**	-.23	.07	-.24
WISC Digit Span	**.55**	-.18	.00	-.10
WISC Letter-Number	**.48**	-.17	.25	.02
WISC Coding	.05	-.10	**.86**	-.07
WISC Symbol Search	.18	-.07	**.83**	.06
CPT # of Omissions	-.25	**.72**	.01	.04
CPT # of Commissions	-.06	.08	-.10	**.93**
CPT Hit RT	-.11	**.68**	-.18	-.60
CPT Hit RT SE	-.17	**.95**	-.10	-.04
CPT Variability of SE	-.18	**.92**	-.06	.12

The second component consists primarily of four CPT-II measures: number of Omissions, Hit RT, Hit RT SE, and Variability of SE. The HIT RT SE and Variability of SE loaded highly onto this component, and the number of Omissions and HIT RT loaded moderately onto this component. Recall, number of Omissions, Hit RT SE, and Variability of SE were proposed as CPT-II subtests measuring attention. Accordingly, this component could be labeled G_{at}, Attention.

Both the Symbol Search and Coding subtests load highly onto the third component. Accordingly, this component could be labeled G_s, Processing Speed.

The fourth component includes only one CPT-II measure with a high loading, the Number of Commissions. However, Hit RT also loaded moderately on this component. This supports Component 4 as the executive control component, because while a high # of commissions indicates impulsivity (lack of executive control), a low Hit RT also indicates impulsivity (-.60). In addition, a high HIT RT may indicate attentiveness, but only in conjunction with other scores being either high or low. So the Hit RT may be more accurately interpreted on component 4 (G_{ec}) rather than component 2 (G_{at}). Containing both number of Commissions and Hit RT, this component could be labeled G_{ec}, Executive Control.

Although the results do not correspond with previous findings of a five-component model of cognition including Processing Speed, Short Term Memory/Conscious Awareness, Fluid Intelligence, Visual Spatial Ability, and Crystallized Intelligence (Keith et al, 2006), the results provide partial evidence that Attention and Executive Control constitute two components separate from traditional G_f-G_c structure. However, because Hit RT did not load significantly onto component 4, it will be eliminated from the structural equation model in order to maximize statistical fit. Therefore, the component G_{ec} cannot be analyzed in the structural equation model because it cannot be statistically defined as a component since it is the only variable which shows a significant relationship with G_{ec}.

4.4. Research Question 2

2. What is the structure of the relationship between attention, executive control, and G_f-G_c stratum II components measured by the WISC-IV? This model will be dependent first on verification of the presence of attention and executive control in research question #1. The second step of this question is dependent on the hypothesis that the components fit a model that is represented by Figure 3.2, with respect to G_f-G_c, and attention and executive control.

    a. Does the Dean Woodcock Neuropsychology Model (Dean et al, 2003) accurately represent the relationship between cognitive components?

4.5. Relationships between the Constructs

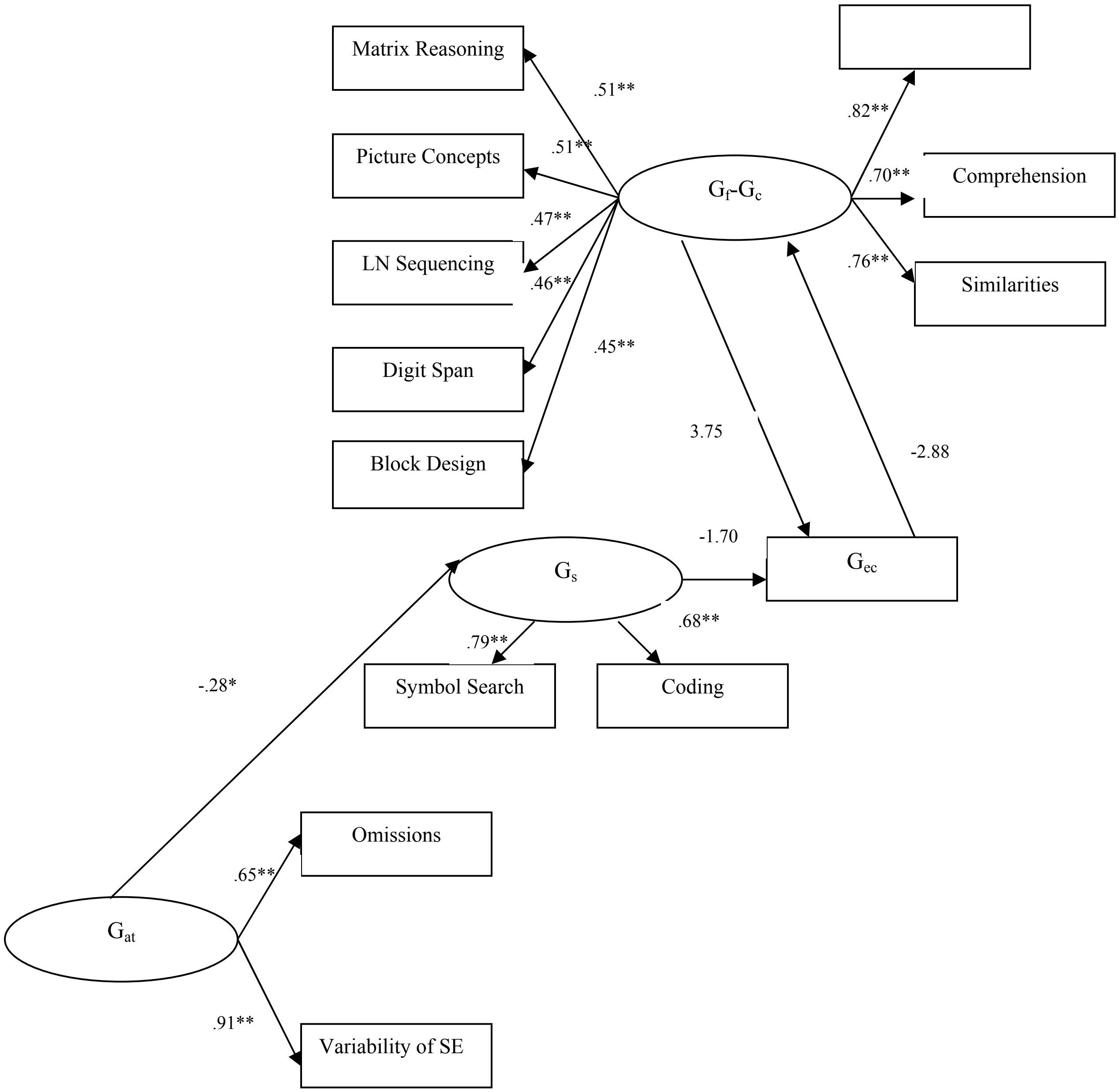
Structural equation modeling procedures were conducted to examine the relationships between the four hypothesized constructs, with Attention and Executive Control added. However, because the component G_{ec} was not statistically identified with at least two indicator variables, rather only through clinical interpretation, it was not fully represented in the SEM as a separate factor.

EFA Model One (Figure 4.1) tested the relationship between the components represented by all WISC-IV subtests and CPT-II sub-scores number of omissions, number of commissions, and variability of SE. EFA Model Two (Figure 4.2) included only the WISC-IV subtests that loaded highly onto the first component, but kept the other components the same as Model One. Note that Hit RT and Hit RT SE were omitted from analyses, because the variance of the error was negative, and thus, the solution generated was "inadmissible."

The model presented in Figure 4.1 did not fit the data very well: $\chi 2 = 153.492$ (df = 62), p = .000, CFI = .876, PCFI = .697, and RMSEA = .081. The CFI index was below the acceptable benchmark of .90 and the RMSEA value of .08 indicates moderate fit (Hu & Bentler, 1999).

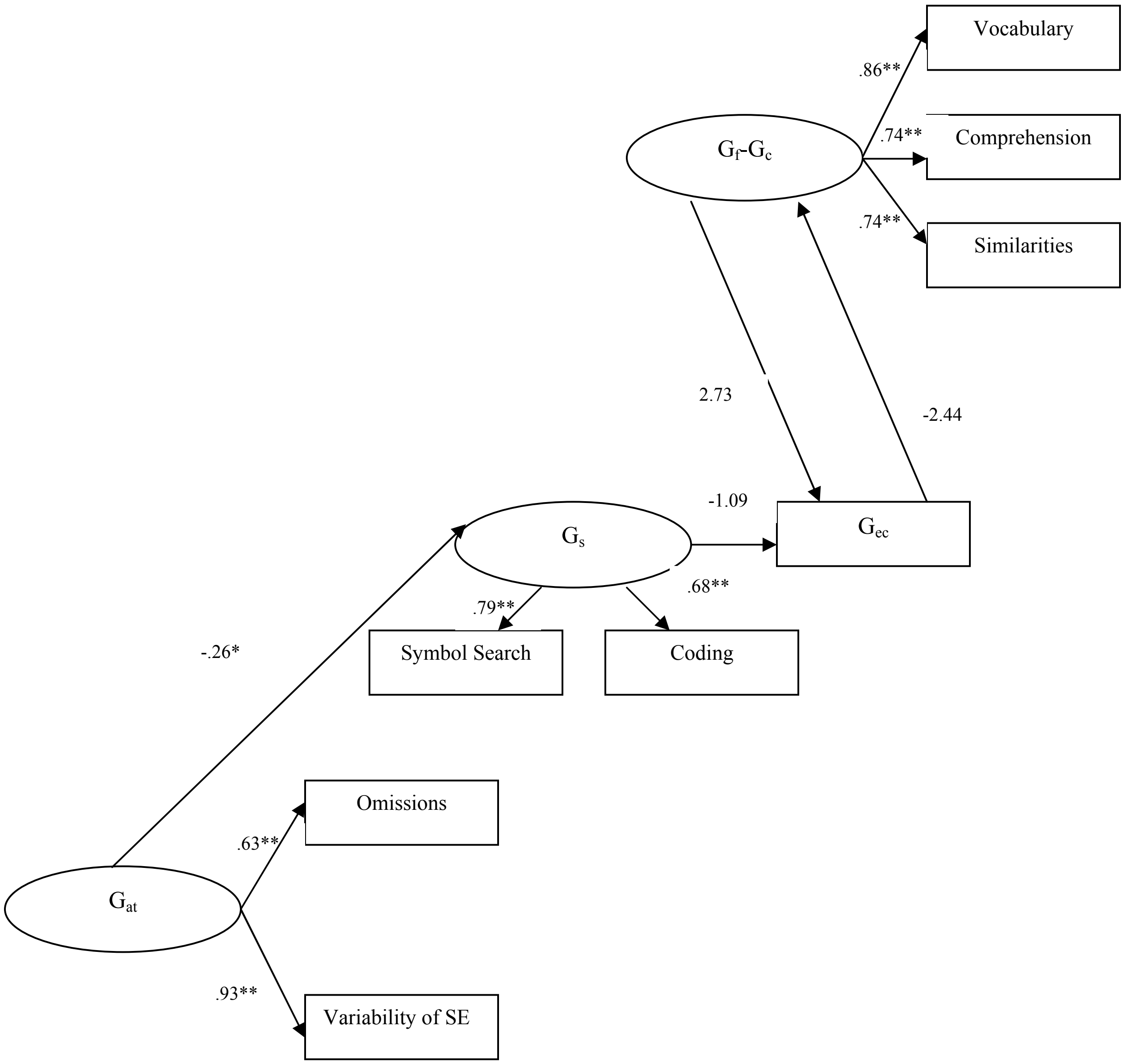
The indicator variables were all significantly correlated to their constructs. Only one of four standardized path coefficients was statistically significant. In particular, G_{at} was significantly related to G_s (r = -.28, p = .05). The path coefficient between G_s and G_{ec} was not significant. Similarly, the path coefficients between G_{ec} and G_f-G_c were not significant.

Figure 4.1 Results for EFA Model One



* Significant at .05
** Significant at .01

Figure 4.2 Results for EFA Model Two



* Significant at .05
** Significant at .01

The three-component model presented in Figure 4.2 fit the data well: $\chi 2 = 46.261$ (df = 17), p = .000, CFI = .937, PCFI = .569, and RMSEA = .088. The CFI index was above the acceptable benchmark of .90; however, the RMSEA of .088 is slightly above an acceptable range of values of .05-.08 for moderate fit (Hu & Bentler, 1999). A higher RMSEA value reflects a larger difference between the estimated model and actual model determined by the analysis.

The indicator variables were all significantly correlated to their constructs. Only one of four standardized path coefficients was statistically significant. In particular, G_{at} was significantly related to G_s (r = -.26, p = .05). The path coefficient between G_s and G_{ec} was not significant. Similarly, the path coefficients between G_{ec} and G_f-G_c were not significant.

4.6. Summary for Structural Equation Model Results

The model that fit the data best was the three component model presented in Figure 4.2. But given that models with fewer parameters generally fit data better, it is difficult to conclude which model accurately represents a hierarchical model of cognitive functioning.

Also, the models described in this research have never been tested with the addition of attention and executive control components. A model including all of the WISC-IV cognitive components (Processing Speed, Short Term Memory/Conscious Awareness, Fluid Intelligence, Visual Spatial Ability, and Crystallized Intelligence) has been verified through other intelligence research literature (Keith et al., 2006), but the presence of the additional attention and executive functioning components is suggested in this research through the results of the factor analytic procedure.

CHAPTER 5

DISCUSSION

5.1 Purpose

The purpose of this study is to continue investigation of the G_f-G_c theory and expand the Keith et al. (2006) validation of G_f-G_c measurement by the WISC-IV. This study explored the inclusion of a new Executive Control (G_{ec}) component and a separate attention component (G_{at}) within the G_f-G_c theory. This study involves an investigation of the G_f-G_c domains measured by Wechsler Intelligence Scale for Children, 4th Edition (WISC-IV) and Conners' Continuous Performance Test, 2nd Edition (CPT-II). These domains were compared via principal components analysis of the WISC-IV and CPT-II.

Also, the relationship of these cognitive components was examined. The second main purpose of this research is to test the structure of the Dean-Woodcock Neuropsychology Model (Dean et al., 2003). The inclusion of G_{ec} and G_{at} components questions the primacy of each component within the Dean-Woodcock (2003) model. Analysis of the cognitive domains measured by the WISC-IV, and attention and executive control, as measured by the CPT-II, shed light on the relationship between executive control, attention, and measures of cognitive ability in children.

5.2 Summary and Results of Research Question 1

1. Are there additional components, in addition to G_f-G_c, that further explain cognitive functioning and processes? Confirming data would include the components G_f, G_c, G_s, G_v, and G_{sm} delineated in the Keith et al (2006) literature, with the addition of attention (G_{at}) and executive control (G_{ec}).

a. Does executive control constitute a separate construct than is accounted for and measured by cognitive tests of G_f-G_c theory?

b. Does attention constitute a separate construct than is accounted for and measured by cognitive tests of G_f-G_c theory?

Results of this exploratory factor analysis indicate the combination of WISC-IV and CPT-II measure four separate components of cognitive skill. The first component was labeled as G_f/G_c, as it includes combined crystallized and fluid reasoning skills (Keith et al., 2006). The second component was labeled G_{at} representing the attention as measured by the CPT-II. The third component represents speed of information processing and will be labeled G_s. The final component, measured by two CPT-II scores that indicate impulsive responding, was labeled as G_{ec} as a measure of executive control.

Although the exploratory factor analysis results do not support previous findings of five-component cognitive functioning model (Keith et al., 2006), the results provide partial evidence that Attention and Executive Control constitute two components separate from traditional G_f-G_c structure, as will be discussed further in the conclusions section of this chapter.

5.3. Summary and Results of Research Question 2

2. What is the structure of the relationship between attention, executive control, and CHC stratum II components measured by the WISC-IV? This model will be dependent first on verification of the presence of attention and executive control in research question #1. The second step of this question is dependent on the hypothesis that the components fit a model that is represented by Figure 3.2, with respect to G_f-G_c, and attention and executive control.

a. Does the Dean Woodcock Neuropsychology Model (Dean et al, 2003) accurately represent the relationship between cognitive components?

Structural Equation Modeling was used to answer the second research question. This analysis took the identified four components: fluid reasoning/crystallized ability, processing speed, attention, and executive control, and investigated possible reciprocal relationship between the cognitive skills. Results of this analysis provide limited evidence for a structure in which attention assumes a role of primacy, followed by speed of processing, and finally a reciprocal relationship between executive control and crystallized ability/fluid reasoning. However, since only the relationship between attention and processing speed was statistically significant, the entire model of cognition cannot be assumed.

As described in Chapter 4, the model presented in Figure 4.2 fit the data best, but given that models with fewer parameters generally fit data better, it is difficult to conclude whether this model accurately represents a hierarchical model of intelligence. In addition, although a model including Processing Speed, Short Term Memory/Conscious Awareness, Fluid Intelligence, Visual Spatial Ability, and Crystallized Intelligence has been verified through other cognitive ability research literature (Keith et al., 2006), the presence of the additional attention and executive control factors has never been tested.

Based on this research, there is not enough evidence to disconfirm that components of the Dean Woodcock Neuropsychology Model accurately explain cognitive skill relationships. Attention was identified as a primary skill necessary for the initiation of other cognitive abilities; however, the full intact model could not be evaluated.

5.4. Conclusions

5.4.1. Attention and Executive Control as Separate Functions

The research literature for this study supported the separation of attention and executive control as distinct cognitive skills. Multiple studies have analyzed the relationship between cognitive functioning (Duff, Schoenberg, Scott, & Adams, 2005; Floyd, Bergeron, & Hamilton, 2005; Keith, Goldenring Fine, Taub, Reynolds, & Kranzler, 2006; Naglieri, Goldstein, Delauder, & Schwebach, 2005; Wechsler, 2003), attention, and various executive abilities. However, a gap in the literature was noted with regard to a lack of examination of a higher order processing relationship between cognitive skills that includes all of the current G_f-G_c components, notably executive control and attention.

The current study suggests the addition of separate attention (G_{at}) and executive control (G_{ec}) components within a G_f-G_c cognitive model. These findings are in line with the conclusions of several studies (Luria, 1973; Naglieri et al., 2005) that indicate the presence of a separate attention system. The principal components procedure identified attention and makes it distinct from other cognitive skills. This is in contrast to G_f-G_c studies (McGrew, 2003; McGrew & Flanagan, 1998; Keith et al., 2006) in which attention was not indicated separately.

In addition, the current study provides partial evidence for the separation of executive control (G_{ec}) from attention and other component cognitive skills. In conjunction with previous research (Busch, Booth, McBride, Vanderploeg, Curtiss, & Duchnick, 2005; Duff, Schoenberg, Scott, & Adams, 2005; Norman & Shallice, 1986; Minshew et al., 2002), G_{ec} and G_{at} constitute distinct cognitive skills, and as such should be evaluated separately. Data backs G_{ec} as separate factor; however, because of study limitations this assertion must be retested.

The analysis of G_{ec} for this study lies more in test interpretation rather than statistical fit. That is, the presence of G_{ec} was indicated in this study by clinical interpretation of the relationships between specific CPT-II subtests. Test development sets precedent for such interpretation (Conners & MHS Staff, 2002). Recall from Chapter 4, "…Component 4 as the executive control component, because while a high # of commissions indicates impulsivity (lack of executive control), a low Hit RT also indicates impulsivity (-.60). In addition, a high HIT RT may indicate attentiveness, but only in conjunction with other scores being either high or low. So the Hit RT may be more accurately interpreted on G_{ec} rather than G_{at}. Containing both number of Commissions and Hit RT, this component could be labeled G_{ec}, Executive Control." However, caution is recommended when interpreting this finding, because Hit RT was omitted from the following SEM analysis due to the variance of the error being negative. Thus, the solution generated for a structural model including Hit RT was "inadmissible.

5.4.2. Relationship between Cognitive Skills

The processing approach to cognition proposed in this research was not fully validated. This is in contrast to multiple previous studies validating a similar model of cognitive processing (Das, Naglieri, & Kirby, 1994; Dean et al., 2003; Kaufman & Kaufman, 2004; Naglieri, 1999; Reitan, 1988). The best-fit model of cognitive processing (Figure 4.2) shows that the only significant statistical correlation is between attention and processing speed. The process between G_f-G_c cognitive skills, executive control, and processing speed was not statistically significant, and as such did not validate a meaningful relationship using statistics alone. However, it is noted that this interpretation should be made with caution. Because the component G_{ec} was not statistically identified with at least two indicator variables, rather only through clinical interpretation, it was not fully represented in the SEM as a separate factor. This shortcoming likely affected the model's overall stability.

Although the model proposed by Dean et al. (2003) was not validated, the presence of a significant correlation between attention and processing speed shows partial support for an interactive relationship between cognitive skills as described in previous research (Luria, 1973; Das, Naglieri, & Kirby, 1994; Kaufman & Kaufman, 2004; Naglieri et al., 2005). This evidence is significant in that it shows attention as a necessary skill for other resulting cognitive processes. This finding is in line with previous literature, which outlines the possible primacy of attention and the hierarchical nature of cognitive skills (Luria, 1973; Reitan, 1988; Das, Naglieri, & Kirby, 1994; Naglieri, 1999; Dean et al., 2003; Kaufman & Kaufman, 2004).

Speculation based on these findings would point to the importance of measuring attention ability prior to coming to conclusion about cognitive functioning based on standard IQ testing. These results indicate a dependent relationship between one's ability to attend and one's ability to complete any task requiring speed of information processing. In conjunction with Dean et al.'s (2003) model expanding processing speed to all other G_f-G_c abilities, one could then hypothesize, based on these findings, that attention interacts with the remaining abilities outlined in the literature (Dean et al., 2003; Keith et al., 2006).

5.5. Limitations

The first limitation of this study is the lack of cultural and sex diversity of the sample, as well as the lack of a non-referred peer group. Although the sample size was adequate for analysis, the population was clinically referred for cognitive, mental health, or neuro-biological concerns. In addition, the sample consisted of primarily white males. A study of this population versus a population of similar aged non-referred peers would help determine whether the cognitive skills assessed presented differently given disability and across gender and culture.

Another limitation of this study is that it assumes good performances on tasks measuring attention and executive control abilities at a young age are synonymous with good performances at older ages. Recall from Chapter 4, “Table 4.4 shows significance mean differences across age for Vocabulary, Letter-Number Sequencing, Number of Omissions, Hit RT, Hit RT SE, and Variability of SE. Significance in this situation indicates that older children tended to have better developed abilities on those tests. Of note, based on these findings attention improves with age.” This could have affected the outcome of this study in that age was measured continuously rather than in age categories, which doesn’t account for skill development and thus increase in skill performance as kids get older. Categorical analysis better allows researchers to analyze developmental skill acquisition. Future research could measure cognitive factors across age through a multiple confirmatory factor analytic procedure across multiple age ranges. The future analysis can be considered confirmatory because this study suggests the presence of attention and executive control in a clinically referred population.

An indication of these findings is that the measurement of attention and executive control potential should be assessed developmentally within a cognitive structure during childhood. Also, additional investigation of smaller age ranges may yield better age-related construct stability, thus providing better data for developmentally related progress.

5.6. Recommendations for Future Research

The first recommendation for future research is to expand the factor analysis to validate the presence of a separate executive control factor. While partial evidence was found, this study was unable to provide the multiple variables necessary to authenticate G_{ec} as a distinct component. Such research should take the form of a confirmatory, rather than exploratory factor analysis. Because the analysis of executive control was not yet validated at the time of this research an exploratory analysis was indicated. However, future research now has some basis by which to confirm G_{ec}.

Although this research did not validate the proposed cognitive structure in it's entirety (i.e. the Dean-Woodcock Neuropsychology Model, 2003), the results are promising for future analyses. This study provides evidence for the existence of attention and executive control within a global G_f-G_c cognitive structure, as well as a relationship between attention and processing speed. The additional cognitive structure, including the reciprocal nature of the relationship between cognitive skills has been validated separately. A final recommendation for future research is to first validate executive control separately through confirmatory factor analysis, as stated above, and then re-analyze the cognitive model with attention as a primary component and including executive control. Such a discovery could impact how professionals view the interactive nature of attention, executive control, and specific cognitive skills because it would provide a better understanding of primacy in cognitive skill performance.

REFERENCES

Abdi, H. (2003). Factor Rotations in Factor Analysis. In Lewis-Beck M., Bryman, A., Futing T. (Ed.), *Encyclopedia of Social Sciences Research Methods.* Thousand Oaks, CA: Sage.

Alexander, GE, Crutcher, MD, & DeLong MR. 1990. Basal ganglia-thalamocortical circuits: parallel substrates for motor, oculomotor, "prefrontal" and "limbic" functions. *Prog Brain Res, 85*, 119-46.

Anderson, P. (2002). Assessment and development of executive function (EF) during childhood. *Child Neuropsychology, 8*, 71-82.

Anderson, V.A., Anderson, P., Northam, E., Jacobs, R., & Catroppa, C. (2001). Development of executive functions through late childhood and adolescence in an Australian Sample. *Developmental Neuropsychology, 20*, 385-406.

Andrewes, D. (2001) *Neuropsychology: From Theory to Practice*. Psychology Press, New York, NY.

Antshel, K.M., & Waisbren, S.E. (2003). Timing is everything: Executive functions in children exposed to elevated levels of phenylalanine. *Neuropsychology, 1*, 458-468.

American Psychiatric Association. (2001). *Diagnostic and statistical manual of mental disorders* (4th ed., text revision). Washington, DC.

Ardila, A., Pineda, D., & Rosselli, M. (2000). Correlation between intelligence test scores and executive function measures. *Archives of Clinical Neuropsychology, 15*, 31-36.

Arffa, S., Lovell, M., Podell, K., & Goldberg, E. (1998). Wisconsin card sorting test performance in above average and superior school children: Relationship to intelligence and age. *Archives of Clinical Neuropsychology, 13*, 713-720.

Artiola I Fortuny, L., & Heaton, R.K. (1996). Standard versus computerized administration of the Wisconsin Card Sorting Test. *The Clinical Neuropsychologist, 10*, 419-424.

Baddeley, A.D., & Hitch, G.J. (1974). Working memory. In G.A. Bower (Ed.), *The Psychology of Learning and Motivation* (Vol. 8, pp. 47-89). San Diego, CA: Academic Press.

Baddeley, A.D., & Hitch, G.J. (1994). Developments in the concept of working memory. *Neuropsychology, 8*, 485-493.

Baddeley, A.D. (2003). Working memory: looking back and looking forward. *Neuroscience: Nature Reviews*, Volume 4, 829-839.

Barker, L.A., Andrade, J., & Romanowski, C.A.J. (2004). Impaired implicit cognition with intact executive function after extensive bilateral prefrontal pathology: a case study. *Neurocase, 10*, 233-248.

Barkley, R.A., & Grodzinsky, G.M. (1994). Are tests of frontal lobe functions useful in the diagnosis of attention deficit disorders? *The Clinical Neuropsychologist, 8*, 121-139.

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

Barkley, R.A. (1999). Response inhibition in attention-deficit hyperactivity disorder. *Mental Retardation and Developmental Disabilities Research Reviews, 5*, 177-184.

Barley, R.A. (2001). Executive functioning, temporal discounting, and sense of time in adolescents with Attention Deficit Hyperactivity Disorder (ADHD) and Oppositional Defiant Disorder (ODD). *Journal of Abnormal Child Psychology, 29*, 541-556.

Bentler, P.M. (1992). *On the fit of models to covariances and methodology to the Bulletin*. Psychological Bulletin, 112, 400-404.

Baron, I.S. (2004). *Neuropsychological Evaluation of the Child*. Oxford University Press, New York, NY.

Benton, A. (1991). Prefrontal injury and behavior in children. *Developmental Neuropsychology, 7*, 275-281.

Boone, K.B., Ponton, M.O., Gorsuch, R.L., Gonzalez, J.J., & Miller, B.L. (1998). Factor analysis of four measures of prefrontal lobe functioning. *Archives of Clinical Neuropsychology, 13*, 585-595.

Busch, R.M., Booth, J.E., McBride, A., Vanderploeg, R.D., Curtiss, G., & Duchnick, J.J. (2005). Role of executive functioning in verbal and visual memory. *Neuropsychology, 19*, 171-180.

Byrne, B.M. (1998). *Structural equation modeling with Lisrel, Prelis, and Simplis: Basic concepts, applications, and programming*. Mahwah, New Jersey: Lawrence Erlbaum Associates, Inc.

Carroll, J.B. (1993). *Human cognitive abilities: A survey of factor-analytic studies*. Cambridge, England: Cambridge University Press.

Chase-Carmichael, C.A., Ris, M.D., Weber, A.M., Schefft, B.K. (1999). Neurologic validity of the Wisconsin Card Sorting Test with a pediatric population. *The Clinical Neuropsychologist, 13*, 405-413.

Chelune, G., & Baer, R.A. (1986). Developmental norms for the Wisconsin Card Sorting Test. *Journal of Experimental and Clinical Neuropsychology, 8*, 219-228.

Conners, C. Keith, & MHS Staff. (2002). *Conners' Continuous Performance Test-II: Computer program for Windows™ Technical Guide and Software Manual*. Multi-Health Systems, Inc., North Tonawanda, NY.

Cooley, W.W., & Lohnes, P.R. (1971). *Multivariate Data Analysis.* New York, NY: Wiley.

Crinella, F.M., & Yu, J. (2000). Brain mechanisms and intelligence: Psychometric g and executive function. *Intelligence, 27*, 299-327.

Cummings, J.L., & Coffey, L.E. (2000). Geriatric Neuropsychiatry. In J.L. Cummings & L.E. Coffey (Eds.). *Textbook of geriatric neuropsychiatry*, 2nd Ed. New York: American Psychiatric Press.

Das, J.P., Naglieri, J.A., & Kirby, J.R. (1994). *Assessment of cognitive processes: The PASS theory of intelligence*. Boston, MA: Allyn & Bacon.

Davies, P.L., & Rose, J.D. (1999). Assessment of cognitive development in adolescents by means of neuropsychological tasks. *Developmental Neuropsychology, 15*, 227-248.

Dean, R.D., Woodcock, R.W., Decker, S.L., & Schrank, F.A. (2003). A cognitive neuropsychological assessment system. In *WJ III Clinical Use and Interpretation*. Elsevier Science, USA.

DeJong, P.F., & Das-Smaal, E.A. (1995). Attention and intelligence: The validity of the Star Counting Test. *Journal of Educational Psychology, 87*, 80-92.

Delis, D.C., Kaplan, E., & Kramer, J.H. (2001*). Delis-Kaplan Executive Function System (D-KEFS)*. San Antonio, TX: The Psychological Corporation.

Denckla, M.B. (1996). Research on executive function in a neurodevelopmental context: Application of clinical measures. *Developmental Neuropsychology, 12*, 5-15.

Duff, D., Schoenberg, M.R., Scott, J.G., & Adams, R.L. (2005). The relationship between executive functioning and verbal and visual learning and memory. *Archives of Clinical Neuropsychology, 20*, 111-122.

Durston, S., Thomas, K.M., Yang, Y., Ulug, A.M., Zimmerman, R.D., & Casey, B.J. (2002). A neural basis for the development of inhibitory control. *Developmental Science, 5*, F9-F16.

Eisenberg, N., Spinrad, T.L., Fabes, R.A., Reiser, M., Cumberland, A., Shepard, S.A., Valiente, C., Losoya, S.H., Guthrie, I.K., & Thompson, M. (2004). The relations of effortful control and impulsivity to children's resiliency and adjustment. *Child Development, 75*, 25-46.

Epstein, J.N., Erkanli, A., Conners, C.K., Klaric, J., Costello, J.E., & Angold, A. (2003). Relations between continuous performance test performance measures and ADHD behaviors. *Journal of Abnormal Child Psychology, 31*, 543-554.

Fabrigar, L.R., Wegener, D.T., MacCallum, R.C., & Strahan, E.J. (1999). Evaluating the use of exploratory factor analysis in psychological research. *Psychological Methods, 3,* 272-299.

Filley, C.M., Young, D.A., Reardon, M.S., & Wilkening, G.N. (1999). Frontal lobe lesions and executive dysfunction in children. *Neuropsychiatry, Neuropsychology, and Behavioral Neurology, 12*, 156-160.

Floyd, R.G., Bergeron, R., & Hamilton, G. (2005). *Joint Exploratory Factor Analysis of the Delis-Kaplan Executive Function System and the Woodcock-Johnson III Test of Cognitive Abilities*. Poster presentation at the 2005 National Association of School Psychologists National Convention. Atlanta, GA.

Garcia, A.V., Torrecillas, F.L., de Arcos, F.A., & Garcia, M.P. (2005). Effects of executive impairments on maladaptive explanatory styles in substance abusers: clinical implications. *Archives of Clinical Neuropsychology, 20*, 67-80.

Garson, G.D. (2005). *PA 765 Statnotes: An Online Textbook*. Retrieved from www2.chass.ncsu.edu/garson/pa765/factor.htm on 6/9/05 at 8:30AM. North Carolina State University, North Carolina.

Garson, G.D. (2008). *PA 765 Statnotes: An Online Textbook*. Retrieved from http://www2.chass.ncsu.edu/garson/PA765/correl.htm on 6/29/08 at 8:00PM. North Carolina State University, North Carolina.

Gioia, G.A., Isquith, P.K., Guy, S.C., & Kenworthy, L. (2000). *Behavior Rating Inventory of Executive Function (BRIEF) – Manual*. Psychological Assessment Resources, Inc. Lutz, Fl.

Gnys, J.A., & Willis, W.G. (1991). Validation of executive function tasks with young children. *Developmental Neuropsychology, 7(4)*, 487-501.

Goldberg, E., & Bilder, R.M., Jr. (1987). The frontal lobes and hierarchical organization of cognitive control. In E. Perecman (Ed.), *The Frontal Lobes Revisited*. New York, NY: The IRBN Press.

Goldberg, E., Podell, K., & Lovell, M. (1994). Lateralization of frontal lobe functions and cognitive novelty. *Journal of Neuropsychiatry and Clinical Neurosciences, 6*, 371-378.

Goldman-Rakic, P. S. (1987). Circuitry of primate prefrontal cortex and regulation of behavior by representational memory. In V. B. Mountcastle, F. Plum & S. R. Geiger (Eds.), *Handbook of physiology: The nervous system*. 373-417. Bethesda, MD: American Physiology Society.

Grodzinsky, G.M., & Barkley, R.A. (1999). Predictive power of frontal lobe tests in the diagnosis of attention deficit hyperactivity disorder. *The Clinical Neuropsychologist, 13*, 12-21.

Guadagnoli, E., & Velicer, W. (1988). Relation of sample size to the stability of component patterns. *Psychological Bulletin, 103,* 265-175.

Gustafsson, J.E. (1984). A unifying model for the structure of intellectual abilities. *Intelligence, 8*, 179.

Hasher, L., & Zachs, R.T. (1984). Automatic processing of fundamental information: The case of frequency of occurrence. *American Psychologist, 39,* 1372-1388.

Heaton, R.K. (1981). *A Manual for the Wisconsin Card Sorting Test*. Odessa, Fl: Psychological Assessment Resources.

Heaton, R.K., Chelune, G.J., Talley, J.L., Kay, G.G., & Curtiss, G. (1993). *Wisconsin Card Sorting Test manual: Revised and Expanded*. Odessa, Fl: Psychological Assessment Resources.

Holland, J., McIntosh, D., & Huffman, L. (2004). The role of phonological awareness, rapid automatized naming, and orthographic processing in word reading. *Journal of Psychoeducational Assessment, 22*, 233-260.

Hooper, S.R., Swartz, C.W., Wakely, M.B., deKruif, R.E.L., & Montgomery, J.W. (2002). Executive functions in elementary school children with and without problems in written expression. *Journal of Learning Disabilities, 35*, 57-68.

Huck, S.W., & Cormier, W.H. (1996). *Reading Statistics and Research, Second Edition*. Boston: Addison-Wesley.

Huttenlocher, P. (1979). Synaptic density in human frontal cortex - developmental changes and effects of aging. *Brain Res, 163,* 195-205.

Jöreskog, K.G., & Sörbom, D. (1993). *PRELIS 2: User's reference guide*. Chicago: Scientific Software International.

Kaiser, H.F. (1960). The application of electronic computers to factor analysis. *Educational and Psychological Measurement, 20,* 141-151.

Kaufman, A.S., & Kaufman, N.L. (2004). *Kaufman Assessment Battery for Children, Second Edition, Manual*. Circle Pines, Minnesota: AGS Publishing.

Keith, T.Z., Goldenring Fine, J., Taub, G.E., Reynolds, M.R., & Kranzler, J.H. (2006). Higher order, multisample, confirmatory factor analysis of the Wechsler Intelligence Scale for Children-Fourth Edition: What does it measure? *School Psychology Review, 35*, 108-127.

Klenberg, L., Korkman, M., & Lahti-Nuuttila. (2001). Differential development of attention and executive functions in 3- to 12-year old Finnish children. *Developmental Neuropsychology, 20*, 407-428.

Korkman, M., Kirk, U., & Kemp, S. (1998) *NEPSY – A Developmental Neuropsychological Assessment.* San Antonio, TX: The Psychological Association.

Lezak, M.D. (1995). *Neuropsychological Assessment, Third Edition*. Oxford University Press, New York, NY.

Luria, A.R. (1966). *Human brain and psychological processes*. New York, NY: Harper & Row.

Luria, A.R. (1970). The functional organization of the brain. *Scientific American*, 222, 66-78.

Luria, A.R. (1973). *The working brain: An introduction to neuropsychology*. New York, NY: Basic Books, Inc.

Luria, A.R. (1980). *Higher cortical functions in man, 2nd Ed*. New York, NY: Basic Books.

MacCallum, R.C., Wideman, K.F., Zhang, S. & Hong, S. (1999). Sample size in factor analysis. *Psychological Methods, 4*, 84-99.

Mahone, E.M., Hagelthorn, K.M., Cutting, L.E., Schuerholz, L.J., Pelletier, S.F., Rawlins, C., Singer, H.S., & Denckla, M.B. (2002). Effects of IQ on executive function measures in children with ADHD. *Child Neuropsychology, 8*, 52-65.

Manly, T., Anderson, V., Nimmo-Smith, I., Turner, A., Watson, P., Robertson, I.H. (2001). The differential assessment of children's attention: The Test of Everyday Attention for Children (TEA-Ch), normative sample and ADHD performance. *Journal of Child Psychology and Psychiatry, 42*, 1065-1081.

Mattson, S.N., Goodman, A.M., Caine, C. Delis, D.C., & Riley, E.P. (1999). Executive functioning in children with heavy prenatal alcohol exposure. *Alcoholism: Clinical and Experimental Research, 23*, 1808-1815.

McGrew, K.S., & Flanagan, D.P. (1998). *The Intelligence Test Desk Reference (ITDR).* Allyn & Bacon. Needham Heights, MA.

McGrew, K.S., (2003). *Cattell-Horn-Carroll Definition Project*. Institute for Applied Psychometrics, LLC. Retrieved from www.iapsych.com/chcdef/htm on 4/26/2004.

Messick, S. (1995). Validity of psychological assessment: Validation of inferences from persons' responses and performance as scientific inquiry into scoring meaning. *American Psychologist, 9,* 741-749.

Meyer, D.E. & Kieras, D.E. (1997). A computational theory of executive cognitive processes and multiple-task performance: Part 1 basic mechanisms. *Psychological Review, 104*, 3-65.

Minshew, N.J., Meyer, J., & Goldstein, G. (2002). Abstract reasoning in autism: A dissociation between concept formation and concept identification. *Neuropsychology, 16*, 327-334.

Murji, S. & DeLuca, J.W. (1998). Preliminary validity of the cognitive function checklist: Prediction of Tower of London performance. *The Clinical Neuropsychologist, 12*, 358-364.

Murphy, G.L., & Allopenna, P.D. (1994). The locus of knowledge effects in concept learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20*, 904-919.

Naglieri, J.A. (1999). *Essentials of CAS assessment*. New York, NY: Wiley.

Naglieri, J.A., Goldstein, S., Delauder, B.Y., & Schwebach, A. (2005). Relationships between the WISC-III and the Cognitive Assessment System with Conners' rating scales and continuous performance tests. *Archives of Clinical Neuropsychology, 20*, 385-401.

Newman, S.D., Carpenter, P.A., Varma, S., & Just, M.A. (2003). Frontal and parietal participation in problem solving in the Tower of London; fMRI and computational modeling of planning and high-level perception. *Neuropsychologia, 41*, 1668-1682.

Norman, D.A., & Shallice, T. (1986). Attention to action: Willed and automatic control of behavior. In R.J. Davidson, G.E. Schwartz, & D. Shapiro (Eds.), *Consciousness and self-regulation: Advances in research and theory*. New York: Plenum Press.

Phelps, L., McGrew, K.S., Knopik, S.N., & Ford, L. (2005). The general (g), broad, and narrow CHC stratum characteristics of the WJ-III and WISC-III tests: A confirmatory cross-battery investigation. *School Psychology Quarterly, Spring 2005, 20*, 66.

Pineda, D., Ardila, A., Rosselli, M., Cadavid, C., Mancheno, S., & Mejia, S. (1998). Executive dysfunction in children with Attention-Deficit/Hyperactivity Disorder. *International Journal of Neuroscience, 96*, 177-196.

Plucker, J. A. (Ed.). (2003). *Human intelligence: Historical influences, current controversies, teaching resources*. Retrieved [6/04/2006], from http://www.indiana.edu/~intell

Posner, M.I., & Petersen, S.E. (1990). The attention system of the human brain. *Annual Review of Neuroscience, 13,* 25-42.

Posner, M.I., & Rothbart, M.K. (1998). The conscious brain: Abnormal and normal. *Philosophical Transactions: Biological Sciences, 353,* 1915-1927.

Prigatano, G.P. (1991). Disturbances of self-awareness of deficit after traumatic brain injury. In G.P. Prigatano (Ed.) *Neuropsychological rehabilitation after brain injury*.143-151. Baltimore, MD: Johns Hopkins University Press.

Reitan, R.M. (1988). Integration of neuropsychological theory, assessment, and application. *The Clinical Neuropsychologist, 2*, 331-349.

Rosenzweig, M.R., Breedlove, S.M., & Leiman, A.L. (2002). *Biological Psychology, Third Edition*. Sunderland, MA: Sinauer Associates, Inc.

Schonfeld, A.M., Mattson, S.N., Lang, A.R., Delis, D.C., & Riley, E.P. (2001) Verbal and nonverbal fluency in children with heavy prenatal alcohol exposure. *Journal of Studies in Alcohol, March 2001*, 239-246.

Schumacker, R.E. & Lomax, R.G. (1996). *A Beginner's Guide to Structural Equation Modeling*. Mahwah, NJ: Erlbaum.

Seidman, L.J., Biederman, J., Monuteaux, M.C., Doyle, A.E., & Faraone, S.V. (2001). Learning disabilities and executive dysfunction in boys with Attention-Deficit/Hyperactivity Disorder. *Neuropsychology, 15*, 544-556.

Shallice, T. (1982). Specific impairments of planning. *Philosophical Transactions of the Royal Society of London B, 298,* 199-209.

Simon, H.A. (1975). The functional equivalence of problem solving skills. *Cognitive Psychology, 7,* 268-288.

Stevens, J.P. (2002). *Applied Multivariate Statistics for the Social Sciences, Fourth Ed.* Mahwah, New Jersey: Lawrence Erlbaum Associates, Inc.

Stuss, D.T., & Benson, D.F. (1984). Neuropsychological Studies of the Frontal Lobes. *Psychological Bulletin, 95*, 3-28.

Stuss, D.T., & Benson, D.F. (1987). Frontal lobes and control of cognition and memory. In E. Perecman (Ed.), *The Frontal Lobes Revisited*. New York, NY: The IRBN Press.

Stuss, D.T., & Gow, C.A. (1992). "Frontal dysfunction" after traumatic brain injury. *Neuropsychiatry, Neuropsychology, and Behavioral Neurology, 5*, 272-282.

Tabachnick, B.G., & Fidell, L.S. (2001). *Using Multivariate Statistics, Fourth Ed.* Boston, MA: Allyn & Bacon.

Thompson, R.F. (2000). *The Brain: A Neuroscience Primer, Third Edition*. Worth Publishers, New York, NY.

Thurstone, L. L. (1938). Primary mental abilities. *Psychometric Monographs*, No. 1.

Varney, N.R., & Stewart, H. (2004). Is impaired executive function a single or multidimensional disability? *Applied Neuropsychology, 11*, 229-234.

Wang, P.L. (1987). Concept formation and frontal lobe function: The search for a clinical frontal lobe test. In E. Perecman (Ed.), *The Frontal Lobes Revisited*. New York, NY: The IRBN Press.

Wechsler, D. (2003) *WISC-IV Technical and Interpretive Manual*. San Antonio, Texas: The Psychological Corporation.

Wecker, N.S., Kramer, J.H., Wisiewski, A., Delis, D.C., & Kaplan, E. (2000). Age effects on executive ability. *Neuropsychology, 14*, 409-414.