EVALUATING THE RELATIONSHIP BETWEEN CHC FACTORS

AND EXECUTIVE FUNCTIONING


A DISSERTATION

SUBMITTED TO THE GRADUATE SCHOOL

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

BY

ELIZABETH L. ROBERDS

BALL STATE UNIVERSITY

MUNCIE, INDIANA

MAY 2015

EVALUATING THE RELATIONSHIP BETWEEN CHC FACTORS

AND EXECUTIVE FUNCTIONING

A DISSERTATION

SUBMITTED TO THE GRADUATE SCHOOL

IN PARTIAL REQUIREMENTS

FOR THE DEGREE

DOCTOR OF PHILOSOPHY

BY

ELIZABETH L. ROBERDS

DISSERTATION ADVISOR: DR. ANDREW S. DAVIS

APPROVED BY:

_____   _____
Andrew S. Davis, Ph.D.             Date
Committee Chairperson


_____   _____
Nicole Etcheson, Ph.D.             Date
Committee Member


_____   _____
Holmes Finch, Ph.D.              Date
Committee Member


_____   _____
Eric Pierson, Ph.D.              Date
Committee Member


BALL STATE UNIVERSITY
MUNCIE, INDIANA
MAY 2015

# ACKNOWLEDGMENTS

With abundant gratitude I would like to recognize several individuals who made possible the completion of this dissertation and who have supported me throughout my graduate career. I must first thank my advisor, Dr. Andrew Davis, for both challenging and encouraging me, for graciously creating opportunities for me, and for being an exceptional model as a professor, supervisor, and psychologist. Thank you for trusting me with the responsibilities that let me grow as a professional. I cannot thank you enough for your support and inspiration.

I must also thank the other members of my dissertation committee, Drs. Nicole Etcheson, Holmes Finch, and Eric Pierson. I truly appreciate the opportunity to have worked with all of you and am so thankful for the experience of receiving your feedback and mentorship. Dr. Finch, thank you also for your instruction and advisement throughout my time as a student, as well as your kindness and generosity with your time. And Dr. Pierson, for your excellent supervision, instruction, counsel, and support, I will be forever grateful.

To my fellow Ball State students and friends, thank you for the companionship and support. Amy Zimmerman, Sarah Connolly, Beth Trammell, Kathleen Niegocki and Amanda Skierkiewicz, whether you realize it or not, you were all integral to my survival of my years in graduate school. To my LAS*PIC cohort, but especially to the now Drs. Erin Leichman and Evan Dart, and to my supervisor, Dr. Cicily Prestridge, thank you for the professional and personal support during the internship year. Words cannot express my gratitude.

To my family and friends, thank you for your love, support, encouragement, and patience. My Pennsylvania family (Lance, Anne, Jonathan and Diane), my New Orleans family (Mere, Catherine, Jerry and Leslie), and my Durham friends (Jennie, Colin, Sarah, and especially Barbara and Margy), I couldn't have done it without you. I am fortunate to have you all in my

life.

Last, but certainly not least, I would like to thank my husband, Alex Lemann, and my children, Jack and Katie Anne, for your patience and sacrifices as I worked toward completing my degree. Statistical analysis indicated that approximately 33.3% of you were helpful toward the completion of this dissertation; however, 100% of you facilitated joy.

**TABLE OF CONTENTS**

# LIST OF TABLES

# CHAPTER I

# INTRODUCTION

## Overview

Despite the popularity of using Cattell-Horn-Carroll (CHC; Carroll, 1993, 2005; Horn, 1988, 1991; Horn & Blankson, 2005; Horn & Noll, 1997; McGrew, 2014) factors to conceptualize intelligence and inform assessment of cognitive abilities, very little investigation has explored the relationship between intelligence as represented by CHC factors and tests of executive functions. Currently, most well accepted tests of intelligence have illustrated how CHC factors are represented in their batteries, with the *Woodcock-Johnson III Tests of Cognitive Abilities* (WJ-III-Cog; Woodcock, McGrew, & Mather, 2001) being considered for some time the test that best encompasses CHC theory factors. The specific CHC factors represented by the WJ-III-Cog include seven broad ability clusters: Fluid Intelligence (*Gf*), Crystallized Intelligence (*Gc*), Short-term Memory (*Gsm*), Visual Processing (*Gv*), Auditory Processing (*Ga*), Long-Term Storage and Retrieval (*Glr*), and Processing Speed (*Gs*) (Flanagan, Ortiz, & Alfonso, 2007). While some research has supported the idea that tests of intelligence and tests of executive functioning share considerable variance (Davis, Pierson, & Finch, 2011; Floyd, Bergeron, Hamilton, & Parra, 2010), little research has specifically addressed the relationship between the WJ-III-Cog and the *Delis-Kaplan Executive Function System* (D-KEFS; Delis, Kaplan, & Kramer, 2001).

This study used Cattell-Horn-Carroll (CHC) theory to explore the relationship between intelligence and executive functioning in young adults. Examination of this relationship is important, as previous research has not been conclusive regarding whether or not tests of executive function measure that which is distinct from that which is measured by tests of

intelligence. Researchers and practitioners commonly use intelligence measures to infer executive functioning deficits (Duff, Schoenberg, Scott, & Adams, 2005), though the relationship between commonly used measures of intelligence and executive functioning remains unclear. A greater understanding of this relationship has great practical application for psychologists as they seek to select appropriate assessment tools for work with their clients. Given that the majority of commonly used intelligence measures use CHC theory as their primary theoretical rationale, it is important to explore tests of executive functioning through this lens. As such, this study investigated the relationship between executive functions and intelligence through this lens.

## Intelligence

Intelligence has been conceptualized in a variety of ways and is a term that has been somewhat historically difficult to define (Batholomew, 2004). Spearman's (1904) theory of general intelligence was the first to propose that overall intelligence could be represented as a quantity expressed by the symbol $g$ (Bartholomew, 2004). Spearman developed his theory of intelligence around the same time that significant contributions were being made in the field of intelligence by Binet (1905). Binet's approach to quantifying intelligence was different from that of Spearman's, and led to the development of the Intelligence Quotient (IQ). Both approaches are still identifiable in intelligence testing in the present day. Importantly, significant analytic investigation has been conducted in support of a general intelligence model (Deary, 2001; Gardner, Kornhaber, & Wake, 1996; Johnson, Bouchard, Krueger, McGue, & Gottesman, 2004).

General intelligence ($g$) was included in the Cattell-Horn-Carroll (CHC) theory of intelligence, which is the theory through which this study conceptualized intelligence. CHC

theory grew not only from Spearman's theory of general intelligence, but also by the work of

Cattell and Horn (Cattell, 1941; Horn & Cattell, 1966), who proposed a hierarchical theory of

intelligence that did not include *g*, but focused on broad factors of intelligence including fluid

ability (*Gf*) and crystallized ability (*Gc*) (Gardner et al., 1996).  Horn and Cattell's theory was

expanded to include as many as 10 broad factors (Schrank, Miller, Wendling, & Woodcock,

2010), and came to be known as *Gf-Gc* theory.  Later, Carroll (1993) expanded upon the work of

Cattell and Horn in his three stratum theory.  This theory is hierarchical and based on exploratory

factor analysis of tests of cognitive ability.  Within three stratum theory, Carroll identified *g*,

eight broad abilities, and 70 narrow abilities (Schrank et al., 2010); current CHC theory is based

on combination of *Gf-Gc* theory and the three-stratum theory, and has undergone a number of

expansions (McGrew, 2014).

Currently used tests of intelligence are generally normative, meaning that they represent

an individual's performance relative to those of the individuals that were in the standardization

sample of the given measure.  A variety of comprehensive tests of intelligence are in use today,

the majority of which employ CHC theory as their primary theoretical rationale (Urbina, 2011).

The WJ-III-Cog is one such test. A recent survey indicates that the majority of school

psychologists base their assessment practices in CHC theory (Sotelo-Dynega & Dixon, 2014).

Intelligence has been found to be influenced by both genetics (Deary, Spinath, & Bates,

2006; Plomin & Spinath, 2004) and environment (Mandelman & Grigorenko, 2011); and may be

effected differently based on interaction between the two (Harden, Turkheimer, & Loehlin,

2007).  While intelligence has been found to remain fairly stable across the lifespan (Larsen,

Hartmann & Nyborg, 2008), prior to adolescence some malleability may be present (Bloom,

1964; Gustaffson & Undheim, 1992).  Additionally, there is some evidence that fluid intelligence declines in advanced age (Elderkin-Thompson, Ballmaier, Hellemann, Pham, & Kumar, 2003).

## Executive Function

Difficulty defining executive functions is similar to that of defining intelligence. Consensus regarding a definition of executive function has been elusive (Alvarez & Emory, 2006; Eslinger, Biddle, & Grattan, 1997; Hass, Patterson, Sukraw, & Sullivan, 2014; Jurado and Rosselli, 2007); however, similarities between definitions are present.  Definitions frequently include that executive functions are necessary adaptive capacities that direct cognition and behavior (Anderson, 2008; McCloskey, Perkins, & Van Divner, 2009).  Specific abilities associated with executive function include planning, working memory, inhibition, set shifting, and attention (Denckla & Reiss, 1997; Jurado & Rosseli, 2007).

A debate is present regarding whether executive function should be conceptualized as a unitary construct or as a non-unitary construct (Jurado & Rosselli, 2007).  Based on evidence that individuals rarely present with global deficits in executive function, there has been movement away from the unitary construct idea, and movement toward conceptualizing executive function as interconnected components (Anderson, 2008; McCloskey et al., 2009).

Executive functions have long been associated with the frontal lobe of the brain (Alvarez & Emory, 2006; Jurado & Rosselli, 2007; McCloskey et al., 2009).  Of particular relevance to executive functions are the lateral prefrontal cortex (Fuster, 2001) and the medial prefrontal cortex/cingulate cortex (Wahlstrom & Luciana, 2011).  Planning, initiating, and executing actions are associated with the lateral prefrontal cortex (Goldman-Rakic, 1987a; Fuster, 1989; Luria, 1966, as cited in Wahlstrom & Luciana, 2011).  Set-shifting ability and verbal fluency are also associated with this area of the brain (Wahlstrom & Luciana, 2011).  The orbitofrontal

cortex, another frontal lobe area, is primarily associated with social regulation (Beer, Shimamura, & Kight, 2004).  In addition to the frontal lobe, the cerebellum has been implicated in the area of executive functioning, specifically with regard to attention (Akshoomoff & Courchesne, 1992; Allen et al., 2011; Courchesne et al., 1994; Strick, Dum, & Fiez, 2009). However, additional executive functions including planning, set shifting, reasoning, working memory, and verbal fluency, have also been associated with the cerebellum (Schumahmann & Sherman, 1998).  It is important to consider that areas of the brain most associated with executive functions likely are involved in complex interactions with other areas of the brain (Adcock, Constable, Gore, & Goldman-Rakic, 2000; Alvarez & Emory, 2006; Jurado & Rosselli, 2007).  Studies of both humans and primates have allowed researchers to gain insight into the localization of executive functions, and gains in neuroimaging have also greatly aided in this endeavor.

It has been argued that, given the nature of executive functions, most tests of executive function inherently measure multiple abilities (McCloskey et al., 2009; Rabbitt, 1997).  There has been a trend in the measurement of executive function to rely on well-established historical measures, primarily those that have been associated with frontal lobe function (Jurado & Rosselli, 2007).  Examples of such measures include the Stroop task (Stroop, 1935) and tower tests, such as the Tower of London and Tower of Hanoi.

As with intelligence, age is a factor that must be considered with regard to executive functions.  Executive functioning differences can be identified as early as infancy (Cuevas & Bell, 2014), are not fully developed in adolescence (McCloskey et al., 2009) and continue to develop into early adulthood, possibly into the twenties (Diamond, 2002).  However, it is important to recognize that development of executive function is different from individual to

individual (McCloskey et al., 2009).  Additionally, there is some evidence that different executive functions develop at different rates and times, and may decline with advanced age (Jurado & Rosselli, 2007).

Past research suggests at least a moderate positive relationship between overall intelligence and executive functions (Ardila, Pineda, and Rosselli, 1999; Davis, Pierson, & Finch, 2011; de Frais, Dixon, & Strauss, 2006; Floyd, Bergeron, Hamilton, & Parra, 2010; Floyd et al., 2006; Friedman et al., 2006; Fuchs & Day, 2010; Unsworth et al., 2009; Zook, Davalos, DeLosh, & Davis, 2004; Zook, Welch, & Ewing, 2006).  Such research has been especially indicative of a likely relationship between fluid intelligence and executive functions (Davis et al., 2011; de Frais, Dixon, & Strauss, 2006; Unsworth et al., 2009; Zook et al., 2004; Zook et al., 2006); however, differences in the measurement of both intelligence and executive function across studies have made comparison difficult.  While the relationship between executive functions as measured by the D-KEFS and intelligence as measured by the WJ-III-Cog have been explored empirically, past investigations have mostly studied children and adolescents (Floyd et al., 2010) or have focused on the relationship between executive functions and the WJ-III-Cog clinical clusters (Floyd et al., 2006).  The WJ-III-Cog clinical clusters are optional scores with unestablished validity (Schrank et al., 2010), including Phonemic Awareness, Working Memory, Broad Attention, Cognitive Fluency, Executive Processes, Delayed Recall, and Knowledge.  Given that executive functions are not fully developed in adolescence (McCloskey et al., 2009), investigation with adults is needed.

## Rationale and Significance of the Study

Review of the literature indicated that the relationship between intelligence and executive function remains unclear.  While some studies suggest that there is little that is unique between

that which is measured by tests of intelligence and that which is measured by tests of executive functions (Floyd et al., 2010), other studies suggest that despite substantial shared variability, some aspects of executive function are unique and not accounted for by tests of intelligence (Ardila et al., 1999; Davis et al., 2011). Further, a predictive relationship between some components of both constructs has been identified, though remains largely unexplored (Richland & Burchinal, 2013).

The primary purpose of this study was to further illuminate the relationship between intelligence and executive functioning.  Knowledge of whether or not there is overlap between intelligence as measured by the CHC factors of the WJ-III-Cog and tests of executive functioning such as those of the D-KEFS has the potential to guide clinical practice. Specifically, such knowledge may enable practitioners to use reduced and briefer batteries when assessing neuropsychological functioning.  Not only is a briefer battery important for individuals with neuropsychological impairment, who frequently have poor test taking skills, but is also consistent with constrains of managed care, which often limits the amount of assessment time allotted (Davis et al., 2011).  While greater understanding of the relationship between cognitive and executive functioning profiles will aid in the appropriate interpretation of profiles, and may allow for a briefer test battery, an increased understanding of the relationship may also allow practitioners who choose to administer both measures in full to better compare data points.  In all cases, an increased understanding is likely to allow practitioners to more confidently support statements regarding an individual's functional ability.

Differences in conclusion between past studies exploring the relationship between intelligence and executive function may be accounted for by differences in the populations involved.  Floyd and colleagues (2010) explored intelligence, as measured by the WJ-III-Cog,

and executive functions, as measured by the D-KEFS, in a population of children and adolescents.  Given the knowledge that executive functions are not fully developed in adolescence, and certainly not in childhood, it would be inappropriate to extend their conclusions to an adult population.  While Floyd and colleagues (2010) concluded, as stated previously, that there is little that is unique between that which is measured by tests of intelligence and that which is measured by tests of executive functions, it remains unclear if these measures would present similarly in adults.

Differences in conclusion between past studies may also be accounted for differences in instruments.  Many measures used in past research have limited clinical application, as they are not commonly employed. While some research has indicated a connection between a tower task and intelligence (Zook et al., 2006), Floyd and colleagues (2010) did not include the D-KEFS Tower Test in their analysis.  This is one of the tests that Davis and colleagues (2011) concluded did not significantly contribute to shared variability between tests of executive function and intelligence.  As part of the purpose of this study, a comparison of executive function and intelligence was made using an adult population, and the Tower Test was a focus of exploration. Davis and colleagues (2011) additionally found that Color-Word Interference Test from the D-KEFS did not significantly contribute to shared variance between executive functions and intelligence; this measure was also a focus of the current study.  Variants of both the Tower Test and Color-Word Interference Test are well established tests of executive function; considering this in addition to their seeming lack of a conclusively strong relationship with intelligence in past research, made them ideal measures with which to extend knowledge of the relationship in question.  Additionally, these two tests, or variations of these tests, are frequently used by neuropsychologists in clinical practice, potentially increasing the generaliziability of the results

of this investigation. In sum, given the paucity of knowledge about the relationship between intelligence and executive functioning, especially with regard to commonly used measures of both, such as the WJ-III-Cog and the D-KEFS, it was of interest to explore this relationship, to further understanding of both constructs, and to further inform assessment practices and assessment interpretation.

### Research Questions

1. Is there a significant canonical correlation between tests of intelligence and tests of executive functions?

2. If there is a significant canonical correlation between tests of intelligence and tests of executive functions, what are the factors of intelligence and executive function that contribute most to this relationship?

3. Is there a significant correlation between Color-Word Interference Test Condition 3 (Inhibition) and the subtests of the WJ-III-Cog?

4. Is there a significant correlation between Color-Word Interference Test Condition 4 (Inhibition/Switching) and the subtests of the WJ-III-Cog?

5. Is there a significant correlation between Tower Test Total Achievement and the subtests of the WJ-III-Cog?

6. Is there a significant correlation between Tower Test Time-Per-Move Ratio and the subtests of the WJ-III-Cog?

7. Do the seven Woodcock-Johnson III Tests of Cognitive Abilities subtest scores (subtests 1-7) predict the four D-KEFS scores (Color-Word Interference Test Condition 3 (Inhibition), Color-Word Interference Test Condition 4

(Inhibition/Switching), Tower Test Total Achievement, and Tower Test Time-Per-Move Ratio)?

## List of Terms

*Auditory Processing:* The ability to recognize, synthesize, and analyze similarities, differences, and subtleties of sounds.

*Broad CHC factors:* Abilities, which underlie a general intelligence factor, identified in the second stratum of CHC theory of intelligence.

*Cerebellum:* An area of the brain most often associated with motor control, which has also been implicated in the executive function of attention.

*CHC theory:* A theory of intelligence derived from two separate intelligence theories: Cattell and Horn's *Gf-Gc* theory and Carroll's Three Stratum theory.  CHC theory is hierarchical, and asserts the presence of a general intelligence factor (*g*), under which are a number of broad and narrow cognitive abilities.

*Crystallized Intelligence:* Knowledge and skills acquired through life experience and education.

*Executive Functions:* Adaptive capacities, traditionally associated with frontal lobe functioning, which direct cognition and behavior, and include such abilities as planning, working memory, inhibition, set shifting, and attention.

*Fluid Intelligence:* The ability to reason with unfamiliar or novel information.

*Inhibition:* The cognitive ability to overcome sensory distractions by focusing attention on relevant information, and stopping automatic processing of that which is task-inappropriate.

*General Intelligence Factor* (*g*): An overall general intellectual ability first introduced by Spearman and later included in later conceptualizations of intelligence such as CHC theory.

*Lateral Prefrontal Cortex:* An area of the prefrontal cortex associated with the ability to plan, initiate and execute actions.

*Long-Term Storage and Retrieval:* The ability to store information in memory and retrieve this information when necessary.

*Medial Prefrontal Cortex:* An area of the prefrontal cortex associated with attention, response inhibition and concentration.

*Orbitofrontal Cortex:* An area of the prefrontal cortex primarily associated with the regulation of social behavior.

*Planning:* The cognitive ability to think through task relevant steps and create a plan of action, prior to engaging in a task.

*Prefrontal Cortex (PFC):* A part of the frontal lobes of the brain; the area of the brain most associated with executive functions.

*Processing Speed:* The ability to quickly and accurately complete simple, clerical-type tasks.

*Set-Shifting:* The cognitive ability to move attention from one task to another and concentrate on appropriate stimuli; also referred to as task switching.

*Short-Term Memory:* The ability to hold presented information in immediate awareness and use it within a short period of time.

*Visual Processing:* The ability to process visually presented information and to perceive and analyze visual patterns.

**CHAPTER II**

**REVIEW OF THE LITERATURE**

This review of the literature is organized into four sections that are relevant to the present investigation.  The first section will review the construct of intelligence, including relevant theory and history.  The second section will review the construct of executive functions, with an emphasis on neuroanatomy.  The third section reviews the literature concerning the relationship between intelligence and executive functioning.  Finally, the conclusion summarizes the literature and suggests implications for the current study.

**Intelligence**

Intelligence is one of the most controversial topics in the field of psychology.  Various theories of intelligence have and do conceptualize this construct in a variety of ways; while most subscribe to the concept of an overall intelligence factor, others assert that multiple intelligences best represent human cognitive ability.  Measurement of intelligence and implications of such measurement have also long been topics of controversy, with many approaches to assessment developed, and some arguing that intelligence simply cannot be measured.  With such disparate views of intelligence present in the field of psychology, it is not surprising that defining the term intelligence is a challenge.

Though definitions of intelligence differ, they generally focus on common concepts, such as cognitive ability to engage in goal-directed or purposeful behavior that is adaptive.  One definition of intelligence that has been cited frequently comes from David Wechsler, who himself developed numerous tests of intelligence.  Wechsler asserted that intelligence is "the aggregate or global capacity of the individual to act purposefully, to think rationally, and to deal effectively with his environment" (1944, p. 3).  Similar threads can be identified in another

definition of intelligence, put forth by Howard Gardner: "a human intellectual competence must entail a set of skills or problem solving – enabling the individual to resolve genuine problems or difficulties that he or she encounters and, when appropriate, to create an effective product – and must also entail the potential for finding or creating problems – and thereby laying the groundwork for the acquisition of new knowledge" (Gardner, 2004, pp. 60-61).  Although Wechsler and Gardner disagree in many ways on how intelligence should be conceptualized and measured, it is interesting to note that their definitions of intelligence are not vastly different in nature.  Though there are those who disagree (e.g. Gardner), there is general widespread acceptance of a theory of general intelligence, commonly abbreviated as $g$, in the field of psychology.

Models of intelligence have been one way to address the question of what defines intelligence.  Intelligence is commonly conceptualized as something that can be quantified.  Charles Spearman (1904), in his model of intelligence, is the first to propose that overall intelligence be conceptualized as a quantity represented by the symbol $g$.  Spearman's theory and model are reviewed in detail below.  Following Spearman, Arthur Jensen argued that the word *intelligence* is not acceptable for scientific application and described intelligence as 'the $g$ factor' (Bartholomew, 2004).  In the present, intelligence is also commonly quantified as an Intelligence Quotient (IQ), and is often treated as synonymous to $g$ in discussion of intelligence, though they are distinct concepts with divergent histories (Bartholomew, 2004).

There are arguably two distinct paths that have led to current conceptualization and measurement of intelligence in the present day (Barthlolmew, 2004).  One path was forged by Alfred Binet beginning at the turn of the twentieth century.  Binet's work in intelligence, which

led to that of Lewis Terman, grew from the work of Francis Galton.  The other path, which also began at the turn of the twentieth century, was initiated by Charles Spearman.

In early assessment of intelligence, Binet sought to measure the abilities of children in an educational setting.  Binet's work led to the conceptualization of mental age, which was calculated by taking an individual child's score on a number of test items and comparing the child's score to the average score obtained by children of various ages.  The child's mental age would be defined by comparing his score to reference scores.  Dividing mental age by chronological age determined the Intelligence Quotient (IQ).  Historically, this was the first use of the term IQ (Bartholomew, 2004).  Test items developed by Binet were later revised by Terman, who is known for the development of the Stanford-Binet intelligence test, which continued to use the IQ.  This approach proved unhelpful in the calculation of intelligence in adults, as mental age does not continue to increase indefinitely into adulthood.  This issue was addressed by Wechsler around 1939, who proposed that an individual's total score be divided by the average score obtained by individuals of the same age (Bartholomew, 2004).  Wechsler scaled his test to have a mean of 100 and a standard deviation of 15.  His conceptualization of intelligence and his calculation of IQ are still in use to this day.

Around the time that Binet and Terman conducted their work leading to the IQ, Charles Spearman put forth a paper titled '"General Intelligence" objectively defined and measured', in which he presented the first factor analysis (Bartholomew, 2004).  Spearman proposed that a general ability or common factor underlies test performance across items; this general ability has come to be known as *g*.  Though Spearman's initial model contained two factors (a common factor and a specific factor, *s*), subsequent investigation in the 1930s by Thurstone led to the

development of a multiple factor model, with multiple abilities underlying a general *g* (Garner, Kornhaber, & Wake, 1996).

Factor analytic studies have continued to support a theory of general intelligence (Garner et al., 1996). Contemporary investigation into whether different intelligence tests measure the same underlying factor of *g* has revealed that *g* is identified in most measures (Johnson, Bouchard, Krueger, McGue, & Gottesman, 2004). Furthermore, inter-correlation between subtests of well-established tests of intelligence suggests an underlying *g* factor (Deary, 2001). The general intelligence is linked explicitly to some measures of intelligence, such as the *Woodcock-Johnson III Tests of Cognitive Abilities* (WJ-III-Cog; Woodcock, McGrew, & Mather, 2001), in which it is represented by an overall score. However, it is important to acknowledge that much of the literature concerning intelligence has focused on IQ and not *g*. The general *g* is the scientifically preferred conceptualization of intelligence (Bartholomew, 2004). One widely accepted contemporary theory that encompasses *g* is the Cattell-Horn-Carroll (CHC) theory.

In the mid twentieth century, Raymond B. Cattell (1941) and John Horn (Horn & Cattell, 1966) proposed a hierarchical theory of intelligence that did not include *g*, but focused on broad factors of intelligence including fluid ability (*Gf*), crystallized ability (*Gc*), general visualization (*Gv*), general fluency (*Gr*), and general speediness (*Gs*), which have under them narrower abilities (Gardner et al., 1996); this theory was expanded to include as many as 10 broad factors (Schrank, Miller, Wendling, & Woodcock, 2010). This theory came to be known as *Gf-Gc* theory, due to the emphasis placed on these two particular factors. In the late twentieth century, John Carroll (1993) expanded upon the work of Cattell and Horn and introduced what is known as the three stratum theory. This theory is also hierarchical in nature and was based on exploratory factor analysis of cognitive ability tests. From his analysis, Carroll identified a

general intelligence factor of *g*, eight broad abilities, and 70 narrow abilities (Schrank et al., 2010).  Current CHC theory is based on an amalgamation of these independent theories (*Gf-Gc* theory and the three-stratum theory) and has gone through expansions (McGrew, 2014).  Within this theory, an overall intellectual ability is represented by *g*.  At the time of this study, seven broad abilities were identified in CHC theory (Carroll, 2005; Horn & Blankson, 2005), including Fluid Intelligence (*Gf*), Crystallized Intelligence (*Gc*), Short-term Memory (*Gsm*), Visual Processing (*Gv*), Auditory Processing (*Ga*), Long-Term Storage and Retrieval (*Glr*), and Processing Speed (*Gs*).  Narrow abilities underlie these broad abilities.

Intelligence testing can historically be traced to Binet, who, as previously discussed, constructed a test of ability for children in 1905. Binet's test, which he designed with Theodore Simon, went through numerous revisions and versions.  Lewis Terman conducted one revision which was known as the *Stanford-Binet* (1916), which has continued to be revised and is still in use today.  The Stanford-Binet was influential in the development of the first Wechsler scale, the *Wechsler-Bellevue Intelligence Scale*, which was published in 1939 by David Wechsler. Wechsler scales continue to be popular to this day.  Other early tests of intelligence were group administered, such as the *Army Alpha*, which was used during World War I to classify troops (Urbina, 2011).  This test was developed by Arthur S. Otis, who subsequently developed group intelligence tests for other contexts such as in education.  A variety of intelligence tests are in use today.  Most contemporary tests of intelligence are individually administered measures.  These tests are administered by a trained examiner in a standardized manner.

Scores from tests of intelligence are normative, meaning that they represent an individual's performance relative to those of the individuals that were in the standardization sample of the given measure.  Normative data should be representative of the population for

which the test will be used.  Representativeness should include age and a variety of demographic characteristics (Urbina, 2011).  Tests require normative updates, in part due to the Flynn effect (Flynn, 1985, 1999).  The Flynn effect refers to the trend for the mean levels of intelligence to increase with time.  This phenomenon has been attributed to a variety of potential causes including better nutrition and medical care, technology, and familiarity with test related tasks, though a clear cause remains unknown (Urbina, 2011).

As stated previously, a number of comprehensive tests of intelligence are in use today, one of which is the *Woodcock-Johnson III Test of Cognitive Abilities* (WJ-III-Cog; Woodcock, McGrew, & Mather, 2001). The WJ-III-Cog is an individually administered assessment of intelligence that assesses an overall intellectual ability, as well as both fluid and crystallized intelligence and cognitive efficiency.  Specific subtests purport to measure broad CHC factors. The WJ-III-Cog consists of a standard battery of 10 subtests, seven of which are necessary for the calculation of general intellectual ability.  Other comprehensive measures of intelligence in use today include the *Cognitive Assessment System* (CAS; Naglieri & Das, 1997), the *Differential Ability Scales* (DAS-II; Elliott, 2007), the Kaufman scales (*Kaufman Adolescent and Adult Intelligence Test* (KAIT) and *Kaufman Assessment Battery for Children, Second Edition* (KABC-II); Kaufman & Kaufman, 1993, 2004), the *Reynolds Intellectual Assessment Scales* (RAIS; Reynolds & Kamphaus, 2003), the *Stanford-Binet, Fifth Edition* (SB-V; Roid, 2003), and the Wechsler scales (*Wechsler Adult Intelligence Scale, Fourth Edition* (WAIS-IV); *Wechsler Intelligence Scale for Children, Fourth Edition* (WISC-IV), and *Wechsler Preschool and Primary Scale of Intelligence* (WPPSI-III); Wechsler, 2008, 2003, 2002).  Of these, the following measures utilize CHC theory as their primary theoretical rationale: the DAS, RAIS, and SB-V.  The Kaufman scales (KAIT and KABC) utilize both CHC theory and Luria's

neuropsychological theory.  In contrast, the Wechsler scales employ composites that are derived through factor analysis.

Intelligence has been found to be highly heritable (Deary, Spinath, & Bates, 2006; Plomin & Spinath, 2004); however, many studies indicate that heritability estimates vary across different environments (Mandelman & Grigorenko, 2011).  There is some evidence that environmental influences do not affect all individuals in the same manner.  For example, adolescents from families with low socioeconomic status have been found to be more influenced by environment than their peers from high socioeconomic backgrounds (Harden, Turkheimer, & Loehlin, 2007).  In general, current investigations into the heritability of intelligence focus on mediating factors.  What is clear is that both genetics and environment play a role in outcomes of intelligence.

Research regarding the stability of intelligence across the lifespan has indicated that general intelligence appears to be a fairly stable construct after approximately age 10-13 years (Bloom, 1964; Gustaffson & Undheim, 1992).  A longitudinal study following adult males from early adulthood to middle age suggests stability in general intelligence (*g)*; this is consistent with other longitudinal studies (Larsen et al., 2008).  However, some age related decline in intelligence has been noted, particularly with regard to fluid intelligence (*Gf*; Elderkin-Thompson, Ballmaier, Hellemann, Pham, & Kumar, 2003), which has been found to be less stable in late adulthood than is crystallized intelligence (*Gc*).

## Executive Functions

Though many definitions of executive functions exist, there is a lack of consensus in the literature regarding this term.  A universally accepted definition of executive functions does not currently exist (Alvarez & Emory, 2006; Eslinger, Biddle, & Grattan, 1997; Hass et al., 2014).

Executive functions have been defined in diverse and inconsistent ways.  Despite the plethora of literature surrounding executive functions, the term remains somewhat loosely defined in the field of psychology.  The nebulousness of the definition is reflected in the definition of executive functions put forth by the American Psychological Association (2006) in their dictionary, which states that executive functions are "higher level cognitive processes that organize and order behavior, including (but not limited to) logic and reasoning, abstract thinking, problem solving, planning, and carrying out and terminating goal-directed behavior" (p. 350).  The lack of specificity reflected in the language used in this definition is apparent.  Perhaps Jurado and Rosselli (2007) say it best when they state: "Despite the frequency with which it is mentioned in the neuropsychological literature, the concept of executive function is one that still awaits a formal definition" (p. 213).

Despite a lack of concrete agreement regarding one definition, similarities between many definitions of executive functioning are present.  Executive functions are often described as cognitive processes that are "supervisory…because they involve higher level organization and execution of complex thoughts and behavior" (Alvarez & Emory, 2006, p. 17).  Definitions frequently include that executive functions direct cognition and behavior.  McCloskey, Perkins, and Van Divner (2009) have defined executive functions as "a set of multiple cognitive capacities that act in a coordinated way. Executive functions are directive capacities that are responsible for a person's ability to engage in purposeful, organized, strategic, self-regulated, goal-directed processing of perceptions, emotions, thoughts, and actions" (p. 15). Gioia, Isquith, and Guy (2001) define executive function as "a collection of interrelated functions, or processes, which are responsible for goal-directed or future-oriented behavior" (Anderson, 2008, p. 4). They refer to executive function as a "conductor" which controls, organizes, and directs

cognitive activity, emotional responses and behavior" (Gioia, Isquith, & Guy, 2001 as cited in Anderson, 2008, p. 4).

Others have based their definitions on the specific abilities associated with executive functioning. Some common abilities associated with executive function include planning, working memory, inhibition, set shifting, and attention. For example, Denckla & Reiss (1997) define executive function as "a cognitive module consisting of effector output elements involving inhibition, working memory, and organizational strategies necessary to prepare a response" (p. 283). What is common across subtly different definitions of executive function is the consensus that executive functions are necessary for typical adaptive functioning. Specifically, intact executive functions allow the individual to adapt to their environment, to plan and execute plans to achieve successful task completion, to inhibit inappropriate behavior, and to maintain organization – abilities that are clearly necessary for independent functioning and success across multiple societal contexts (Jurado & Rosseli, 2007).

Some definitions and descriptions have centered on supposed neuroanatomical location. For example, executive functions have often been referred to as "frontal functions" due to the historical linkage of executive functions and the frontal lobe (Alvarez & Emory, 2006). Alvarez and Emory (2006) point out that this strong association has maintained the use of this term despite evidence that executive functions are not associated solely with the frontal lobe.

Difficulty in defining executive function stems in part from different theoretical conceptualizations of executive functioning. As McCloskey and colleagues (2009) describe, "no single reference work, to date, has attempted to synthesize the various writings on executive functions into a single overarching theory of executive control that can be used to guide clinical practice" (p. 17). One theory that explains executive functioning is Shimamura's (2000) dynamic

filtering theory.  Within this theory, "the prefrontal cortex monitors and controls information

processing by a filtering or gating mechanism. Four aspects of executive control can be

characterized in terms of dynamic filtering of information processing – selecting, maintaining,

updating, and rerouting.  Selecting refers to the ability to focus attention on perceptual features

or on activated memory representations.  Maintaining refers to the ability to keep active any

selected information…Updating refers to processes involved in modulating and rearranging

activity in working memory…[and] Rerouting refers to the ability to switch from one cognitive

process or response set to another" (Shimamura, 2000, p. 211).  Dynamic filtering theory is

closely tied to specific areas of the brain: "The dynamic filtering theory suggests that these four

aspects of executive control can be described in terms of the interplay between regions within the

prefrontal cortex and regions in the posterior cortex.  This dynamic interplay involves

feedforward and feedback activations between prefrontal and posterior activity and then control

these activations by recurrent circuits back to posterior regions.  These feedback circuits act to

select and maintain certain activations and filter (i.e., inhibit) others.  By this view, posterior

cortical activations at any given moment consist of a cacophony of neural signals in response to

sensory information and memory activations.  The prefrontal cortex orchestrates these signals by

maintaining certain activations and inhibiting others. As such, the prefrontal cortex refines

cortical activity by increasing signal-to-noise ratios" (p. 211).

Specific abilities are associated with executive functioning.  While there may not be total

agreement in the literature regarding the exact terms used to describe these abilities, much

consistency is present.  Some of these abilities include planning, cognitive flexibility, abstract

thinking, rule acquisition, initiation and inhibition, and attention.  Cognitive control is a term

used to describe some executive functions, or executive functions in general (Aron, 2007), and

may be defined as "controlling cognition in a manner that permits efficient processing of information" (Beer, Shimamura, & Knight, 2004, p. 1101), or as "mechanisms that permit an individual to access and work with internal representations in a goal-directed manner" (Wagner, Bunge, & Badre, 2004, p. 709).  Anderson (2008) asserts that "the key elements of executive function include (a) anticipation and deployment of attention; (b) impulse control and self-regulation; (c) initiation of activity; (d) working memory; (e) mental flexibility and utilization of feedback; (f) planning ability and organization; and (g) selection of efficient problem-solving strategies" (p.4). However, some argue that terms often used to describe specific executive function abilities lack construct validity (Rabbitt, 1997).  According to Rabbitt (1997), "it is clear that each of these hypothetical processes can be ostensively [sic] defined in terms of a *different set of exemplary situations or tasks*, but it is not at all clear that each of them involves quite *distinct functional processes*" (p. 8).

Some disagreement exists in the literature regarding whether executive function should be conceptualized as a unitary construct or as a non-unitary construct (Jurado & Rosselli, 2007). More recently, there has been movement away from considering executive function as a unitary construct, and a movement toward conceptualizing executive function as multiple separate components that interconnect (Anderson, 2008); this is supported by evidence such that individuals rarely present with global deficits in executive function (Bigler, 1988; Gratan & Eslinger, 1991; Pennington & Ozonoff, 1996, as cited in Anderson, 2008).  Those that argue that executive functions are non-unitary see executive functions as independent but coordinated (McCloskey et al., 2009).  At present, executive function is most usually described as a coordinated cognitive system that directs other cognitive processes.  Some investigations of executive functions have concluded that the various executive functions are separate but

correlated with one another (Unsworth et al., 2009).  Some propose categorization of executive

functions as "cool" or "hot", with "cool" executive functions "considered purely cognitive, and

tapped during abstract, decontexulized problems," and "hot" executive functions as "affective

aspects of executive functioning…required when a situation is meaningful and involves

regulation of affect and motivation" (Anderson, 2008, p. 4).

Locating the areas of the brain associated with executive functions is complicated by

differences in definition.  Moreover, it is not simple to localize executive functioning; although

specific areas of the brain appear most associated with certain executive function abilities, the

fact remains that complex interactions involving multiple brain systems are likely to influence

functioning.  While for some time executive functions were attributed to the frontal lobes alone

(Jurado & Rosselli, 2007), research suggests that associating executive functioning with only one

or a few areas of the brain is indeed too limited (Adcock, Constable, Gore, & Goldman-Rakic,

2000).  Still, there appears to be agreement in much of the literature that executive functions are

associated in great part with the frontal lobe regions of the cerebral cortex (McCloskey et al.,

2009).  It is important to note that while the frontal lobe is associated with executive functions,

evidence suggests that other specific areas are also implicated (Alvarez & Emory, 2006).  For

example, another area of the brain that has been specifically associated with executive

functioning is the cerebellum.

As with much of what is known regarding localization in general, most of what we know

about the localization of executive functions has been obtained through the study and

observation of individuals who have had lesions to different parts of the brain.  This is a practice

that has been present historically for some time.  One of the most famous and historical cases

now associated with executive function deficit is the case of Phineas Gage.  Phineas Gage was a

railroad construction foreman who was injured in an accident in which an iron rod was driven through his skull and brain during an explosion.  This accident allegedly destroyed a large portion of his left frontal lobe.  Due to subsequent drastic changes in his behavior and personality, the case of Phineas Gage has been cited to illustrate the effect that damage to specific areas of the brain can have regarding behavior, though it is important to note that little is definitively known about his injuries.  Following the accident and his recovery, Gage was described as follows:

> The equilibrium or balance, so to speak, between his intellectual faculties and animal propensities, seems to have been destroyed. He is fitful, irreverent, indulging at times in the grossest profanity (which was not previously his custom), manifesting but little deference for his fellows, impatient of restraint or advice when it conflicts with his desires, at times pertinaciously obstinate, yet capricious and vacillating, devising many plans of future operations, which are no sooner arranged than they are abandoned in turn for others appearing more feasible. A child in his intellectual capacity and manifestations, he has the animal passions of a strong man. Previous to his injury, although untrained in the schools, he possessed a well-balanced mind, and was looked upon by those who knew him as a shrewd, smart businessman, very energetic and persistent in executing all his plans of operation. In this regard his mind was radically changed, so decidedly that his friends and acquaintances said he was "no longer Gage." (Harlow, 1868 as cited in Gordy, 1898, p. 21).

In this description, it seems apparent that post-injury, Gage exhibited impairment in much of what is now associated with executive functions, including impaired inhibition, impaired planning and reasoning, and impaired persistence.

While the case of Phineas Gage is possibly the most famous, many other individuals have been studied post-injury and disease in order to gain a better understanding of the brain-behavior relationship with regard to executive functions. One population that has been especially important for this purpose is soldiers wounded in battle (Jurado & Rosselli, 2007). Individuals with lesions to the frontal lobe have been identified as having a collection of problems that came to be known as dysexecutive syndrome (Jurado & Rosselli, 2007). Dysexecutive syndrome has been described as being characterized by difficulties in planning, problem-solving, decision-making, and abstract reasoning (Jurado & Rosselli, 2007).

Humans are not the only subjects of study with regard to executive functions. Research with nonhuman primates has also aided in advancing our understanding of executive functions. For example, the Rhesus monkey (Macaca mulatta) has been studied using an adapted version of the Wisconsin Card Sorting Test (Moore, Schettler, Killiany, Rosene, & Moss, 2009). Moore and colleagues (2009) found that Rhesus monkeys with dorsolateral prefrontal cortex lesions evidenced impairment in "abstraction, establishing a response pattern to a specific category and maintain and shifting that response pattern" in a set-shifting task (p. 231). Studies such as this one serve to support similar studies of human subjects, and allow for more experimental methods, given the impossibility and unethical nature of causing intentional brain injury to humans.

In addition to the study of the behaviors of individuals and primates who have suffered injury or disease, advancements in neuroimaging have furthered our understanding of the areas of the brain involved in executive functions. Specific techniques that have been helpful in studying functionality include single-positron emission computed tomography, positron emission tomography, functional magnetic resonance imaging, and magnetoencephalography (Jurado &

Rosselli, 2007).  These imaging techniques have been utilized in tandem with tests of executive function, including tests of planning, cognitive flexibility, attentional control, and both verbal and nonverbal fluency (Jurado & Rosselli, 2007).  Investigation with neuroimaging has aided researchers in gaining a more complete understanding of the localization of executive functions and has not only implicated the frontal lobe.  While the prefrontal cortex of the frontal lobe is still the area of the brain most associated with executive functions, other cerebral and also subcortical areas have been identified as important (Jurado & Rosselli, 2007).   Additionally, within the prefrontal region, a more specific understanding of localization has been achieved. Importantly, due to the connections that the prefrontal cortex has with areas throughout the brain, optimal performance with regard to executive functions requires intact ability of the whole brain (Jurado & Rosselli, 2007).  This perspective is articulated by Juardo and Rosseli (2007) in their statement that "the pattern of connectivity of the frontal lobes suggests that, although the prefrontal regions might orchestrate behavior, they depend on other areas for input and efficient functioning relies on the quality of the information received form [sic] other parts of the brain" (p. 217).   The understanding that complex connections throughout the brain in all probability affect executive functions, illustrates the difficulty of precisely localizing executive functions.

Though executive functions cannot at this time be completely neatly and easily localized, the fact remains that the prefrontal cortex is the area of the brain most commonly and most strongly associated with executive functioning.  This part of the brain is most complex in primates (Miller, Freedman, & Wallis, 2003).  The prefrontal cortex is considered to be an essential element in the development of practical abilities such as behavioral self-regulation, morality, achievement, social understanding, and independence (Eslinger, Biddle, & Grattan, 1997).  The location of the prefrontal cortex and its connections to other areas of the brain are

significant.  As described by Eslinger and colleagues (1997), "the prefrontal cortex is in a unique position to monitor, integrate, and influence the neural activity of diverse cortical and subcortical regions through feedforward and feedback pathways devoted to body systems, perceptions of the environment, and access to stored knowledge as well as to the motor system for actions of initiation, inhibition, and modification of responding" (p. 295).

This area of the brain is particularly interesting because while in most areas of the brain, "regional specializations can be designated by single terms such as language, vision…no single term is yet available to encompass all the specializations attributed to prefrontal cortex" (Mesulam, 2002, p. 25).  The prefrontal cortex is indeed involved in a complex array of functions, such as those involved in attention, monitoring, working memory, and planning (Fuster, 2002).  The position of this area of the brain is an important consideration: "The prefrontal cortex is in a unique position to control both cognitive and social processes through its extensive reciprocal connections with cortical, limbic, and subcortical sites.  Evidence from neuropsychological, electrophysiological, and functional neuroimaging research suggests that lateral areas of the frontal lobes are involved in processes that permit the adaptive control of cognition, whereas orbitofrontal and medial prefrontal areas are involved in processes underlying the regulation of social behavior" (Beer, et al., 2004, p. 1091).  In addition to the prefrontal cortex regions being connected to one another, the prefrontal cortex is connected with and relies on subcortical structures of the brain including the brainstem, thalamus, basal ganglia, and the limbic system; these connections are reciprocal in nature (Fuster, 2001).  Different brain structures provide the prefrontal cortex with various kinds of information: the brainstem, diencephalon, and limbic system provide information regarding the internal state of the individual (e.g. motivation, drive, arousal); the amygdala and hypothalamus provide information

regarding internal state but also may inform the motivational significance of sensory stimuli (Fuster, 2001).

The prefrontal cortex is made up of three regions that many consider to be functionally divergent.  However, it is important to consider that although they may be functionally divergent, they are not isolated, and rely on their connections to multiple, complex cerebral configurations (Fuster, 2001).  These three regions are the orbitofrontal cortex, the lateral cortex, and the medial prefrontal cortex/anterior cingulate cortex (Fuster, 2001; Wahlstrom & Luciana, 2011).  Of particular interest with regard to executive functions are the lateral prefrontal cortex (Fuster, 2001) and the medial prefrontal cortex/cingulate cortex (Wahlstrom & Luciana, 2011).  The location of these the different areas of the cortex can be described using Brodmann's areas (BAs).

Brodmann's areas are based on Brodmann's map, which was developed by the anatomist Korbinain Brodmann and was originally published in 1909.  This map defines and numbers areas of the cortex.  It has been refined since original publication and is commonly used to identify areas of the cortex associated with various functions.  However, Brodmann's map is considered to be a general outline and does not necessarily represent the exact location of specific areas of functioning on an individual level.  According to Fuster (2001), the prefrontal cortex as a whole includes areas 8-13, 24, 32, 46, and 47 of Brodmann's map; however, slight differences in opinion of location can be seen throughout the literature regarding this topic, as may be seen below in the identification of the specific areas within the prefrontal cortex.

The lateral prefrontal cortex consists of BAs 9-12 and 45-47 (Wahlstrom & Luciana, 2011).  When damage occurs to the lateral prefrontal cortex, deficits in planning, initiating, and executing actions are typically present (Goldman-Rakic, 1987a; Fuster, 1989; Luria, 1966, as

cited in Wahlstrom & Luciana, 2011).  This is especially apparent regarding tasks that involve

novel information or materials, tasks that are complex, and tasks that require that they be

completed in specific order (Goldman-Rakic, 1987a; Fuster, 1989; Luria, 1966, as cited in

Wahlstrom & Luciana, 2011).  Specifically, individuals with lateral prefrontal lesions frequently

evidence difficulty in both formulating and carrying out activities that involve plans or require

the following of a sequence of actions (Fuster, 2001).  Planning deficits due to lateral prefrontal

cortex damage were recognized by Luria in 1966, and extends to behavior, speech, and reasoning

(Fuster, 2001).  It has been established that the prefrontal cortex is implicated on both the

"inhibitory and excitatory control of widespread neural systems" (Beer et al., 2004, p. 1091).

The prefrontal cortex has an established response bias toward novelty (Beer et al., 2004)

meaning that novel information is more likely to garner attention.  Beer and colleagues (2004)

assert that "the role of lateral prefrontal areas in controlling online cognition takes two specific

forms: the ability to filter out irrelevant information and the ability to orient to, sustain, and

manipulate relevant information in working memory.  The manipulation of relevant information

includes both expected and novel information" (Beer et al., 2004, p. 1091).

The prefrontal cortex is vital to working memory; specifically, to incorporating

information to carry out goal-directed activities (Wahlstrom & Luciana, 2011).  Behavioral

inhibition, which is "an umbrella term that refers to the ability to forgo immediate responding for

more adaptive behaviors," is also associated with the lateral prefrontal cortex, as are set-shifting

ability, verbal fluency, and planning abilities (Wahlstrom & Luciana, 2011, p.166).  Set-shifting,

also referred to as task switching, is critical for tasks that involve moving attention from one task

to another and concentrating on appropriate stimuli; this is highly associated with the

dorsolateral prefrontal cortex (Diamond, 2002).  This area of the brain allows for functions

critical to goal directed activity and heavily influences an individual's attentional abilities.

Specifically, in order to successfully focus attention, the individual must not only attend to

relevant information, but also filter out irrelevant information, all while assessing and monitoring

novel information for relevance (Beer et al., 2004).  When tasks are novel or complicated and

concentration is necessary, the dorsolateral prefrontal cortex is certainly required (Diamond,

2002). The lateral prefrontal cortex also relates to representations of plans of behavior and

language (Fuster, 2002).

There is some evidence to suggest that cognitive control, and the prefrontal cortex

specifically, are related to long-term memory (Wagner, Bunge, & Badre, 2004). Wagner and

colleagues argue that the interaction between memory and cognitive control is present in

retrieval of goal-relevant knowledge from semantic memory.  Memory is also related to

cognitive control with regard to priming; previous experience allows for reduced cognitive

demands and therefore reduces the cognitive control necessary in a given situation.

The medial prefrontal cortex and cingulate cortex include BAs 24, 25, 32, and 33

(Wahlstrom & Luciana, 2011).  Of specific interest to executive functioning are areas 24b-c and

32, which make up the dorsal region, and which are connected to the lateral prefrontal cortex

(Wahlstrom & Luciana, 2011).  Damage to this area of the brain is associated with impaired

attention, as well as difficulty with inhibition of response, such as required in the Stroop color-

word test (Wahlstrom & Luciana, 2011).  Furthermore, individuals with medial/cingulate lesions

have been noted to frequently be apathetic and disinterested in the environment, to have

difficulty concentrating and maintaining attention in both behavioral and cognitive tasks, and to

evidence problems in initiation or speech and movement (Fuster, 2001).

Not all agree that the prefrontal cortex is organized with such fixed functional specialization (Duncan & Miller, 2002).  Duncan and Miller (2002) suggest that the neural properties of areas of the prefrontal cortex are more flexible and "adapt their properties to code just that information of relevance to current behavior" (p. 278).

Many studies have examined the effects of damage to the frontal lobe in human patients. Such studies suggest that damage to this area of the brain is associated with impairment with regard to social behavior, self-regulation, planning, goal formation, flexibility, and inhibition (Eslinger et al., 1997).  Importantly, the resulting outcome following damage to the frontal lobe is affected by developmental age of the individual (Eslinger et al., 1997). In their review of the existing literature regarding childhood cerebral lesions, Eslinger and colleagues (1997) identified three distinctions that separate childhood lesion recovery from adult lesion recovery: "1) that childhood cerebral lesions cause less severe impairments immediately after the event, 2) that a greater recovery of function occurs after childhood cerebral lesions, and 3) that certain impairments after childhood cerebral lesions may not appear until later in development" (p. 296). However, it is important to note that the studies under their consideration were not specific to lesions of the prefrontal cortex.  There is a distinct lack of information on which to draw conclusions regarding the differences between damage sustained at various points in development, and more research is needed in this area.  Further research will be complicated by the low rate of damage isolated to the prefrontal cortex in subjects.  However, the limited number of studies that have been conducted with children support that following prefrontal cortex damage, social impairment commonly develops (Eslinger, et al., 1997).  Additionally, what is clear is that damage to the prefrontal cortex in adults is very different from prefrontal cortex damage in children, in that in adults damage results in the loss or impairment of previously

acquired abilities, in children damage results in a disruption of the development of these abilities (Eslinger et al., 1997).  For this reason, some argue that in children, damage to the prefrontal cortex may disrupt normal development to not only this area of the brain, but also to areas of the brain to which it is connected (Eslinger et al., 1997).  Depending on specific stage of development, as well as site and severity of the lesion, functional outcome is likely to vary greatly.

Some theories of executive function, such as Shimamura's (2000) theory of dynamic filtering, specifically address the role of the prefrontal cortex in executive functioning. The prefrontal cortex "regulates the selection, timing, monitoring, and interception of behavior" and "is consequently said to provide the critical substrate for executive functions through the top-down modulation of other neural systems in the brain.  This top-down modulation is exerted through widespread prefrontal connections that are in a position to activate a given network, inhibit another, influence network combinations, and perhaps even allow anticipatory readouts of contemplated actions" (Mesulam, 2002, p. 25).

Miller and Cohen (2001) have put forth an integrative theory of prefrontal cortex function that addresses the neural basis of the prefrontal cortex's role in cognitive control.  They propose that the prefrontal cortex allows for cognitive control due to the following features: "the ability of experience to modify its distinctive anatomy; its wide-ranging inputs and intrinsic connections that provide a substrate suitable for synthesizing and representing diverse forms of information needed to guide performance in complex tasks; its capacity for actively maintaining such representations; and its regulation by brainstem neuromodulatory systems that provide a means for appropriately updating these representations and learning when to do so" (p. 193).  There remains much that is unknown regarding the function of the prefrontal cortex (Miller & Cohen,

2001).

Though most often associated with motor control, the cerebellum has been implicated in the area of executive functioning.  Research has established that the cerebellar output projects to the cerebral cortex, and influences nonmotor areas of the cerebral cortex (Schweizer, Alexander, Cusimano, & Stuss, 2007), and as such, damage to the cerebellum may present as having cognitive, affective, and attention deficits (Strick, Dum, & Fiez, 2009).  Individuals with acquired cerebellar lesions have been found to be impaired in a task that required shifting attention rapidly between visual and auditory stimuli; motor dysfunction was ruled out as the cause of this impairment (Courchesne et al., 1994).   This study suggests that the cerebellum is implicated in rapid shifts of attention (Courchesne et al., 1994).  Additional research suggests that the neocerebellum is involved in the rapid and accurate shift of selective attention between sensory modalities; specifically, visual and auditory (Akshoomoff & Courchesne, 1992).  This has been attributed to the fact that the neocerebellum is connected to various areas of the brain that control and effect attention, including the dorsolateral prefrontal cortex (Akshoomoff & Courchesne, 1992).  Functional neuroimaging additionally supports that the cerebellum is involved in attention (Allen et al., 2011), including shifting of attention (Salmi, Rinne, Koistinen, Salonen, & Alho, 2009, as cited in Allen et al., 2011).   Impaired executive functioning, including planning, set shifting, reasoning, working memory, and verbal fluency, have been associated with diseases of the cerebellum (Schumahmann & Sherman, 1998).  Specifically, Schumahmann and Sherman (1998) found that individuals with lesions of the posterior lobe and the vermis presented with impaired executive functioning including planning, set shifting, verbal fluency, abstract reasoning, and working memory.  Individuals with lesions to the anterior lobe of the cerebellum evidenced only minor impairment in executive functioning (Shumahmann &

Sherman, 1998).  Other aspects of executive functioning that have been associated with the

cerebellum include reasoning and problem solving.  For example, the cerebellum, in addition to

the frontal lobe, is active during performance on the Wisconsin Card Sorting Task (Berman et

al., 1995; Lie, Specht, Marshall, & Fink, 2006; Nagahama et al., 1997; Riehemann et al., 2001 as

cited in Allen et al., 2011).

While executive functions can be associated with different areas of the brain, it is

important to not over generalize the connection between location and function.  Some behaviors

associated with executive functions can be impaired due to damage to areas of the brain not

discussed above.  For example, the basal ganglia have been associated with attention and

inhibition (Graybeil & Saka, 2004).  This is perhaps not surprising given that the basal ganglia

directs towards the frontal cortex by way of the thalamus.  The basal ganglia illustrates how the

functioning of the frontal cortex may be influenced by areas of the brain that are not the first to

come to mind with regard to executive functions. As another example of how damage to areas of

the brain other than the prefrontal cortex and cerebellum, we may consider that impaired

attention is the top neurological soft sign of brain damage and may be the result of damage to

many different locations.  It is critical to recognize that the location of all aspects of all abilities

associated with executive functions is complicated by the interconnectedness of multiple neural

systems.  Moreover, impaired functioning in many areas of the brain has the potential to

complicate assessment of executive functions.  For example, an individual who has impaired

vision due to damage to the occipital lobe, or an individual with language comprehension

difficulties, would be difficult to assess using typical tests of executive function.

Age must be considered with regard to executive functioning, as the functions develop

over time.  Executive functions begin to develop in infancy and continue to develop in

subsequent years, with notable gains made in adolescence (McCloskey et al., 2009), and continued development in early adulthood (Davis et al., 2011), though it is important to note that development is different from individual to individual (McCloskey et al., 2009).  The prefrontal cortex specifically "undergoes one of the longest periods of development of any brain region, taking over two decades to reach full maturity in humans" (Diamond, 2002, p. 466).  The prefrontal cortex is one of the last areas of the brain to develop, not only at the individual developmental level, but also when considered from an evolutionary perspective (Fuster, 2001).

Different executive functions develop at different rates and times (Jurado & Rosselli, 2007).  Attentional control (including selective attention, sustained attention, and response inhibition), set-shifting, planning, and verbal fluency continue to develop into adolescence, but have periods of greatest advancement at different times (Jurado & Rosselli, 2007).

Developmental stage must be taken into account with regard to the assessment of executive functions.  The reason for this is that the assessment of children, especially young children, can be complicated by factors such as language ability.  When such tests are utilized with children, they may unintentionally tap into non-executive function abilities (Jurado & Rosselli, 2007).  Tests specifically designed for children are important for this reason.

Changes in executive functions are not limited to childhood and early adult development. Decline in executive functions has also been documented in late adulthood and has been attributed by some investigators to age-related decline.  Furthermore, there is some evidence to suggest that decline is not uniform across executive functions and may be context dependent (Jurado & Rosselli, 2007).  However, literature supporting this claim is currently lacking and additional investigation regarding aging and executive functions is needed (Jurado & Rosselli, 2007).

There is some debate regarding how executive functions should be measured (Alvarez & Emory, 2006).  There are numerous tests that are supposed to measure executive functions in humans.  When describing what aspects of executive function are measured by specific tests, it is important to consider that these tests likely measure multiple abilities (Rabbitt, 1997).  According to McCloskey and colleagues (2009), all executive functioning tasks "are measures of multiple executive functions; no measure assesses the use of only one self-regulation executive function capacity" (p. 114).  This difficulty has also been termed "task purity" (Rabbitt, 1997, p. 13).  As executive functioning is generally considered to be comprised of a number of interrelated functions, it follows that isolating these functions would be difficult and may potentially lack validity.

The measurement of executive functions is additionally complicated by the lack of agreement within the field of psychology with regard to what counts as executive functions.  Here again, we see that the lack of consensus regarding definition is potentially problematic.  Construct validity is clearly difficult to establish in a test of executive functions when the construct itself is not well defined (Jurado & Rosselli, 2007).  Until we achieve or develop a more complete understanding of executive functions and develop new tests, we are likely to rely on measures that have been previously linked to executive function.  Jurado and Rosselli (2007) argue that "until new methods are developed…the study of executive functions must rely on tests that have been historically purported as measuring the functions of the frontal lobe" (p. 218).  Two tests that contend to measure executive functions include variations of the tower test and the Stroop color word test, which have been longstanding and accepted measures of planning and inhibition, and inhibition, respectively (Jurado & Rosselli, 2007).  Variations of these tests have been designed to assess these executive functions and more.  Not surprisingly given their

common foci, there is some evidence that the Tower Test and Stoop task are related (Koppenol-Gonzalez, Bouwmeester, & Boonstra, 2010).  Some research suggests that performance on the Stroop task is predicative of performance on the Tower task; this has been attributed to their common inhibition demands.

Though tests such as tower test and Stroop test are well established and accepted, they have been criticized for not being precise measures of specific function (Jurado & Rosselli, 2007).  It has been argued that many tests of executive functions measure more than one function (Jurado & Rosselli, 2007).  Additional criticism has centered on the fact that such tests assume novelty, which is lost after the first administration (Jurado & Rosselli, 2007).  Lastly, tests of executive functions have been criticized for having poor ecological validity (Jurado & Rosselli, 2007).  Despite these criticisms, both the tower and Stroop tests overall are well respected measures of executive functions.  Specifically, tower tests have been considered primarily tests of planning ability, while Stroop tests have been considered tests of inhibition and, in some versions, of set-shifting.

### The Relationship between Intelligence and Executive Functions

Research suggests a relationship between executive functions and intelligence (Ardila et al., 1999; Davis et al., 2011; de Frais et al., 2006; Floyd, Bergeron, Hamilton, & Parra, 2010; Floyd et al., 2006; Friedman et al., 2006; Fuchs & Day, 2010; Unsworth et al., 2009; Zook et al., 2004; Zook et al., 2006).  Associations have been identified between executive functions and fluid intelligence (Davis et al., 2011; de Frais et al., 2006; Unsworth et al., 2009; Zook et al., 2004; Zook et al., 2006). There is also some evidence of a possible relationship between crystallized intelligence and executive functions (Davis et al., 2011; Friedman et al., 2006; Fuchs & Day, 2010).  However, there is a lack of agreement in the literature concerning whether or not

tests of executive function additionally measure that which is independent of intelligence tests. Importantly, differing conceptualizations of executive functions, as well as different assessments of both executive functions and intelligence, have complicated comparison of past research.

Preliminary research investigating the relationship between specific CHC factors and executive functions with a child and adolescent population suggests that tests of the *Delis-Kaplan Executive Function System* (D-KEFS) measures five broad cognitive factors, as well as a general ability construct (Floyd et al., 2010).  However, such investigation has focused on children.  Of particular interest to the current study is the D-KEFS Color-Word Interference Test Condition 3 (Inhibition) score appeared to load to a Processing Speed (*Gs*) factor (Floyd et al., 2010); importantly, this investigation did not include the Tower Test from the D-KEFS.  In their investigation, Floyd and colleagues (2010) conclude that "every DKEFS test or condition measures the general factor as well as broad ability factors outlined in CHC theory" (p. 734). They assert that this implies that "if there are measures of abilities associated with executive functions, they are contaminated by the general factor and more specific ability factors, so that there is probably little unique about them" (p. 734).  An investigation of the performance of adults on a seemingly similar measure of executive functioning, the Tower of London Revised, indicated that Fluid Intelligence (*Gf*) was predicative of performance on the Tower task (Zook et al., 2006). However, extrapolation from the Tower of London test to the D-KEFS Tower Test must be done with caution, as although individuals tend to perform similarly on the two tests, the tests may share little variance; this suggests they may primarily address two different constructs (Larochette, Benn, & Harrison, 2009).  It is important to note that Floyd and colleagues specify that "the conclusions drawn about the other DKEFS based on this research do not necessarily

apply to the Tower Test or other laboratory- or computer based measures of executive functions"
(p. 736).

Though some investigators, such as Floyd and colleagues (2010) have concluded that
measures of executive functions such as the D-KEFS do not measure that which is unique from
intelligence, other research has come to a different conclusion.  Davis and colleagues (2011),
who examined the relationship between intelligence and executive functioning in an adult
college population, concluded that while there is substantial shared variability between the
*Wechsler Adult Intelligence Scale, Third Edition* (WAIS-III) and the D-KEFS, the D-KEFS
retains distinctive variance that is not accounted for by the WAIS-III.  As such, some constructs
measured by the D-KEFS did not appear to be measured by the WAIS-III.  Of the D-KEFS
subtests, Word Context Test, which "taps the examinee's abilities to use deductive reasoning,
hypothesis testing, and mental flexibility to determine the meaning of nonsense words", and
Sorting Test, which requires abstract problem solving, were most associated with the WAIS-III.
Interestingly, some D-KEFS subtests including the Tower Test and Color-Word Interference
Test, did not make large contributions to the canonical correlation, and are likely not accounted
for by the WAIS-III.  Analysis revealed that Vocabulary, Comprehension, and Matrix Reasoning
had the strongest relationships with the D-KEFS subtest scores, suggesting that fluid and
crystallized abilities are be strongly associated with executive functioning.

Investigation using other measures of executive functioning has also been conducted.
Ardila and colleagues (1999) investigated the relationship between intelligence test scores from
the *Wechsler Intelligence Scale for Children, Revised* (WISC-R) Spanish version and three
measures of executive functions: the *Wisconsin Card Sorting Test* (WCST), Verbal Fluency, and
Trail Making Test (TMT), Form A and Form B, which is a test of set-shifting ability, in a

population of adolescents.  Though most verbal subtests of the WISC-R as well as the Verbal

and Full Scale IQs were positively correlated with Verbal Fluency, correlation was weak to

moderate.  With regard to the WCST, the Preservative errors score was weakly to moderately

negatively correlated with Verbal IQ and Full Scale IQ, Information, Similarities, Arithmetic,

and Block Design.  With regard to the TMT, TMT form B errors negatively and moderately

correlated with the WISC-R Vocabulary subtest and TMT form A time negatively correlated

with Performance IQ.  Due to the lack of abundant, strong relationships between variables, the

researchers conclude from their analysis that "these results support the assumption that

traditional intelligence tests do not appropriately evaluate executive functions" (Ardila et al.,

1999, p. 35).  While the analyses used in this study are appropriate for a preliminary

investigation into the relationships among these variables, some concerns exist regarding the

methodology of this study, including possible language issues given that the WISC-R Spanish

version that was utilized as a measure of intelligence was normed in Spain, but the participants

of this study were from Colombia.  Similar concern exists regarding the executive function

measures utilized.  While the WCST was reported to have been normed with Spanish-speaking

children, the basis of these norms is not specified. The generalizability of these findings to an

English speaking population using English language tests is unclear without additional

investigation.  However, this study supports the assertion that executive function abilities cannot

entirely be extrapolated from intelligence.

Age has been found to potentially play a role in the relationship between executive

functions and intelligence.  de Frais and colleagues (2006) investigated four tests of executive

functioning, and explored the relationship between age and intelligence and executive

functioning in a population of older adults.  Measures included the Hayling Sentence Completion

Test, which was purported to be a test of inhibition, the Brixton Spatial Anticipation Test, which was purported to be a test of set-shifting based on the WCST, a Stroop Test, and the Color Trails Test (CTT), which was similar to the Trail Making Test (TMT).  A letter series task in which participants had to identify a pattern in a series of letters was used as a measure of fluid intelligence, and a multiple choice vocabulary test was used as a measure of crystallized intelligence.  The researchers concluded that poorer executive functioning performance is related to older age and lower fluid intelligence; crystallized intelligence was not significantly related to executive functioning.  However, this study was limited by the measures used to assess fluid and crystallized intelligence, which are not well established and may not appropriately represent the constructs they were meant to represent.

## Conclusion

Despite great interest in the field of psychology in both intelligence and executive functions, the relationship between the two remains unclear.  Intelligence is a difficult term to define and has been conceptualized in a variety of ways throughout the history of the field. Although some debate is still present regarding what constitutes intelligence and if and how it can be measured, there is majority agreement regarding a general intelligence factor or *g*. Similar to intelligence, the term "executive functions", despite being quite popular and of great interest, is one that does not have a clear and universally accepted definition in the field of psychology.  This complicates localization of functions, as there is some debate regarding what functions count as executive functions.  Lack of a clear and agreed upon definition also complicates assessment.  Despite all of this, it is important to recognize that the terms "intelligence" and "executive functions" are both helpful and meaningful, as they capture

important behaviors for typical human functioning.  In the future, with continued research, these terms are likely to be debated and refined, and more specific understanding is likely to emerge.

The relationship between intelligence and executive functioning remains unclear.  While a positive relationship has been found between intelligence and executive function, there is some debate regarding whether tests of executive functions measure constructs beyond that which is captured by tests of intelligence.  Answering this question has important practical application for clinicians with regard to test selection and administration.  Past research has been complicated by differences in definition of both constructs, as well as by the use of varying measures of both intelligence and executive functioning.  Further research that conceptualizes intelligence using established theoretical constructs and utilizes respected and established measures of executive functions is needed in order to further illuminate the relationship between intelligence and executive functions.  This study investigated the relationship between intelligence, as conceptualized using CHC theory, and a subset of executive functions, using well-established measures of both intelligence and executive functions.  The following chapter provides a description of the methodology used in this study.

**CHAPTER III**

**METHODOLOGY**

This chapter is organized into four sections: (1) Participants; (2) Procedures; (3) Instrumentation; and (4) Statistical Procedures and Data Analysis.  The purpose of this chapter is to describe the recruitment and selection of participants, procedures involved in data collection, and the instruments utilized.  This study utilized data collected from a larger study investigating the relationship between Quantitative Electroencephalography (QEEG) and neuropsychological variables.

**Participants**

The participants were 64 undergraduate students enrolled in psychology courses at a Midwestern university. All of the participants were recruited through a university research pool. In accord with university departmental procedures, participants were granted three credit hours of research participation towards academic requirements.  The university Internal Review Board granted permission to conduct this study.

An adult college population differs greatly with regard to executive functioning ability as compared to an adolescent or child or older adult population. Given their age, these participants were most likely at a point where their frontal lobes and executive functioning abilities were still developing; their particular stage of development makes them a population unique from children and adolescents.  A college population is a good fit for this study because they are likely to represent the general population better than a clinical population. College students have a wide range of abilities, though they are often slightly above average (Davis, Pierson, & Finch, 2011).

**Procedures**

Permission to recruit undergraduate students in psychology classes was obtained through the university's Institutional Review Board and the university department. Students learned of the study through an online sign up system to which they had access through course enrollment. Graduate students from the department of educational psychology who had completed extensive training in the administration of standardized measures conducted all data collection. Data were collected by these individuals and organized by this writer, as well as overseen by the study's primary investigator. Upon arrival to their scheduled appointment, participants read and signed an informed consent document that had been approved by the university Institutional Review Board. Participants involved in this study participated in multiple assessments in a process that took approximately three hours. Each participant was assessed during one meeting. Examiners involved in this study were advanced graduate students who had considerable training in psychological and neuropsychological assessment; specifically in the administration and scoring of the assessments utilized. Data were collected over the course of multiple semesters in 2009 and 2010. Participants were administered the *Woodcock-Johnson III Tests of Cognitive Abilities* (WJ-III-Cog; Woodcock, McGrew, & Mather, 2001) and the *Delis-Kaplan Executive Function System* (D-KEFS; Delis, Kaplan, & Kramer, 2001) according to procedure specified in the test manuals. The order of test administration was held constant for all participants: WJ-III-Cog Verbal Comprehension, Visual-Auditory Learning, Spatial Relations, Sound Blending, Concept Formation, Visual Matching, and Numbers Reversed; D-KEFS Color-Word Interference Test; and D-KEFS Tower Test.

**Instrumentation**

**Woodcock-Johnson Test of Cognitive Abilities.**

*Description*. The WJ-III-Cog was administered to measure individual broad CHC factors. The third iteration of the WJ-III-Cog is a popular, individually administered assessment of intelligence that assesses an overall intellectual ability, as well as both fluid and crystallized intelligence and cognitive efficiency. Specific subtests purport to measure broad CHC factors. The WJ-III-Cog consists of a standard battery of 10 subtests, seven of which are necessary for the calculation of general intellectual ability.  Each participant was individually administered seven subtests from this measure, including Verbal Comprehension, Visual-Auditory Learning, Spatial Relations, Sound Blending, Concept Formation, Visual Matching, and Numbers Reversed, which assess the CHC factor of Comprehension-Knowledge (*Gc*), Long-Term Retrieval (*Glr*), Visual-Spatial Thinking (*Gv*), Auditory Processing (*Ga*), Fluid Reasoning (*Gf*), Processing Speed (*Gs*), and Short-Term Memory (*Gsm*), respectively. Standard scores were calculated for each of the seven subtests.  A standard score has a mean of 100 and a standard deviation of 15.  General Intellectual Ability (GIA) was also calculated for each participant, also represented by a standard score.

*Validity and reliability*. The WJ-III-Cog is a valid and reliable individually administered measure of cognitive ability categorized by seven broad CHC factors (McGrew & Woodcock, 2001). The theoretical foundation of the WJ-III-Cog is derived from the CHC theory of cognitive abilities (McGrew & Woodcock, 2001) and guided test content, which supports content validity. Internal structural validity is supported for the WJ-III-Cog. Confirmatory factor analysis was utilized during test development to assess which tests loaded onto the CHC factors; tests that were deemed inadequate were not included in the final version of this measure. Final

confirmatory analyses suggested that a seven-factor CHC model is appropriate.  Low correlation

between clusters suggests that they measure abilities that are dissimilar; however, most tests

from the WJ-III-Cog load onto a general ability factor.  Studies suggest that WJ-III-Cog general

ability correlates in the .70s with general ability scores from other tests of intelligence, including

the *Wechsler Preschool and Primary Scales of Intelligence, Revised* (WPPSI-R; Wechsler,

1989), the *Wechsler Intelligence Scale for Children, Third Edition* (WISC-III; Wechsler, 1991);

the *Differential Ability Scales* (DAS; Elliot, 1990), the *Kaufman Adolescent and Adult*

*Intelligence Test* (KAIT; Kaufman & Kaufman, 1993), and the *Stanford-Binet Intelligence Scale,*

*Fourth Edition* (SB-IV; Thorndike, Hagen, & Sattler, 1986).

The WJ-III-Cog was normed using a nationally representative sample of 8,818 subjects

from over 100 communities across the United States, selected to be representative of individuals

in the United States ages 24 months to 90 years and older (McGrew & Woodcock, 2001). The

normative sample was randomly selected within stratified sampling that controlled for a number

of variables including census region, community size, sex, race, Hispanic/non-Hispanic, type of

school/college, education of adults, occupational status of adults, and occupation of adults in the

labor force (McGrew & Woodcock, 2001).

The subtest-level reliability coefficients for ages 18, 19, and 20-29 range as follows: .93-

.93 (Vocabulary), .85-.91 (Visual-Auditory Learning), .80-.81 (Spatial Relations), .88-.91

(Sound Blending, .94 (Concept Formation), .88-.91 (Visual Matching), and .86-.87 (Numbers

Reversed) (McGrew & Woodcock, 2001). The cluster intelligence reliability coefficients for

ages 18, 19, and 20-29 are generally higher than the individual subtest reliability coefficients: .97

(General Intellectual Ability), .92-.93 (Verbal Ability), .95-.96 (Thinking Ability), and .91-.92

(Cognitive Efficiency) (McGrew & Woodcock, 2001). Test-retest reliability data indicate that

scores on the WJ-III-Cog are adequately stable across time for children and adults (McGrew & Woodcock, 2001).  Studies have addressed interrater reliability for subtests on the WJ-III-Cog that require subjective evaluation of examinee response; however, none of these subtests were included in the current study.

**Delis-Kaplan Executive Function System.**

*Description*. Tests from the D-KEFS were utilized as measures of skills associated with executive functioning.  The D-KEFS consists of nine stand-alone tests: Trail-Making Test, Word Context Test, Sorting Test, Twenty Questions Test, Tower Test, Color-Word Interference Test, Verbal Fluency Test, Design Fluency Test, and Proverbs Test.  Tests on the D-KEFS measure interdependent neurocognitive processes including processing speed and cognitive efficiency, memory and learning, visual-spatial processing, sensory-motor functioning, and language functioning (Miller, 2007).  In the larger study investigating the relationship between EEG and neuropsychological variables, participants were administered two tests from the D-KEFS: Color-Word Interference Test and Tower Test and these tests were used in the current study. Each participant was individually administered both of these subtests. For the Tower Test, scaled scores were calculated, representing total achievement for this task (Tower Test Total Achievement), as well as for the average time the examinee takes to make their moves (Time-Per-Move Ratio).  For the Color-Word Interference Test, scaled scores were calculated and recorded for inhibition ability (Inhibition), as well as inhibition-switching (Inhibition/Switching). A scaled score has a mean of 10 and a standard deviation of 3.

The D-KEFS includes tests common to many practitioners. Color-Word Interference Test is a variant of the Stroop task (Stroop, 1935), and the Tower Test is similar to Tower of Hanoi and Tower of London tests (Remine, Care, & Brown, 2008).  Importantly, the D-KEFS has the

added advantage of standardized procedure and a normative sample, which was not present in

most previous versions of tower tests (Miller, 2007; Remine et al., 2008).

*Reliability and validity*. The D-KEFS is a measure of executive functioning for ages 8

years through 89 years.  Examination of the reliability estimates provided in the D-KEFS

technical manual indicate that most are below a value of .80 (Schmidt, 2003).  With regard to the

Tower Test and Color-Word Interference Test, historical acceptance and widespread use of such

measures in neuropsychological assessment prior to inclusion in the D-KEFS is cited as evidence

of validity (Shunk, Davis, & Dean, 2006).  Convergent and discriminant validity are supported

by evidence in the D-KEFS manual, including correlation between D-KEFS tests, correlations of

D-KEFS tests to other tests of executive function, and evidence from studies of clinical

populations.

**D-KEFS Color-Word Interference Test**

*History*. The Color-Word Interference Test on the D-KEFS originates from the Stroop

test (Stroop, 1935).  Historically, the Stroop test is one of the most commonly used tests of

executive functions (Alvarez & Emory, 2006).  While different versions of the Stroop test have

been developed (e.g. *The Stroop Color and Word Test*; Golden, 1978), within the traditional

version of the test, the individual taking the test must first read a page of color words (names of

colors) that are printed in black ink.  Next, the individual is asked to name the ink color of Xs

printed on a page.  Last, the individual is asked to name the ink color in which color words are

printed, and not read the word itself (Jurado & Rosselli, 2007).  As described by Humphreys and

Samson (2004), "the Stroop task requires that attention be applied to the dimension of the

stimulus deemed relevant by the task instructions (the hue rather than the name of the word),

even though this may not be the most salient aspect of the stimulus; thus it requires endogenous

[originating from within] control" (p. 610).  However, some versions of the test additionally

include a set-shifting dimension, such as the Color-Word Interference Test on the D-KEFS.  The

Stroop test is associated with frontal lobe functioning, specifically with inhibition (Wahlstrom &

Luciana, 2011) and response monitoring; damage to both the right and left frontal lobes has been

associated with impaired performance on this test (Humphreys & Samson, 2004).

It is generally accepted that the Stroop test is a test of inhibitory control (De Luca &

Leventer, 2008).  While the Stroop test has been touted by some as extremely sensitive to deficits

in inhibition (Knight & Stuss, 2002), some argue that it is a poor measure of inhibition (Heflin et

al., 2011).  The Stroop test in general requires inhibition of automatic response; the additional

task switching involved in the Color-Word Interference Test requires the involvement of both

working memory and inhibition (Diamond, 2002).  Within the Stroop color-word task,

individuals must block the information of the written text and they must inhibit their automatic

response to read the word that is printed before them.

*Description*.  The Color-Word Interference Test on the D-KEFS includes the initial

reading of color words printed in black ink, but does not include a trial of naming colors printed

as Xs.  Instead, prior to the initial word reading, the individual is required to name the color of

blocks printed on a page.  Following the reading of color words printed in black ink, the

individual is required in the next task to name the color in which color words are printed, and not

read the word itself.  This is a task of inhibition, as the individual must inhibit the

automatic/over-learned response to read the word itself.  In the next and final task, which sets

this particular version apart from traditional Stroop measures, the individual is required to

engage in a combination inhibition and set-shifting task.  Specifically, the individual is presented

with a page of color words printed in different colored ink, with some of these words being

inside the confines of a printed box.  When the individual encounters a word outside of a box,

they are required to name the ink color in which the word is printed; however, if the color word

is inside a box, they must instead read the word.  When this additional set-shifting dimension is

added to the test, cognitive demands are increased because the individual must inhibit an over-

learned response (Wahlstrom & Luciana, 2011).  This difference can be described in the

following way: "While it is difficult to resist a natural inclination or inhibit a dominant response,

after awhile such inhibition no longer requires DL-PFC [dorsolateral prefrontal cortex] action so

long as you consistently do that without interruption.  For example, on the classic Stroop task…it

is difficult to report the color of the ink, ignoring the words, but it is far easier to do that over

many trials than to switch back and forth between reporting the ink color and reporting the word,

even though many trials in the latter condition are purportedly easy because the correct response

on those trials is to make the prepotent response (that is, read the word)" (Diamond, 2002, p.

466).

*Reliability and validity*. The D-KEFS Color-Word Interference Test was utilized in this

study to assess the executive functions of inhibition and set-shifting.  A large, nationally

representative sample of individuals aged 8-89 years was utilized to estimate reliability and

validity information for the D-KEFS Color-Word Interference Test.  Internal consistency for the

combined Color Naming and Word Reading composite score were .72 for the 16-19 year old age

group, and .82 for the 20-29 age group (Delis, Kaplan, & Kramer, 2001).  Test-retest reliability

was moderate to high across conditions, with improved scores noted during second testing

(Delis, Kaplan, & Kramer, 2001).  Moderate positive correlations between the conditions have

been identified; high correlations are present between the Color Naming and Word Reading

conditions, as well as between the Inhibition and Inhibition/Switching conditions (Delis, Kaplan, & Kramer, 2001).

**D-KEFS Tower Test**

*History*. As a measure, the tower test has a long history.  The test was originally developed in 1883 by Edouard Lucas, a French mathematician, and was called the Tower of Hanoi (Koppenol-Gonzalez et al., 2010).  The Tower of London test was developed in 1982 with the intention of measuring executive planning ability (Koppenol-Gonzalez et al., 2010).  As is evident by history, there are multiple versions of the tower test, the most well known and researched of which include the Tower of London Test, the Tower of Hanoi Test, and the Tower Test from the D-KEFS.  While there are differences between these various versions of the test, and while some caution should be made with regard to extrapolating from one to another, their common attributes allow for a general consideration.  The Tower Test is assumed to measure planning, inhibition, and working memory (Koppenol-Gonzalez et al., 2010). According to McCloskey (2009), the D-KEFS Tower Test involves the following information processing demands: attention processing, visual motor processing, sequencing, visuospatial ability, reasoning ability, as well as creating and accessing strategies.  In the context of neuropsychological testing, the total move score on the Tower Test is considered the primary score. A low total move score is reflective of good planning ability (Koppenol-Gonzalez et al., 2010).  Also considered in many cases is the total number of problems solved correctly, as well as time.

As stated previously, the Tower Test is purported to measure planning ability (Wahlstrom & Luciana, 2011).  Planning ability appears to be related to the prefrontal cortex.  Studies of individuals with prefrontal damage suggest that compared to controls, impaired individuals

perform poorly with regard to planning ability as measured by the Tower Test. While they did not differ on first move time, their overall execution time was significantly longer, and they were less likely to use an effective problem-solving strategy (Owen, Downes, Sahakian, Polkey, & Robbins, 1990 as cited in Koppenol-Gonzalez et al., 2010). In addition to planning, working memory and inhibition are components of executive functions that contribute to performance on the Tower of London and the Tower of Hanoi (Goel & Grafman, 1995; Huizinga, Dolan, & van der Molen, 2006; Miyake et al., 2000 as cited in Koppenol-Gonzalez et al., 2010).

*Description*. The Tower Test on the D-KEFS involves the use of a wooden board with three vertical pegs and five wooden disks that vary in size from small to large. The examinee is required to move the discs from a predetermined starting point so as to match a pictorial representation that is presented to the examinee by the examiner. The predetermined starting point of the discs on the pegs is arranged by the examiner prior to the start of each item administration. The examinee is instructed to move the discs from this starting point to the end point in the fewest number of moves possible. Additionally, the examinee is presented with rules that must be followed including that only one disc may be moved at a time, using only one hand, and that a larger disc may not be placed on top of a smaller disc. Items on the Tower Test differ in difficulty. The minimum number of moves possible increases with item difficulty. The examiner assesses number of moves, but additionally records first-move completion time, item completion time, final achievement (indicating if the final tower is correct or incorrect), and the number of move violations made by the examinee. The D-KEFS Tower Test is designed to measure a number of executive functions including "spatial planning, rule learning, inhibition of impulsive responding, inhibition of perseverative responding, and establishing and maintaining the instructional set" (Delis et al., 2001).

*Reliability and validity*. The D-KEFS Tower Test was utilized in this study to assess planning. A large, nationally representative sample of individuals aged 8-89 years was utilized to estimate reliability and validity information for the D-KEFS Tower Test. Internal consistency for the Total Achievement score was .60 for the 16-19 year old age group, and .62 for the 20-29 age group. Test-retest reliability was in the moderate range, with improved scores noted during second testing (Delis et al., 2001).

## Statistical Procedures

Analysis using canonical correlation was implemented so as to assess the strength and nature of the relationship between broad intelligence and executive functions. Specifically, canonical correlation was utilized to assess the relationship between the seven broad CHC factors and four scores from the D-KEFS. The four scores on the D-KEFS include Tower Test Total Achievement Score, Tower Test Time-Per-Move-Ratio, Color-Word Interference Test Condition 3 (Inhibition), and Color-Word Interference Test Condition 4 (Inhibition/Switching), all of which are scaled scores. Canonical correlation is an analysis that assesses the relationship between variables (Thompson, 1984). Specifically, canonical correlation analysis allows for the identification of common dimensions across two sets of variables, and estimates correlation coefficients between sets of variables (Thompson, 1984). It is utilized as an analysis when there are two sets of variables, and the variables within each set are correlated with one another. Canonical correlation functions by identifying linear combinations within the sets of variables that maximizes the correlation found amongst the sets of variables. Importantly, canonical correlation allows not only for the correlation between variable sets, but also identifies which individual variables contribute the most to the identified linear combinations (Davis et al., 2011). With regard to this study, canonical correlation allowed for evaluation of the null hypothesis that

the two variable sets are independent of one another (Johnson & Wichern, 2002). Analysis with canonical correlation specifically addressed the question of whether the two sets of variables are related.

Canonical correlation is an infrequently employed technique of multivariate analysis. However, in specific circumstances, it is the most suitable analysis (Thompson, 1984).  While ideally a sample size larger than that of this study would be employed for canonical correlation (MacCalum, Widaman, Preacher, & Hong, 2001), there is evidence that samples as small as 50 to 60 participants are adequate for the appropriate use of this analysis (Mendoza, Markos, & Gonter, 1978; Naylor, Lin, Weiss, Raby, & Lange, 2010).  Given that the sample size of this study was not ideal, caution should be employed in the interpretation of the results.  However, this study may be considered an appropriate preliminary analysis of the relationships in question.

### Description of the Sample

Participants were 64 undergraduate students (38 females and 26 males) enrolled in psychology courses at a large Midwestern university. They ranged in age from 18 to 37 years; with 96.9 percent of the participants age 25 or younger (mean age = 19.88, standard deviation = 2.73 years). The ethnicity of the sample was as follows: Caucasian (87.5%), Black/African American (6.3%), Biracial/Multiracial (3.1%), Hispanic/Latino (1.6%), and Other (1.6%; see Table 1). Three participants (4.7%) reported a history of learning disabilities, 4 participants (6.3%) reported a history of attention deficit hyperactivity disorder, and 7 participants (10.9%) reported a history of traumatic brain injury. The majority of participants identified as right hand dominant (90.6%), with most of the remaining participants identifying as left hand dominant (7.8%), and one participant identifying as having equal dominance in both hands (1.6%).  All of the participants were recruited from a Psychological Science research pool.  In accordance with

the Psychological Science department procedures, participants were granted three credit hours of

research participation towards academic requirements.  The Internal Review Board at the

institution in which this research was conducted approved this study.

Table 1: *Descriptive Statistics for the Sample*

| Variable | *N* | (%) |
|---|---|---|
| *Gender* | | |
| Male | 26 | 40.6 |
| Female | 38 | 59.4 |
| *Race* | | |
| Caucasian | 56 | 87.5 |
| Black/African American | 4 | 6.3 |
| Biracial/Multiracial | 2 | 3.1 |
| Hispanic/Latino | 1 | 1.6 |
| Other | 1 | 1.6 |

*N*=64

# CHAPTER IV

# RESULTS

The results provide information regarding the relationship between scores on measures of cognitive abilities and executive functioning in a college sample, and may have additional implications regarding the relationship between the seven broad CHC factors and components of executive functioning. In this chapter, the results of implemented statistical analyses are presented. This chapter is composed of two sections: (1) results and analyses and (2) summary of the statistical analysis.

## Results and Analyses

### Descriptive Statistics

Descriptive statistics for this sample including means and standard deviations of all *Woodcock-Johnson III Tests of Cognitive Abilities* (WJ-III-Cog; Woodcock, McGrew, & Mather, 2001) and *Delis-Kaplan Executive Function System* (D-KEFS; Delis, Kaplan, & Kramer, 2001) variables appear in Table 2. The WJ-III-Cog normative data, which is based on a representative sample of the general population, specifies a mean score of 100 and a standard deviation of 15 for all subtests and composites. As the scores in Table 2 indicate, mean scores from this college sample ranged from 96.5 (Visual-Auditory Learning) to 105.5 (Sound Blending), with all mean scores falling within the expected average range. The D-KEFS test scores have a mean of 10 and a standard deviation of 3. Mean sample scores ranged from 9.4 to 11.3, which is within the expected range.

Table 2: *Mean and Standard Deviation Statistics for the WJ-III-Cog and D-KEFS*

| Variable | Mean | SD |
|---|---|---|
| **WJ-III-Cog Subtests** | | |
| Verbal Comprehension | 99.0 | 9.7 |
| Visual-Auditory Learning | 96.5 | 10.5 |
| Spatial Relations | 102.3 | 8.6 |
| Sound Blending | 105.5 | 10.6 |
| Concept Formation | 103.6 | 9.6 |
| Visual Matching | 101.4 | 12.2 |
| Numbers Reversed | 100.5 | 12.2 |
| **D-KEFS Test Variables** | | |
| Color-Word Interference Test Condition 3 (Inhibition) | 11.3 | 2.1 |
| Color-Word Interference Test Condition 4 (Inhibition/Switching) | 11.3 | 1.6 |
| Tower Test Total Achievement Score | 10.2 | 2.4 |
| Tower Test Time-Per-Move Ratio | 9.4 | 2.3 |

Analysis using Pearson's product moment correlation was performed to assess the relationship between each of the four scores from tests of the D-KEFS and each of the seven subtest scores of the WJ-III-Cog. The subtests of the WJ-III-Cog that were analyzed included Verbal Comprehension, Visual-Auditory Learning, Spatial Relations, Sound Blending, Concept Formation, Visual Matching, and Numbers Reversed. Scores from the D-KEFS included Color-Word Interference Test Condition 3 (Inhibition); Color-Word Interference Test Condition 4

(Inhibition/Switching); Tower Test Total Achievement Score; and Tower Test Time-Per-Move

Ratio Score. Results of the correlation analysis appear in Table 3.

Table 3: *Correlations Between D-KEFS Scores and WJ-III-Cog Scores*

| Variable | Color-Word Interference Test Condition 3 (Inhibition) | Color-Word Interference Test Condition 4 (Inhibition/ Switching) | Tower Test Total Achievement | Tower Test Time-Per-Move Ratio |
|---|---|---|---|---|
| Verbal Comprehension | .21* | .10 | .18 | .09 |
| Visual-Auditory Learning | .21* | -.09 | .13 | .18 |
| Spatial Relations | .28* | .21* | .10 | .26* |
| Sound Blending | .26* | .08 | .10 | -.04 |
| Concept Formation | .22* | .16 | .33** | -.04 |
| Visual Matching | .28* | .39* | .08 | .05 |
| Numbers Reversed | .38** | .16 | .32** | .27* |

*Denotes significance at p < .05*
*\*\*Denotes significance at p < .01*

All four D-KEFS scores were significantly correlated with at least two of the WJ-III-Cog

subtest scores. Color-Word Interference Test Condition 3 (Inhibition) was significantly

correlated with all seven WJ-III-Cog scores (see Table 3). Pearson's correlation coefficient *r* was

used as a measure of effect size (Field, 2005). Effect sizes were interpreted using guidelines set

forth by Cohen (1992). The correlations with Color-Word Interference Test Condition 3

(Inhibition) were positive and small in nature with regard to effect size for Verbal

Comprehension, Visual-Auditory Learning, Spatial Relations, Sound Blending, Concept

Formation, and Visual Matching.  A medium effect size was indicated for the positive correlation

between Color-Word Interference Test Condition 3 (Inhibition) and the Numbers Reversed subtest.

Two significant correlations between WJ-III-Cog subtests and Color-Word Interference Test Condition 4 (Inhibition/Switching) were noted (see Table 3). A small effect size was indicated for the positive correlation with Spatial Relations. A medium effect size was indicated for the positive correlation with Visual Matching. Two significant positive correlations between WJ-III-Cog subtests and the Tower Test Total Achievement Score were also noted (see Table 3). A medium effect size was indicated for positive correlations with Concept Formation and Numbers Reversed. Lastly, two significant positive correlations between WJ-III-Cog subtests and the Tower Test Time-Per-Move Ratio score were noted (see Table 3). Small, positive correlations were indicated for both Spatial Relations and Numbers Reversed. All other correlations between subtest scores were not significant. Assessment of these relationships addressed the following research questions:

$R_3$ Is there a significant correlation between Color-Word Interference Test Condition 3 (Inhibition) and the subtests of the WJ-III-Cog?

$R_4$ Is there a significant correlation between Color-Word Interference Test Condition 4 (Inhibition/Switching) and the subtests of the WJ-III-Cog?

$R_5$ Is there a significant correlation between Tower Test Total Achievement and the subtests of the WJ-III-Cog?

$R_6$ Is there a significant correlation between Tower Test Time-Per-Move Ratio and the subtests of the WJ-III-Cog?

This allowed for initial appraisal of the relationship between the variables.

**Statistical Assumptions**

Data were assessed to ensure that the assumptions of the analyses were met. Q-Q plots indicated that all variables closely approximated a normal distribution. Scatterplots were employed to assess for linearity and homoscedasticity of the relationships among the variables. These scatterplots demonstrated that relationships between all pairs were linear and that the width of the scatterplots was approximately the same across the values for all variables.

**Canonical Correlation**

Analysis using canonical correlation was implemented to assess the strength and nature of the relationship between broad intelligence and executive functions. Specifically, canonical correlation was utilized to assess the relationship between the seven broad CHC factors and four scores from the D-KEFS, thereby answering the following research question:

$R_1$ Is there a significant canonical correlation between tests of intelligence and tests of executive functions?

The seven broad CHC factors included Comprehension-Knowledge (*Gc*), Long-Term Retrieval (*Glr*), Visual-Spatial Thinking (*Gv*), Auditory Processing (*Ga*), Fluid Reasoning (*Gf*), Processing Speed (*Gs*), and Short-Term Memory (*Gsm*), and were represented by Verbal Comprehension, Visual-Auditory Learning, Spatial Relations, Sound Blending, Concept Formation, Visual Matching, and Numbers Reversed subtest scores from the WJ-III-Cog. The four scores on the D-KEFS include Tower Test Total Achievement Score, Tower Test Time-Per-Move-Ratio, Color-Word Interference Test Condition 3 (Inhibition), and Color-Word Interference Test Condition 4 (Inhibition/Switching), all of which are scaled scores. The first canonical correlation between the two sets of variables was the only one found to be statistically significant ($p = .012$). This canonical correlation had a value of .57 and a canonical $R^2$ of 0.33,

specifying that approximately 33% of the variation in one set of measures is accounted for by the other set.  The $R^2$ indicates a medium effect size, as defined by Cohen (1992).

Structure coefficients between each measure and the overall canonical variate for their set were also analyzed to gain additional insight into the nature of each linear combination, answering the following research question:

$R_2$ If there is a significant canonical correlation between tests of intelligence and tests of executive functions, what are the factors of intelligence and executive function that contribute most to this relationship?

In accordance with accepted guidelines set forth by Tabachnick and Fidell (2007), structure coefficients greater than 0.32 were considered to be important contributors to the canonical correlation.  All WJ-III-Cog variables as well as all D-KEFS variables were associated with their canonical variates (see Table 4).  Among the WJ-III-Cog variables, Numbers Reversed was observed to be the strongest contributor to the canonical correlation between the two sets of variables. It is important to note that all WJ-III-Cog variables met the 0.32 criterion and were associated with the canonical variate of their set.  Among the D-KEFS variables, Color-Word Interference Test Condition 3 (Inhibition) had the highest correlation with the canonical variate (0.82). With correlations above .40, the other three D-KEFS variables were also clearly associated with the canonical variate of this set.

Table 4: *Correlations Between Observed Variables and Their Canonical Variates*

| Variable | Structure Coefficient |
|---|---|
| **WJ-III-Cog Subtests** | |
| Verbal Comprehension | .45 |
| Visual-Auditory Learning | .41 |
| Spatial Relations | .55 |
| Sound Blending | .39 |
| Concept Formation | .54 |
| Visual Matching | .49 |
| Numbers Reversed | .84 |
| **D-KEFS Test Variables** | |
| Color-Word Interference Test Condition 3 (Inhibition) | .82 |
| Color-Word Interference Test Condition 4 (Inhibition/Switching) | .43 |
| Tower Test Total Achievement Score | .65 |
| Tower Test Time-Per-Move Ratio | .43 |

## Multiple Linear Regression

Multiple linear regression analysis was implemented to further assess the nature of the relationship between broad intelligence and executive functions, as represented by the seven broad CHC factors and four scores from the D-KEFS. This analysis addresses the following research question:

$R_7$ Do the seven Woodcock-Johnson III Tests of Cognitive Abilities subtest scores (subtests 1-7) predict the four D-KEFS scores (Color-Word Interference Condition 3 (Inhibition), Color-Word Interference Condition 4 (Inhibition/Switching), Tower Test Total Achievement, and Tower Test Time-Per-Move Ratio)?

The four scores on the D-KEFS included Tower Test Total Achievement Score, Tower Test Time-Per-Move-Ratio, Color-Word Interference Test Condition 3 (Inhibition), and Color-Word Interference Test Condition 4 (Inhbition/Switching). Analysis with multiple linear regression further clarifies the nature of the relationship between the variables. Specifically, multiple linear regression allowed for an exploration of potentially relevant predictive relationships, and assisted in identifying key predictive variables. Results appear in Tables 5-8.

Table 5: *Multiple Regression Model Predicting D-KEFS Color-Word Interference Test Condition 3 (Inhibition) Score from WJ-III-Cog Subtest Scores*

| Predictors | b | SE | ß | t | P | $R^2$ |
|---|---|---|---|---|---|---|
| Constant | -3.735 | 4.017 | | -.930 | .356 | |
| Overall Model | | | | | <.05 | .234 |
| Verbal Comprehension | -.009 | .032 | -.042 | -.258 | .777 | |
| Visual-Auditory Learning | .007 | .025 | .035 | .275 | .784 | |
| Spatial Relations | .038 | .032 | .158 | 1.166 | .249 | |
| Sound Blending | .031 | .025 | .160 | 1.230 | .224 | |
| Concept Formation | .016 | .030 | .076 | .553 | .582 | |
| Visual Matching | .014 | .022 | .084 | .636 | .527 | |
| Numbers Reversed | .049 | .022 | .290 | 2.243 | .029 | |

Table 6: *Multiple Regression Model Predicting D-KEFS Color-Word Interference Test Condition 4 (Inhibition/Switching) Score from WJ-III-Cog Subtest Scores*

| Predictors | b | *SE* | ß | *t* | *P* | *R²* |
|---|---|---|---|---|---|---|
| Constant | 5.419 | 3.203 | | 1.692 | .096 | |
| Overall Model | | | | | .064 | .204 |
| Verbal Comprehension | -.009 | .025 | -.055 | -.361 | .720 | |
| Visual-Auditory Learning | -.028 | .020 | -.180 | -1.380 | .173 | |
| Spatial Relations | .027 | .026 | .145 | 1.055 | .296 | |
| Sound Blending | -.006 | .020 | -.038 | -.284 | .778 | |
| Concept Formation | .014 | .024 | .082 | .582 | .563 | |
| Visual Matching | .048 | .018 | .361 | 2.676 | .010 | |
| Numbers Reversed | .009 | .017 | .071 | .541 | .591 | |

Table 7: *Multiple Regression Model Predicting D-KEFS Tower Test Total Achievement Score from WJ-III-Cog Subtest Scores*

| Predictors | b | SE | ß | t | P | $R^2$ |
|---|---|---|---|---|---|---|
| Constant | -1.425 | 4.864 | | -.293 | .771 | |
| Overall Model | | | | | .074 | .198 |
| Verbal Comprehension | .000 | .038 | .001 | .004 | .997 | |
| Visual-Auditory Learning | -.007 | .030 | -.031 | -.240 | .881 | |
| Spatial Relations | -.013 | .039 | -.044 | -.320 | .750 | |
| Sound Blending | .007 | .031 | .031 | .231 | .818 | |
| Concept Formation | .083 | .036 | .326 | 2.303 | .025 | |
| Visual Matching | -.022 | .027 | -.108 | -.798 | .428 | |
| Numbers Reversed | .065 | .026 | .325 | 2.457 | .017 | |

Table 8: *Multiple Regression Model Predicting D-KEFS Tower Test Time-Per-Move Ratio Score from WJ-III-Cog Subtest Scores*

| Predictors | b | SE | ß | t | P | $R^2$ |
|---|---|---|---|---|---|---|
| Constant | 1.936 | 4.642 | | .417 | .678 | |
| Overall Model | | | | | .213 | .151 |
| Verbal Comprehension | .001 | .036 | .004 | .028 | .977 | |
| Visual-Auditory Learning | .026 | .029 | .123 | .910 | .367 | |
| Spatial Relations | .067 | .037 | .256 | 1.797 | .078 | |
| Sound Blending | -.019 | .029 | -.088 | -.643 | .523 | |
| Concept Formation | -.034 | .034 | -.146 | -1.002 | .321 | |
| Visual Matching | -.005 | .026 | -.027 | -.197 | .845 | |
| Numbers Reversed | .039 | .025 | .212 | 1.554 | .126 | |

Statistical analysis with multiple linear regression with simultaneous entry of variables revealed a significant model in which Verbal Comprehension, Numbers Reversed, Sound Blending, Visual-Auditory Learning, Visual Matching, Spatial Relations, and Concept Formation as predictor variables accounted for approximately 23.4% of the variance in the dependent variable, Color-Word Interference Test Condition 3 (Inhibition) score ($R^2 = .234$, $F$ (7, 56) = 2.446, $p < .05$). Of the individual predictors, when holding all other predictors constant, only one significantly contributed to the prediction (i.e., Numbers Reversed; $\beta = .290$, $p < .05$). This indicates that for every one standardized unit increase in the Numbers Reversed score, there is a .290 standardized unit increase in Color-Word Interference Test Condition 3 (Inhibition) score. Overall, this model is somewhat helpful at predicting the Color-Word Interference Test Condition 3 (Inhibition) score, though it is clear that other influencing factors that could serve as

helpful predictors remain unaccounted for. Multiple linear regression models in which Color-Word Interference Test Condition 4 (Inhibition/Switching), Tower Test Total Achievement score, and Tower Test Time-Per-Move Ratio score served as the dependent variables were not significant (see Tables 6-8).

## Summary

The sample demonstrated average performance on both measures. Analysis employing Pearson product moment correlation indicated positive correlation between Color-Word Interference Test Condition 3 (Inhibition) and all measured subtests of the WJ-III-Cog (Verbal Comprehension, Visual-Auditory Learning, Spatial Relations, Sound Blending, Concept Formation, Visual Matching, and Numbers Reversed) at the .05 level of significance or below. Numbers Reversed was most strongly correlated with this D-KEFS score, and was significant at the .01 level. Color-Word Interference Test Condition 4 (Inhibition/Switching) and two subtests from the WJ-III-Cog, Visual Matching and Spatial Relations, were both significant at the .05 level. A significant positive correlation between Tower Test Total Achievement Score and two subtests from the WJ-III-Cog, Concept Formation and Numbers Reversed, were both significant at the .01 level. Tower Test Time-Per-Move Ratio and two subtests from the WJ-III-Cog, Spatial Relations and Numbers Reversed, were both significant at the .05 level.

The results of the canonical correlation analysis indicated a significant model between the tests of intelligence from the WJ-III-Cog and scores of executive functioning from the D-KEFS. The canonical correlation had a value of .57 and a canonical $R^2$ of 0.33, specifying that approximately 33% of the variation in one set of measures was accounted for by the other set. This canonical correlation was significant at the .05 level.

Analysis of correlations between each measure and the overall canonical variate for their set indicated that all WJ-III-Cog variables as well as all D-KEFS variables were associated with their canonical variates. However, Numbers Reversed from the WJ-III-Cog and Color-Word Interference Test Condition 3 (Inhibition) from the D-KEFS had the highest correlations with their canonical variates, implicating these tests as the ones that contribute most to the relationship between the two variable sets. With correlations above .40, the other three D-KEFS variables were also clearly associated with the canonical variate of this set.

The multiple linear regression analysis indicated a significant model in which Verbal Comprehension, Numbers Reversed, Sound Blending, Visual-Auditory Learning, Visual Matching, Spatial Relations, and Concept Formation as predictor variables account for approximately 23.4% of the variance in the dependent variable, Color-Word Interference Test Condition 3 (Inhibition) score. Of the individual predictors, Numbers Reversed was the only variable to significantly contribute. While this model may be somewhat helpful at predicting the Color-Word Interference Test Condition 3 (Inhibition) score, other predictive variables remain unaccounted for. Multiple linear regression models in which Color-Word Interference Test Condition 4 (Inhibition/Switching), Tower Test Total Achievement score, and Tower Test Time-Per-Move Ratio score served as the dependent variables were not significant.

# CHAPTER V

# DISCUSSION

This chapter is divided into 4 sections: (1) summary of the present investigation; (2) discussion and implications of the relationship between measures of executive functioning and measures of intelligence in a college sample; (3) delimitations and limitations of the study; and (4) directions for future research.

## Summary of the Study

The purpose of the present study was to explore the relationship between measures of executive functioning from the *Delis-Kaplan Tests of Executive Functions* (D-KEFS; Delis, Kaplan, & Kramer, 2001) and a well-established measure of cognitive ability, the *Woodcock Johnson Tests of Cognitive Ability* (WJ-III-Cog; Woodcock, McGrew, & Mather, 2001) in a group of participants who were college students enrolled at a large Midwestern University. Areas of executive functioning that were assessed in the present investigation included set-shifting, planning, attention and inhibition. Areas of cognitive ability that were included in the present investigation were seven broad ability clusters of Cattell-Horn-Carroll (CHC; Carroll, 1993, 2005; Horn, 1988, 1991; Horn & Blankson, 2005; Horn & Noll, 1997) theory: Fluid Intelligence (*Gf*), Crystallized Intelligence (*Gc*), Short-term Memory (*Gsm*), Visual Processing (*Gv*), Auditory Processing (*Ga*), Long-Term Storage and Retrieval (*Glr*), and Processing Speed (*Gs*). This study explored the relationship between these constructs as well as the implications of this relationship for both theory and practice.  The data for this study were collected from 64 participants, (mean age=19.88).  All participants were administered the Verbal Comprehension, Visual-Auditory Learning, Spatial Relations, Sound Blending, Concept Formation, Visual Matching, and Numbers Reversed subtests from the WJ-III-Cog, which represent the seven

broad CHC factors listed above; as well as the D-KEFS Color-Word Interference Test and D-KEFS Tower Test, which assessed the aforementioned executive functions.

Standard scores, with a mean of 100 and a standard deviation of 15, were calculated for each of the seven subtests of the WJ-III-Cog. For the D-KEFS Tower Test, scaled scores were calculated for overall achievement (Tower Test Total Achievement), and timing (Time-Per-Move Ratio).  For the D-KEFS Color-Word Interference Test, scaled scores were calculated for Condition 3 (Inhibition) and Condition 4 (Inhibition/Switching). These scaled scores have a mean of 10 and a standard deviation of 3.  Pearson's Correlation, canonical correlation and multiple linear regression were used to assess the nature of the relationship between broad intelligence and executive functions, as represented by the seven broad CHC factors and four scores from the D-KEFS.

Means and standard deviations were calculated for the sample for each score. The mean scores all fell within the average range for both the WJ-III-Cog and D-KEFS scores. As expected for a college sample, the majority of individual scores fell within the average range, suggesting that this sample is not representative of the general population, where we would see a greater range of scores.

Results indicated some significant positive relationships between individual WJ-III-Cog subtest scores and individual D-KEFS scores. Three of four D-KEFS scores, Color-Word Interference Test Condition 3 (Inhibition), Tower Test Total Achievement, and Tower Test Time-Per-Move Ratio, were significantly correlated with the Numbers Reversed score. Three of four D-KEFS scores, Color-Word Interference Test Condition 3 (Inhibition), Color-Word Interference Test Condition 4 (Inhibition/Switching), and Tower Test Time-Per-Move Ratio, were also significantly correlated with Spatial Relations. Spatial Relations and Visual Matching

were both correlated with Color-Word Interference Test Condition 4 (Inhibition/Switching);

Concept Formation and Numbers Reversed were both correlated with the Tower Test Total

Achievement score; and Spatial Relations and Numbers Reversed were correlated with the

Tower Test Time-per-move Ratio score. All seven of the WJ-III-Cog variables were significantly

correlated with Color-Word Interference Test Condition 3 (Inhibition). None of the relationships

had more than a medium effect size. The results of the canonical correlation showed a significant

model between the collection of subtests from the WJ-III-Cog and collection of scores from the

D-KEFS, indicating that approximately 33% of the variation in one set of measures was

accounted for by the other set; this was significant at the .05 level. These results suggest that the

D-KEFS and the WJ-III-Cog are in part measuring a related construct. Correlation between each

measure and the overall canonical variate for their set indicated that all WJ-III-Cog variables as

well as all D-KEFS variables were significantly associated with their canonical variates.

The emergence of certain subtests and tests as particularly important to the relationship

between the measures is notable.  The results of the multiple linear regression analysis revealed a

significant model, wherein WJ-III-Cog subtests scores as predictor variables accounted for

approximately 23.4% of the variance in the Color-Word Interference Test Condition 3

(Inhibition) score. Within this model, Numbers Reversed was the only variable to significantly

contribute. Multiple linear regression models in which Color-Word Interference Test Condition 4

(Inhibition/Switching), Tower Test Total Achievement score, and Tower Test Time-Per-Move

Ratio score served as the dependent variables were not significant.

**Discussion and Implications of the Relationship**

**Discussion**

The current study investigated the relationship between tests of cognitive ability and tests of executive function in a college population. This explorative study yields further insight into the relationship, adding to the existing literature. Previous studies regarding the relationship between executive functioning and cognitive abilities have been complicated by a lack of agreed-upon definition of executive functioning, have utilized an array of measures, and have resulted in somewhat differing conclusions (Ardila, Pineda, and Rosselli, 1999; Davis, Pierson, & Finch, 2011; de Frais, Dixon, & Strauss, 2006; Floyd, Bergeron, Hamilton, & Parra, 2010; Floyd, McCormack, Ingram, Davis, Bergeron, & Hamilton, 2006; Friedman, Miyake, Corley, Young, DeFries, & Hewitt, 2006; Fuchs & Day, 2010; Unsworth, Miller, Lakey, Young, Meeks, Campbell, & Goodie, 2009; Zook, Davalos, DeLosh, & Davis, 2004; Zook, Welch, & Ewing, 2006). Despite these differences, past research suggests at least a moderate positive relationship between overall intelligence and executive functions.

Within the current study, each of the WJ-III-Cog and D-KEFS variables were significantly associated with their canonical variate. This is not surprising as both measures were designed to assess somewhat cohesive constructs. The WJ-III-Cog was designed to measure aspects of intellectual functioning, while the D-KEFS tests were designed to measure executive functions. These constructs are clearly related, as the canonical correlation indicates; however, the results of this study suggest the D-KEFS tests may be measuring constructs beyond what are typically considered to be executive functions, and the WJ-III-Cog subtests may be tapping into executive functioning. The presence of a significant relationship between executive functioning and cognitive abilities is not unexpected given that these constructs are functionally related;

specifically, working memory and attention have been established to relate to performance on tests of cognitive abilities (Colom, Rebollo, Palacios, Jaun-Espinosa & Kyllonen, 2004; Conway, Cowan, Bunting, Therriault, & Scott, 2002; Engle, Tuholski, Laughlin, & Conway, 1999; Jarrrold & Towse, 2006; Sub, Oberauer, Wittman, Wilhelm, & Schulze, 2002; Conway, Kane & Engle, 2003; Kyllonen & Christal, 1990). Executive functioning is required to effectively problem solve and assists in attaining information, which are critical aspects of intelligence. For example, one must be able to attend to relevant information in order to store it in memory, process information, and problem solve.

It may be that the common variance evidenced in the current study between the two sets is partially explained by attentional ability and functioning of the dorsolateral prefrontal cortex. This area of the brain is associated not only with the ability to filter out irrelevant information as required by the Color-Word Interference Test, but also the ability to orient to, sustain, and manipulate relevant information in working memory, as required by Numbers Reversed (Beer Shimamura, & Knight, 2002).  Set-shifting and planning abilities are also associated with this area of the brain (Diamond, 2002), hence it is not surprising that all D-KEFS variables contributed significantly to their canonical variate, if the results are examined through this lens.

The presence of common underlying abilities was the conclusion of Floyd and colleagues (2010), who specifically explored the relationship between the WJ-III-Cog and the D-KEFS, including the following tests in analysis: Trail Making, Verbal Fluency, Design Fluency, Color-Word Interference, Sorting, 20 Questions, and Word Context. However, Floyd and colleagues (2010) concluded that tests of executive functioning are redundant to tests of cognitive abilities when considered through the lens of CHC theory. The results of the present investigation did not suggest such strong association with all CHC factors, and rather suggested that despite a

significant relationship, both measures are assessing a good deal that is different. Therefore, current results indicate some non-redundancy between the measures.

The results of the current study are consistent with the previous work of Davis et al. (2011), insomuch as a significant relationship between the variable sets were noted; however, the relationship indicated by the current investigation was not as strong as that indicated by Davis and colleagues. Although a similar sample was utilized for both studies, the differences are perhaps not entirely surprising given that different measures of cognitive ability, with differing theoretical bases, were utilized. Davis and colleagues included more tests of executive functioning from the D-KEFS than did the current investigation. Their canonical correlation utilizing the subtests of the *Wechsler Adult Intelligence Scale*, *Third Edition* (WAIS-III; Wechsler, 1997) indicated that while many test scores from the D-KEFS contributed strongly to the relationship between the sets, including Proverb Test: Total Achievement Score: Free Inquiry and Color-Word Interference Test Condition 4 (Inhibition/Switching), the Tower Test Total Achievement Score did not contribute significantly. Importantly, Color-Word Interference Test Condition 3 (Inhibition) was not included in Davis and colleagues (2011) investigation; therefore comparison to the current investigation cannot be completed on this point. Among the WAIS-III variables, the one arguably most similar to Numbers Reversed on the WJ-III-Cog is Digit Span on the WAIS-III; interestingly, Digit Span was not significantly correlated with the canonical variate. The comparison of these studies overall suggests that these two measures of cognitive ability, the WJ-III-Cog and the WAIS-III, may draw upon somewhat different executive functions, though future research in which all D-KEFS tests are considered would need to be carried out before this conclusion could be made.

The current study builds upon our understanding of how the D-KEFS tests fit within a CHC model, particularly as the Tower Test was included in analysis. Correlations between D-KEFS scores and WJ-III-Cog subtest scores, in addition to regression analyses, highlighted the importance of certain factors in the relationship. The CHC factors indicated to be of utmost importance with regard to the relationship between the tests of executive functioning and tests of cognitive ability included short-term memory, visual processing, processing speed, and fluid intelligence.

**Short-term memory.** The finding that three of four D-KEFS scores were significantly correlated with the Numbers Reversed score, suggests the importance of Short-Term Memory in the overall relationship. Importantly, in more recent expansion of CHC theory, the factor of Short-Term Memory has been replaced by Short-Term Working Memory, which reflects the importance of working memory within this factor (McGrew, 2014). Color-Word Interference Test Condition 3 (Inhibition), Tower Test Total Achievement Score, and Tower Test Time-Per-Move Ratio were all significantly correlated with the Numbers Reversed score, suggesting that Short-Term Memory is related specifically to these tasks. Numbers Reversed was also the sole predicative variable in the Color-Word Interference Test Condition 3 (Inhibition) score, indicating that to some extent, Short-Term Memory ability is predicative of this task of inhibition. That both Tower Test scores were correlated with Numbers Reversed suggests that Short-Term Memory may facilitate planning and speed of execution. The ability to hold both rules and a plan of action in working memory, to complete a task such as those that comprise the Tower Test, would logically lead to a more successful outcome and better Total Achievement Score, as well as faster completion, as reflected in the Time-Per-Move Ratio.

**Visual-spatial thinking.** Spatial Relations, which represents the CHC factor of Visual-Spatial Thinking, was positively and significantly correlated with the Tower Test Time-Per-Move Ratio score. This suggests that Visual-Spatial Thinking contributed to the timing score of this planning task. As Visual-Spatial Thinking taps the ability to manipulate visual stimuli in space, which very much describes the Tower Test, this is somewhat unsurprising. What is more surprising is that the Tower Test Total Achievement Score was not significantly correlated with Spatial Relations. This may perhaps be explained in the following way: while the Tower Test Time-Per-Move Ratio score represents the ability to make a move quickly from one move to the next, it does not necessarily reflect accuracy, errors and number of moves. The Tower Test Total Achievement Score is more reflective of planning ability overall. Strong Visual-Spatial Thinking ability may reflect the ability to quickly perceive the immediate visual stimuli and act upon it in *some* way, but may not reflect the reasoning and planning of the Tower Test as a whole.

Spatial Relations was also positively and significantly correlated with both Color-Word Interference trials. The Color-Word Interference Test trials are visual tasks of verbal inhibition. What differentiates Condition 4 from Condition 3 is that Condition 4 requires not only inhibition, but also set-shifting. As described above with regard to the Tower Test, this Visual-Spatial Thinking ability allows the individual to quickly and accurately perceive the immediate visual stimuli and quickly act upon it.

**Processing speed.** Visual Matching, which represents the CHC factor of Processing Speed, was correlated with Color-Word Interference Test Condition 4 (Inhibition/Switching). That Processing Speed would be related to this visual task of verbal inhibition and set-shifting is unsurprising, as it is a timed task. Processing Speed ability reflects the ability of the individual to quickly perceive and act upon simple visual stimuli, which is a primary component of the Color-

Word Interference Test trials. What is more surprising is that while Condition 4 was significantly correlated with Visual Matching, Condition 3 was not as strongly related. This suggests that, as with Visual-Spatial Thinking, something particular to the set-shifting component of Condition 4 taps Processing Speed. One hypothesis is that the set-shifting required by the trial slows the speed of completion and stronger overall Processing Speed minimizes this effect.

**Fluid reasoning.** Concept Formation, which represents the CHC factor of Fluid Reasoning, was positively and significantly correlated with the Tower Test Total Achievement Score. The Tower Test requires problem solving, within the constraint of rules, which must be mentally planned and implemented with physical execution. This implicates Fluid Reasoning, which is consistent with this test of planning.

## Implications

**Implications for research.**  Despite a clear relationship between executive function and cognitive ability in the current study, much variance between the D-KEFS and WJ-III-Cog remains unaccounted for. Though all WJ-III-Cog variables as well as all D-KEFS variables were significantly associated with their canonical variates, when considering their correlation to their canonical variates along with the Pearson correlation analyses, the factors that contributed least to the relationship included Comprehension-Knowledge, Long-Term Retrieval, and Auditory Processing. The subtests that represented these factors were significantly correlated to Color-Word Interference Test Condition 3 (Inhibition) only, but not to any other measured D-KEFS variables, and were least correlated with their canonical variate. Additionally, amongst the D-KEFS variables, Color-Word Interference Test Condition 3 (Inhibition), a test of inhibition, was clearly the strongest contributor to the canonical variate and was also significantly correlated with all WJ-III-Cog variables. The set-shifting of Color-Word Interference Test Condition 4

(Inhibition/Switching) that is not explained by Visual-Spatial Thinking and Processing Speed, as well as the timing component of planning from the Tower Test Time-Per-Move Ratio not explained by Short-Term Memory and Visual Processing, also represents unaccounted variance.

The conclusion that a significant portion of the variance remains unaccounted for is consistent with previous studies in which the relationship between the two is significant but less than robust (e.g. Ardilla, Pineda, & Rosselli, 1999). Such results raise critical questions regarding the definitions and conceptualizations of intelligence and intelligent behavior. Ardila and colleagues (1999) suggest that we must conclude one of two things: either intelligence tests are insufficient in testing for intelligence or executive functions should not be included as elements of intelligent behavior; they conclude the former. It can certainly be argued, as they suggest, that intelligence measures that fail to assess executive functions are failing to assess abilities that are critical to cognition.

**Implications for the practice of school psychology.** The findings of this study can be used to inform evaluation and intervention planning within the educational setting, allowing for more targeted strategies to be applied to address deficits, though some caution should be employed in applying these findings to populations outside of a college setting until further research with participants of other ages are completed. The application of neuropsychological assessment within the school setting is controversial (Jantz & Plotts, 2014); however, the results of this study and others have great potential to assist in informing school assessment. Although we see that a relationship exists between executive functioning and cognitive ability, it is clear that much of what is measured by both tests is not accounted for by the other test. These tests are therefore measuring different though related constructs, and information from both measures is likely to be useful in gathering data and establishing a clear picture of an individual's

functioning. Conceptually and practically, practitioners must recognize the relatedness of tests of executive functioning and intelligence, while remaining cognizant of the limitations of one to assess the other. It is therefore recommended that both the cognitive and executive functioning profile of students referred for special education be considered. This more complete picture allows for the potential understanding of more specific influencing factors with regard to behavioral as well as academic concerns, and also allows parents and educational professionals a more complete picture of a student's strengths and weaknesses, which is critical to successful intervention planning and execution (Otero, Barker & Naglieri, 2014), and may allow for more accurate attribution. Results suggest that interventions that focus on specific aids for working memory may have the potential to effect patients with executive dysfunction. Recognizing that the Numbers Reversed subtest, which represents the CHC factor of Short-Term Memory and taps working memory, emerged as an important factor in the relationship between the measures, and was the sole significant predictor of Inhibition score on the D-KEFS, allows for appreciation of the fact that working memory may be critical to inhibition. This finding in particular is extremely relevant to educational planning and informing interventions. The knowledge that the construct of working memory could be crucial to inhibition suggests that aids to support working memory may be an effective approach to intervention for some executive functioning deficits. Interventions to significantly improve working memory in children, most notably computer-based training, martial arts and other physical activities, and specific school curricula, have been identified (Diamond, 2012; Otero et al., 2014). Intervention targeting working memory has the potential to improve academic achievement (Titz & Karbach, 2014). Interventions for difficulty with inhibition may need to consider getting ahead of a potential working memory deficit through such intervention. In practice, this could manifest as designing and employing specific

aids for working memory deficits (i.e. flowcharts, visual reminders), or avoiding materials of certain modalities. Looking beyond surface level difficulty with inhibition allows for the consideration of other deficits that may be at play, affecting purposeful behavior and ability or achievement.

As an example, the current results are relevant to consideration of the assessment of learning disability, both as an educational categorization and a psychiatric diagnosis. The results of the current study suggest that evaluation of learning disability should consider both cognitive abilities as well as executive functions, as they are related and both have the potential to present as a learning problem. It has been established that executive functions are some of the root causes of learning disabilities (Hoerig, Davis & D'Amato, 2002), and that learning problems are often more accurately identified and addressed through comprehensive evaluation that considers cognitive processes (Decker, Hale, & Flanagan, 2013). If executive functions have the potential to affect both intelligence and academic performance, then interventions or instruction that target these executive functions would be prudent.

## Delimitations and Limitations of the Study

### Delimitations

The current study may be considered an appropriate preliminary analysis of the relationships in question. The sample size of this study was somewhat limited; as such, the results of this study should be interpreted with some caution. Although the sample size met guidelines established to be adequate in previous analyses (Mendoza, Markos, & Gonter, 1978; Naylor, Lin, Weiss, Raby, & Lange, 2010), replication of this or a similar study with a larger sample would allow for increased certainty regarding conclusions. Furthermore, replication of this study with different populations may indicate differences between individuals of different

ages and stages of development, building upon the current study and studies involving various age groups such as that completed by Floyd and colleagues (2006).

Within the current investigation, not all tests of executive functioning from the D-KEFS were included or considered for analysis. Furthermore, not all scores from all measures that were utilized were considered. For example, error scores were not thought to be appropriate indicators for the college population, as participants from a non-clinical population were unlikely to make frequent errors.

**Limitations**

A potential limitation of the current investigation is the concern of task impurity (Miyake et al. 2000).  Task impurity with regard to executive functioning would present as a situation in which a task believed to measure one or more executive function, in fact triggers other non-executive processes. Task impurity is a limitation due to the fact that while we may define a relationship between the tests of executive functioning and subtests of cognitive ability, we may be unsure of what specific aspects of the tests and subtests are indicated in this relationship with one another. Additionally, with regard to the D-KEFS, the tests included within the current investigation arguably measure more than one component of executive functioning. It is therefore difficult to determine precisely which of the executive functions that are being measured are related to the cognitive abilities under investigation.

<div align="center">

**Directions for Future Research**

</div>

**Defining Executive Functioning**

A lack of formal definition of the construct of executive functioning causes difficulty when it comes to comparing research and generally discussing this topic. Moving toward an agreed upon definition of executing functioning within psychology would assist in creating a

more cohesive research outcome overall. Future research should consider ways in which clarity

of definition of this important construct could be increased. This would specifically allow for

better comparison between research.

**Age and the Development of Executive Functioning**

It is known that age is an especially critical component of executive functioning.

Executive functioning develops over time, through the course of normal development.

Furthermore, executive functions, as they have been defined in past research, do not appear to

develop at the same rate or age. For example, verbal fluency appears to be the last executive

function to develop (Jurado & Roselli, 2007). Arguably executive functioning continues to

develop into early adulthood, as the prefrontal cortex continues to develop until this time

(Diamond, 2002; Jurado & Roselli, 2007). This suggests that executive functioning may peak

and be most optimal at this point in early adulthood. It is possible that a decline in abilities

commences after this point, though research regarding changes in executive functioning over the

lifespan are few (Jurado & Rosselli, 2007). While decline in executive functioning has been

found to correlate with increasing age, it has been difficult to establish this decline as separate

from a general cognitive decline (Crawford, Bryan, Luszcz, Obonsawin & Stewart, 2000). Future

research should consider clarifying this important consideration. Additionally, future research

should consider looking at the relationship between intelligence and executive function across

many age groups, as what holds true with regard to relationship between executive functioning

and cognitive abilities for one age may not be replicated at another age. More specific age ranges

may be employed in such future investigation.  However, age may affect future research in

another way as well. Difficulty in the assessment of executive functions in children has been

established when verbal instructions are complex and may strongly engage non-executive

abilities (Jurado & Rosseli, 2007), and this should be considered in any investigations with pediatric populations.

**Research with Clinical Populations**

Future research may wish to focus on the assessment of clinical populations. Exploration of the relationship between executive functions and cognitive ability within clinical samples would offer insight into patterns of presentation within this relationship for specific disabilities. For example, children with attention-deficit/hyperactivity disorder (ADHD) typically exhibit executive dysfunction and therefore may display as a group a different relationship between executive functions and cognitive abilities than found in the current study. Similar exploration could be made with a sample of participants with learning disabilities. Furthermore, inclusion of achievement measure variables would allow for greater exploration of the relationship between diagnostic categories and patterns of relationships. Exploration of the relationship between intelligence, achievement, and executive function within a child ADHD sample or a leaning disability sample may assist in the development of specific, targeted interventions for these groups, based on a common profile of strengths and weaknesses.

**Inclusion of Additional Tests of Executive Functioning**

In addition to including tests of achievement, as suggested above, it is likely that future research may find additional relationships when additional tests of executive functioning or scores are included in analysis. The D-KEFS could potentially be utilized to investigate other aspects of executive functioning in both a college population, as well as other populations. While executive functions are not defined as an agreed-upon set of functions within the field of psychology, other well-established tests could also be considered. For example, the Trail Making Test (TMT), which is also part of the D-KEFS, as well as the *Halstead-Reitan*

*Neuropsychological Test Battery* (Reitan & Wolfson, 1993), assesses visual-motor sequencing, visual attention, and set-shifting, and would be an interesting comparison to the Color-Word Interference Test trials. Additional understanding could be gained by investigation of both verbal and nonverbal executive functioning measures. Color-Word Interference Test trials assessed verbal inhibition, while the TMT assesses non-verbal inhibition, among other constructs. Verbal Fluency could be another verbal test of inhibition to consider.

**Further Exploration of the Role of Inhibition in Cognitive Abilities**

The fact that within the present study, all subtests of the WJ-III-Cog were significantly correlated with the D-KEFS Color-Word Interference Test Condition 3 (Inhibition) score is an important consideration. This suggests that inhibition may play a significant role in cognitive abilities in general, across all areas that were considered in the present investigation. Future research into how inhibition affects cognitive abilities may better clarify the nature of this relationship. Additionally, the CHC broad abilities have been expanded within CHC theory to include additional factors: Quantitative Knowledge and Reading and Writing (McGrew, 2014). Importantly, the factor of Short-Term Memory has been amended to be Short-Term Working Memory, recognizing that working memory is also an important aspect of this factor (McGrew, 2014).

## Conclusions

The results of this study suggest that within this adult college population, there is some significant shared variance between tests of cognitive ability and tests of executive functioning. Analysis using canonical correlation indicated that a moderate percentage of the variation in one set of measures was accounted for by the other set. Specific subtests emerged as contributing more to this relationship than others. Analysis revealed that the Numbers Reversed subtest score

from the WJ-III-Cog and the Color-Word Interference Test Condition 3 (Inhibition) score from the D-KEFS had the highest correlations with the canonical variates of their respective sets, suggesting that the underlying cognitive functioning that these subtests measure is related.

Analysis of the correlation between the subtest scores from both measures revealed a pattern of significance that most strongly links the Color-Word Interference Test Condition 3 (Inhibition) score to the subtest scores of the WJ-III-Cog.  Notably, the Color-Word Interference Test Condition 3 (Inhibition) score was significantly correlated with all measured subtests of the WJ-III-Cog. This test is most associated with the executive function of verbal inhibition. Further analysis using regression revealed that the Color-Word Interference Test Condition 3 (Inhibition) score could in part be predicted by the Numbers Reversed subtest score from the WJ-III-Cog. Overall, these findings support a significant and predictive relationship between tests of intelligence and this measure of executive functioning in particular.

As noted, among the WJ-III-Cog variables, Numbers Reversed contributed most strongly to the canonical correlation and was the only variable to significantly contribute to the prediction of the Color-Word Interference Test Condition 3 (Inhibition) subtest score within the regression analysis. As this subtest is associated with the CHC factor of Short-Term Memory, the analysis suggests this factor of intelligence is an especially important component of the relationship between intelligence and executive functioning. Further, it is interesting to consider that the other WJ-III-Cog subtests and their correlation with their canonical variate all contribute at approximately the same level. Some significant positive relationships between individual WJ-III-Cog subtest scores and individual D-KEFS scores were evident with regard to the correlation analysis, and yield further insight into the relationship between intelligence and executive functioning. Spatial Relations and Visual Matching were both correlated with Color-Word

Interference Test Condition 4 (Inhibition/Switching); Concept Formation and Numbers Reversed were both correlated with the Tower Test Total Achievement score; and Spatial Relations and Numbers Reversed were correlated with the Tower Test Time-per-move Ratio score. None of these relationships had more than a medium effect size. Overall, consideration of these correlations suggests the importance of Short-Term Memory, Visual-Spatial Thinking, Processing Speed, and Fluid Intelligence in the relationship between executive functions and cognitive ability.

In conclusion, there is a need for further investigation before we can confidently say that those relationships indicated by the present investigation are consistently related across populations; however, this analysis builds upon previous studies and suggests that significant shared variance between tests of cognitive ability and executive functioning exists, though much variance remains unaccounted for. As such, the value of both measures stands with regard to clinical application, and consideration of both cognitive abilities and executive function abilities together is recommended. Utilizing both measures gives a more complete picture of the individual's pattern of performance, assists in better intervention planning and therefore the potential for better outcomes.

# REFERENCES

Adcock, R. A., Constable, R. T., Gore, J. C., & Goldman-Rakic, P. S. (2000).  Functional neuroanatomy of executive processes involved in dual-task performance. *Proceedings of the National Academy of Sciences, 97*, 3567-3572.

Akshoomoff, N. A. & Courchesne, E. (1992).   New role for the cerebellum in cognitive operations. *Behavioral Neuroscience, 106*, 731-738.

Allen, G., Byerley, A. K., Lantrip, C., Lane, C., Ho, E., & Hsu, J. Y. (2011). Functional neuroanatomy of the cerebellum. In A. S. Davis (Ed.), *Handbook of pediatric neuropsychology* (147-160). New York, NY: Springer Publishing Company.

Alvarez, J. A. & Emory, E. (2006).  Executive function and the frontal lobes: A meta-analytic review. *Neuropsychology Review, 16*, 17-42.

American Psychological Association (2006). *APA dictionary of psychology.* Washington, DC: American Psychological Association.

Anderson, P. J. (2008).  Towards a developmental model of executive function.  In V. Anderson, R. Jacobs, & P. J. Anderson (Eds.), *Executive functions and the frontal lobes* (3-21). New York, NY: Psychology Press.

Ardila, A., Pineda, D., Rosselli, M. (1999).  Correlation between intelligence test scores and executive function measures. *Archives of Clinical Neuropsychology, 15*, 31-36.

Aron, A. R. (2007).  The neural basis of inhibition in cognitive control. *The Neuroscientist, 13*, 214-228.

Bartholomew, D. J. (2004).  *Measuring intelligence: Facts and fallacies.* New York, NY: Cambridge University Press.

Beer, J. S., Shimamura, A. P., & Knight, R. T. (2004).  Frontal lobe contributions to executive control of cognitive and social behavior.  In M. S. Gassaniga (Ed.), *The cognitive neurosciences III* (1091-1104).  Cambridge, MA: The MIT Press.

Binet, A. (1905).  New methods for the diagnosis of the intellectual level of subnormals. *L'Année Psychologique, 12*, 191-244.

Bloom, B. S. (1964).  *Stability and change in human characteristics.*  New York, NY: John Wiley and Sons.

Cattell, R. B. (1941).  Some theoretical issues in adult intelligence testing. *Psychological Bulletin, 38*, 592.

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

Carroll, J. B. (2005). The three-stratum theory of cognitive abilities. In D. P. Flanagan & P. L. Harrison (Eds.), Contemporary intellectual assessment: Theories, tests, and issues (2nd ed.) (pp. 69-76). New York: The Guilford Press.

Cohen, J. (1992). A power primer. *Pscychological Bulletin, 112*(1), 155-159.

Colom, R., Rebollo, I., Palacios, A., Jaun-Espinosa, M. & Kyllonen, P. C. (2004). Working memory is (almost) perfectly predicted by g. *Intelligence*, *32*, 277-296.

Conway, A. R. A., Cowan, N., Bunting, M. F., Therriault, D. J. & Scott, R. B. (2002). A latent variable analysis of working memory capacity, short-term memory capacity, processing speed, and general fluid intelligence. *Intelligence, 30*, 163-183.

Conway, A. R., Kane, M. J., & Engle, R. W. (2003). Working memory capacity and its relation to general intelligence. *Trends in Cognitive Sciences*, *7*, 547-552.

Courchesne, E., Townsend, J., Akshoomoff, N. A., Saitoh, O., Yeung-Courchesne, R., Lincoln, A. J., et al. (1994).  Impairment in shifting attention in autistic and cerebellar patients. *Behavioral Neuroscience, 108*, 848-865.

Crawford, J. R., Bryan, J., Luszcz, M. A., Obonsawin, M. C. & Stewart, L. (2000). The executive decline hypothesis of cognitibe aging: do executive deficits qualify as differential deficits and do they mediate age-related memory decline? *Aging, Neuropsychology, and Cognition*, *7*, 9-31.

Cuevas, K. & Bell, M. A. (2014). Infant attention and early childhood executive function. *Child Development*, *85*, 397-404.

Davis, A. S., Pierson, E. E., & Finch, W. H. (2011). A canonical correlation analysis of intelligence and executive functioning. *Applied Neuropsychology*, *18*, 61-68.

de Frais, C. M., Dixon, R. A., & Strauss, E. (2006).  Structure of four executive functioning tests in healthy older adults.  *Neuropsychology, 20*, 206-214.

De Luca, C. R. & Leventer, R. J. (2008).  Developmental trajectories of executive functions across the lifespan.  In V. Anderson, R. Jacobs, & P. J. Anderson (Eds.), *Executive functions and the frontal lobes: A lifespan perspective* (23-56).  New York, NY: Psychology Press.

Deary, I. J. (2001).  *Intelligence: A very short introduction.*  New York, NY: Oxford University Press.

Deary, I. J., Spinath, F. M. & Bates, T. C. (2006). Genetics of intelligence. *European Journal of Human Genetics*, *14*, 690-700.

Decker, S. L., Hale, J. B. & Flanagan, D. P. (2013). Professional practice issues in the assessment of cognitive functioning for educational applications. *Psychology in the Schools*, *50*, 300-313.

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

Denckla, M. B. & Reiss, A. L. (1997). Prefrontal-subcortical circuits in developmental disorders. In N. A. Krasnegor, G. R. Lyon, & P. S. Goldman-Rakic (Eds.), *Development of the prefrontal cortex: Evolution, neurobiology, and behavior* (283-293). Baltimore, MD: Paul H. Brookes Publishing Company.

Diamond, A. (2012). Activities and programs that improve children's executive functions. *Current Directions is Psychological Science*, *21*, 335-341.

Diamond, A. (2002). Normal development of prefrontal cortex from birth to young adulthood: Cognitive functions, anatomy, and biochemistry. In D. T. Stuss & R. T. Knight (Eds.), *Principles of frontal lobe function* (466-503). New York, NY: Oxford University Press.

Duff, K., 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.

Duncan, J & Miller, E. K. (2002). Cognitive focus through adaptive neural coding in the primate prefrontal cortex. In D. T. Stuss & R. T. Knight (Eds.), *Principles of Frontal Lobe Function* (278-291). Ney York, NY: Oxford University Press.

Elderkin-Thompson, V., Ballmaier, M., Hellemann, G., Pham, D., & Kumar, A. (2003). Daily functioning and prefrontal brain morphology in healthy and depressed community-dwelling elderly. International Journal of Geriatric Psychiatry, 16, 633-642.

Elliot, C. D. (1990). *Differential Ability Scales.* San Antonio, TX: Psychological Corporation.

Elliott, C. D. (2007). *DAS-II administration and scoring manual.* San Antonio, TX: Psychological Corporation.

Engle, R. W., Tuholski, S. W., Laughlin, W. & Conway, A. R. (1999). Working memory, short-term memory, and general fluid intelligence: A latent variable approach. *Journal of Experiemental Psychology: General*, *128*, 309-331.

Eslinger, P. J., Biddle, K. R., & Grattan, L. M. (1997). Cognitive and social development in children with prefrontal cortex lesions. In N. A. Krasnegor, G. R. Lyon, & P. S. Goldman-Rakic (Eds.), *Development of the prefrontal cortex: Evolution, neurobiology, and behavior* (283-293). Baltimore, MD: Paul H. Brookes Publishing Company.

Field, A. (2005). *Discovering Statistics Using SPSS, Second Edition*. Thousand Oaks, CA: Sage Publications Inc.

Flanagan, D. P., Ortiz, S. O., & Alfonso, V. C. (2007). *Essentials of cross-battery assessment*. Hoboken, NJ: John Wiley and Sons, Inc.

Floyd, R. G., Bergeron, R., Hamilton, G., & Parra, G. R. (2010). How do executive functions fit with the Cattell-Horn-Carroll model? Some evidence from a joint factor analysis of the Delis-Kaplan executive function system and the Woodcock-Johnson III Tests of Cognitive Abilities. *Psychology in the Schools*, *47*, 721-738.

Floyd, R. G., McCormack, A. C., Ingram, E. L., Davis, A. E., Bergeron, R., Hamilton, G. (2006). Relations between the Woodcock-Johnson III clinical clusters and measures of executive functions from the Delis-Kaplan Executive Function System. *Journal of Psychoeducational Assessment*, *24*, 303-317.

Flynn, J. R. (1985). Wechsler intelligence tests: Do we really have a criterion of mental retardation? American Journal of Mental Deficiency, 90, 236–244.

Flynn, J. R. (1999). Searching for justice: The discovery of IQ gains over time. American Psychologist, 54, 5–20.

Friedman, N. P., Miyake, A., Corley, R. P., Young, S. E., DeFries, J. C., and Hewitt, J. K. (2006). Not all executive functions are related to intelligence. *Psychological Science, 17*, 172-179.

Fuchs, M. W. & Day, J. D. (2010).  Verbal ability and executive functioning development in preschoolers at head start. *Developmental Psychology, 47*, 404-416.

Fuster, J. M. (2001). The prefrontal cortex – an update: Time is of the essence. *Neuron, 30*, 319-333.

Fuster, J. M. (2002). Physiology of executive functions: The perception-action cycle.  In D. T. Stuss & R. T. Knight (Eds.), *Principles of frontal lobe function* (96-108).  New York, NY: Oxford University Press.

Gardner, H. E. (2004).  *Frames of mind: The theory of multiple intelligences*.  New York, NY: Basic Books.

Gardner, H., Kornhaber, M. L., & Wake, W. K. (1996).  *Intelligence: Multiple Perspectives*. New York, NY: Harcourt Brace College Publishers.

Graybiel, A. M. & Saka, E. (2004). The basal ganglia and the control of action.  In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (1091-1104).  Cambridge, MA: The MIT Press.

Golden, C. J. (1978).  *Stroop Color and Word Test: A manual for clinical and experimental uses*. Chicago, IL: Skoelting.

Gordy, J. P. (1898).  *New Psychology*.  New York, NY: Hinds and Noble.

Gustafsson, J., & Undheim, J. O. (1992). Stability and change in broad and narrow factors of intelligence from ages 12 to 15 years. *Journal of Educational Psychology*, 84(2), 141-149.

Harden, K. P., Turkheimer, E., & Loehlin, J. C. (2007).  Genotype by environment interaction in adolescents' cognitive aptitude.  *Behavior Genetics, 37*, 273-283.

Hass, M. R., Patterson, A., Sukraw, J. & Sullivan, B. M. (2014). Assessing executive functioning: a pragmatic review. *Contemporary School Psychology*, *18*, 91-102.

Heflin, L. H., Laluz, V., Jang, J., Ktelle, R., Miller, B. L., & Kramer, J. H. (2011).  Let's inhibit our excitement: The relationships between stroop, behavioral disinhibition, and the frontal lobes.  *Neuropsychology, 25*, 655-665.

Hoerig, D. C.,Davis, A. S., & D'Amato, R. C. (2002). Evaluating the relationship between memory and intelligence in children with learning disabilities. *Psychological Reports*, *91*, 1169-1173.

Horn, J. L. (1988). Thinking about human abilities. In J. R. Nesselroade & R. B. Cattell (Eds.), *Handbook of multivariate psychology* (pp. 645-685). New York, NY: Academic.

Horn, J. L. (1991). Measurement of intellectual capabilities: A review of theory. In K. S. McGrew, J. K. Werder, & R. W. Woodcock (Eds.), *Woodcock-Johnson technical manual* (pp. 197-232). Chicago: Riverside Publishing.

Horn, J. L. & Blankson, N. (2005). Foundations for better understanding of cognitive abilities. In D. P. Flanagan & P. L. Harrison (Eds.), *Contemporary intellectual assessment: Theories, tests, and issues* (2$^{nd}$ ed.) (pp. 41-68). New York: The Guilford Press.

Horn, J. L. & Cattell, R. B. (1966).  Refinement and test of the theory of fluid and crystallized general intelligences.  *Journal of Educational Psychology, 57*, 253-270.

Horn, J. L. & Noll, J. (1997). Human cognitive capabilities: G*f-Gc* theory. In D. P. Flanagan, J. L. Genshaft, & P. L. Harrison (Eds.), *Contemporary intellectual assessment: Theories, tests, and issues* (pp. 53-91). New York, NY: Guilford.

Humphreys, G. W. & Sampson, D. (2004). Attention and the frontal lobes. In M. Gazzaniga (Ed.), *The cognitive neurosciences* (pp. 607-619). Cambridge, MA: MIT Press.

Jantz, P. B. & Plotts, C. A. (2014). Integrating neuropsychology and school psychology: potential and pitfalls. *Contemporary School Psychology*, *18*, 69-80.

Jarrold, C. & Towse, J. N. (2006). Individual differences in working memory. *Neuroscience,* *139*, 39-50.

Johnson, W., Bouchard , T. J., Krueger, R. F., McGue, M., & Gottesman, I. (2004). Just one g: Consistent results from three test batteries. *Intelligence, 32*, 95-108.

Johnson, A. R. & Wichern, D. W. (2002). *Applied multivariate statistical analysis* (5th ed.). Upper Saddle River, NJ: Prentice Hall.

Jurado, M. B. & Rosselli, M. (2007). The elusive nature of executive functions: A review of our current understanding. *Neuropsychology Review, 17*, 213-233.

Kaufman, A. S. & Kaufman, N. L. (1993). *The Kaufman Adolescent and Adult Intelligence Test.* Circle Pines, MN: American Guidance Service.

Kaufman, A. S. & Kaufman, N. L. (2004). *The Kaufman Assessment Battery for Children –* *Second Edition*. Circle Pines, MN: American Guidance Service.

Knight, R. T., & Stuss, D. T. (2002). Prefrontal cortex: The present and the future. *Principles of* *frontal lobe function*, 573-597.

Koppenol-Gonzalez, G. V., Bouwmeester, S., & Boonstra, A. M. (2010). Understanding planning ability measured by the Tower of London: an evaluation of its internal structure by latent variable modeling. *Psychological assessment*, *22*, 923-934.

Kyllonen, P. C. & Christal, R. E. (1990). Reasoning ability is (little more than) working memory capacity?!. *Intelligence*, *14*, 389-433.

Larsen, L., Hartmann, P., & Nyborg, H. (2008). The stability of general intelligence from early adulthood to middle age. Intelligence, 36, 29-34.

Larochette, A., Benn, K., & Harrison, A. G. (2009). Executive functioning: A comparison of the Tower of London and the D-KEFS Tower Test. *Applied Neuropsychology*, *16,* 275-280.

MacCallum, R. C., Widaman, K. F., Preacher, K. J., & Hong, S. (2001). Sample size in factor analysis: The role of model error. *Multivariate Behavioral Research, 36*, 611-637.

Mandelman, S. D. & Grigorenko, E. L. (2011). Intelligence: Gnes, environments, and their interactions. In R. J. Sternberg & S. B. Kaufman (Eds.), *The Cambridge handbook of* *intelligence* (85-106). New York, NY: Cambridge University Press.

McCloskey, G., Perkins, L. A., & Divner, B. V. (2009). *Assessment and intervention for* *executive function difficulties.* New York, NY: Routledge.

McGrew, K. S. (2014). *CHC theory 101: from general intelligence g to CHC theory* [PowerPoint Slides]. Retrieved from http://www.slideshare.net/iapsych/chc-theory-101-from-general-intelligence-g-to-chc-theory.

McGrew, K. S. & Woodcock, R. W. (2001). *Technical manual: Woodcock-Johnson III*. Itasca, IL: Riverside Publishing.

Mendoza, J. L., Markos, V. H., & Gonter, R. (1978).  A new persective on sequential testing procedures in canonical analysis: A Monte Carlo evaluation.  *Multivariate Behavioral Research, 13*, 371.

Mesulam, M. M. (2002).  The human frontal lobes: Transcending the default mode through contingent encoding.  In D. T. Stuss & R. T. Knight (Eds.), *Principles of frontal lobe function* (8-30).  New York, NY: Oxford University Press.

Miller, E. K. & Cohen, J. D. (2001).  An integrative theory of prefrontal cortex function.  *Annual Review of Neuroscience, 24*, 167-202.

Miller, E. K., Freedman, D. J., & Wallis, J. D. (2003).  The prefrontal cortex: categories, concepts and cognition.  In A. Parker, A. Derrington, and C. Blakemore (Eds.), *The physiology of cognitive processes* (252-273).  New York, NY: Oxford University Press.

Miller, D. C. (2007). *Essentials of school neuropsychological assessment*. Hoboken, NJ: John Wiley & Sons, Inc.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive psychology*, *41*, 49-100.

Moore, T. L., Schettler, S. P., Killany, R. J., Rosene, D. L., & Moss, M. B. (2009).  Effects on executive function following damage to the prefrontal cortex in the rhesus monkey (macaca mulatta).  *Behavioral Neuroscience, 123*, 231-241.

Naglieri, J. A. & Das, J. P. (1997).  *Das-Naglieri Cognitive Assessment System*.  Chicago, IL: Riverside.

Naylor, M. G., Lin, X., Weiss, S. T., Raby, B. A., & Lange, C. (2010). Using canonical correlation analysis to discover genetic regulatory variants. *PloS one*,*5*(5), e10395.

Otero, T. M., Barker, L. A., & Naglieri, J. A. (2014). Executive function treatment and intervention in schools. *Applied Neuropsychology: Child*, *3*, 205-214.

Plomin, R., & Spinath, F. M. (2004). Intelligence: genetics, genes, and genomics. *Journal of personality and social psychology*, *86*(1), 112.

Rabbitt, P. (1997). Introduction: Methodologies and models in the study of executive function. In P. Rabbitt (Ed.), *Methodology of frontal and executive function* (pp. 1-38). East Sussex, England: Psychology Press.

Reitan, R. M., & Wolfson, D. (1993). The Halstead-Reitan neuropsychological test battery: theory and clinical applications. *Neuropsychology Press, Tucson, AZ.*

Remine, M. D., Care, E, & Brown, P. M. (2008).  Language ability and verbal and nonverbal executive functioning in deaf students communicating in spoken English.  *Journal of Deaf Studies and Deaf Education, 13*, 531-545.

Reynolds, C. R. & Kamphaus, R. W. (2003).  *Reynolds Intellectual Assessment Scales*.  Lutz, FL: Psychological Assessment Resources.

Richland, L. E. & Burchinal, M. R. (2013). Early executive function predicts reasoning development. *Psychological Science*, *24*, 87-92.

Roid, G. H. (2003).  *Stanford-Binet Intelligence Scales, Fifth Edition: Technical Manual.*  Itasca, IL: Riverside.

Schmidt, M. (2003). Hit or miss? Insight into executive functions (Test Review). Journal of the International Neuropsychological Society, 9, 962–964.

Schrank, F. A., Miller, D. C., Wendling, B. J., & Woodcock, R. W. (2010).  *Essentials of WJ III cognitive abilities assessment* (2nd ed.).  Hoboken, NJ: John Wiley & Sons, Inc.

Schumahmann, J. D. & Sherman, J. C. (1998). The cerebellar cognitive affective syndrome. *Brain, 121*, 561-579.

Schweizer, T. A., Alexander, M. P., Cusimano, M, Stuss, D. T. (2007).  Fast and efficient visuotemporal attention requires the cerebellum.  *Neuropsychologica, 45*, 3068-3074.

Shimamura, A. P. (2000).  The role of the prefrontal cortex in dynamic filtering.  *Psychobiology, 28*, 207-218.

Shunk, A. W., Davis, A. S., & Dean, R. S. (2006). Test Review: Delis Kaplan Executive Function System (D-KEFS). Applied Neuropsychology, 13, 275-279.

Sotelo-Dynega, M. & Dixon, S. G. (2014). Cognitive assessment practices: A survey of school psychologists. *Psychology in the Schools*, *51*, 1031-1045.

Spearman, C. (1904). "General intelligence" objectively determined and measured.  American Journal of Psychology, 15, 201-293.

Stroop, J. R. (1935).  Studies of interference in serial verbal reactions.  *Journal of Experimental Psychology, 28*, 643-662.

Strick, P. L., Dum, R. P., & Fiez, J. A. (2009).  Cerebellum and nonmotor function. *The Review of Neuroscience, 32*, 413-434.

Sub, H. M., Oberauer, K., Wittman, W. W., Wilhelm, O. & Schulze, R. (2002). Working memory capacity explains reasoning ability – and a bit more. *Intelligence*, *30*, 261-288.

Tabachnick, B. G. & Fidell, L. S. (2007).  *Using multivariate statistics*.  Boston, MA: Pearson.

Terman, L. (1916).  *The measurement of intelligence: An explanation of and a complete guide for the use of the Stanford revision and extension of the Binet-Simon Intelligence Scale*. Boston, MA: Houghton Mifflin.

Thompson, B. (1984).  *Canonical correlation analysis: Uses and interpretation*.  Thousand Oaks, CA: Sage Publications, Inc.

Thorndike, R. L., Hagen, E. P., & Sattler, J. S. (1986).  *Stanford-Binet Intelligence Scale – Fourth Edition.*  Itasca, IL: Riverside Publishing.

Titz, C. & Karbacj, J. (2014). Working memory and executive functions: effects of training on academic achievement. *Psychological Research*, *78*, 852-868.

Unsworth, N., Miller, J. D., Lakey, C. E., Young, D. L., Meeks, J. T., Campbell, W. K., & Goodie, A. S. (2009).  Exploring the relations among executive functions, fluid intelligence, and personality.  *Journal of Individual Differences, 30*, 194-200.

Urbina, S. (2011).  Tests of intelligence.  In R. J. Sternberg & S. B. Kaufman (Eds.), *The Cambridge handbook of intelligence* (20-38).  New York, NY: Cambridge University Press.

Wagner, A. D., Bunge, S. A., & Badre, D. (2004).  Cognitive control, semantic memory, and priming: Contributions from prefrontal cortex.  In M. S. Gazzaniga (Ed.), *The cognitive neurosciences III* (1091-1104).  Cambridge, MA: The MIT Press.

Wahlstrom, D. & Luciana, M. (2011). Functional neuroanatomy of the cerebral cortex. In A. S. Davis (Ed.), *Handbook of pediatric neuropsychology* (147-160). New York, NY: Springer Publishing Company.

Wechsler, D. (1944).  *The measurement of adult intelligence.*  Baltimore, MD: Williams and Wilkins.

Wechsler, D. (1989).  *Wechsler Preschool and Primary Scale of Intelligence – Revised.*  San Antonio, TX: Psychological Corporation.

Wechsler, D. (1991).  *Wechsler Intelligence Scale for Children – Third Edition.*  San Antonio, TX: Psychological Corporation.

Wechsler, D. (1997). *WAIS-III: Administration and scoring manual: Wechsler adult intelligence scale*. Psychological Corporation.

Wechsler, D. (2002).  *Wechsler Preschool and Primary Scale of Intelligence – Third Edition.* San Antonio, TX: Psychological Corporation.

Wechsler, D. (2003).  *Wechsler Intelligence Scale for Children – Fourth Edition.*  San Antonio, TX: Psychological Corporation.

Wechsler, D. (2008).  *Wechsler Adult Intelligence Scale – Fourth Edition.*  San Antonio, TX: Psychological Corporation.

Woodcock, R. W., McGrew, K. S., & Mather, N. (2001). *Woodcock-Johnson III Tests of Cognitive Abilities*. Itasca, IL: Riverside Publishing.

Zook, N. A., Davalos, D. B., DeLosh, E. L., & Davis, H. P. (2004).  Working memory, inhibition, and fluid intelligence as predictors of performance on tower of Hanoi and London tasks.  *Brain and Cognition, 56*, 286-292.

Zook, N., Welsh, M. C., & Ewing, V. (2006). Performance of healthy, older adults on the Tower of London Revised: Associations with verbal and nonverbal abilities. *Aging, Neuropsychology, and Cognition*, *13*, 1-19.