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NORMING OF THE EXECUTIVE CONTROL BATTERY IN CHILDREN

A Dissertation

Submitted to the School of Education

Duquesne University

In partial fulfillment of the requirements for
the degree of Doctor of Philosophy

By

John J. Thornton, M.A., M.S.Ed.

May 2011

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John Jay Thornton

2011

DUQUESNE UNIVERSITY
SCHOOL OF EDUCATION
Department of Counseling, Psychology, and Special Education

Dissertation

Submitted in partial fulfillment of the requirements
for the degree
Doctor of Philosophy (Ph.D.)

School Psychology Doctoral Program

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March 2, 2011

NORMING OF THE EXECUTIVE CONTROL BATTERY IN CHILDREN

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ABSTRACT

NORMING OF THE EXECUTIVE CONTROL BATTERY IN CHILDREN

By

John J. Thornton

May 2011

Dissertation supervised by Jeffrey A. Miller, Ph.D, ABBP

Executive functions include the ability of inhibiting responses, goal formation, planning, carrying out goal-directed plans, and effective performance (Jurado & Roselli, 2007). This study presents the findings of statistical analyses that were conducted to examine this study's five research questions related to the Executive Control Battery (ECB; Goldberg, Bilder, Jaeger, & Podell, 2000). The ECB is a neuropsychological battery designed to assess executive deficits based on theoretical approaches developed by Alexander Luria and Elkhonon Goldberg. The primary objective of the research study is to examine normative data of the ECB and its four respective subtests in children. This was accomplished by determining adequate variance on the four ECB subtests and examining descriptive statistics. Reliability data was examined through both internal consistency and inter-rater reliability analyses. Finally, convergent and divergent validity

was explored as ECB subtests were compared to other measures of EF (Stroop, WCST) as well as non-EF measures (WISC-III, WRAT-R) via multiple regression analysis. Results indicate that the ECB demonstrates adequate variance when administered to a sample of children. The ECB was found to be a reliable measure, as internal consistency was adequate on the four subsets and agreement among raters was established on the Graphical Sequences test. Convergent validity analysis, via multiple regression, indicated that Stroop Color Word Standard Score significantly explained Graphical Sequence Errors, and WCST Perseverative Errors Scaled moderately explained Motor Sequences Errors. Predictive validity did not produce a significant relationship between the ECB subtests and IQ. However, the Motor Sequences test was found to significantly predict WRAT-R Arithmetic performance. Implications of these findings and recommendations for future research were discussed.

DEDICATION

I would like to dedicate this work to my family. This process has taken a significant amount of time as my family has continued to grow. I hope that my children will learn through this process the importance of setting and achieving goals, the pursuit of education, and the possibilities that arise from hard work. I would also like to thank my wife, Bethany, who was more supportive than she believes. She has given me countless evenings and weekend afternoons to continue my work when she herself could have used help. Without her continued support, this would not have been possible.

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CHAPTER 1: INTRODUCTION

Significance of the Problem

Executive functions (EFs) are a complex array of higher order cognitive abilities that have significant impact on the development of children. Despite an ever growing amount of research into EF in children, few assessments offer a developmentally appropriate measure of EF behaviors. The assessment utility of the Executive Control Battery (ECB; Goldberg, Bilder, Jaeger, & Podell, 2000) in adult patients with focal frontal lesions and “frontal lobe” like syndromes has been established (Podell, Zimmerman, Sovation, Lovell, & Goldberg, 1991). However, data on the usefulness of the ECB in children has yet to be examined. The ECB is a unique measure of EFs as it promises to offer a rich source of developmentally appropriate manifestations of EF. This is achieved by sampling a broad range of perseverative functions across different modalities such as echopraxia, field dependent behavior, and simple and complex motor sequencing. These phenomena represent the productive symptoms associated with executive deficits and are the foundation of Lurian neuropsychology. The study and measurement of positive symptoms is a contemporary and welcome departure from the study and measurement of negative symptoms by other EF instruments.

Historically, the approach to assessing the neuropsychological functioning of children has been problematic because of an over-reliance on adult findings. The development of a comprehensive, psychometrically sound, and developmentally appropriate pediatric frontal lobe battery promises to be of value to clinicians and clinical researchers. Such a battery can be of great value to the study of the pediatric brain injured and the developmentally impaired.

The main purpose of this study is to establish normative data of the ECB in children. Reliability will be examined through internal consistency measures as well as inter-rater reliability on select subtests. Additionally, other executive and nonexecutive measures will be compared with this data to determine if the ECB is a valid measure of EF in children.

What are Executive Functions?

The frontal lobes of the human brain have been described as a “riddle” (Teuber, 1964). Although the function of the prefrontal cortex has evoked debate for over a century, there is now consensus that the prefrontal cortex is central for a variety of higher-order cognitive processes. These processes, termed executive functions (EFs), refer to a collection of interrelated, but distinct abilities such as planning, inhibition, set maintenance, impulse control, shifting, updating, and attentional control (Roberts & Pennington, 1996). The prefrontal cortex, which is where EF resides, has also been viewed as serving a coordinative function, integrating component cognitive processes across space and time (Roberts & Pennington, 1996).

EFs are central processes that are most intimately involved in giving organization and order to our actions and behavior. Frequently noted as higher-order, frontal, or pre-frontal processing, EF governs/monitors a number of cognitive domains housed in neighboring cerebral regions including linguistic, motoric and memory functions.

The construct of EF is heterogeneous, and it describes some broad, as well as some very specific behaviors. Theorists postulate EFs includes inhibition, anticipation, goal selection, planning, initiation of activity, self-regulation, mental flexibility and problem solving, deployment of attention, and utilization of feedback (Anderson, 2002).

In healthy individuals, EF improves through childhood and reaches mature levels in adolescence and early adulthood (Anderson, 2002).

How does EF develop?

There are many challenges to the study of EF development in children. EFs are thought to develop in spurts, rather than in a linear fashion (Anderson, 2002). Second, EF growth includes qualitative not just quantitative change/improvement often requiring alternative approaches to measurement such as behavioral observation. Third, many behaviors thought to signal impaired EF is common in young children. For example, poor impulse control is normal in 2-year-old children. Researchers must be sensitive to developmental stages by employing tasks that a child would be expected to perform at a given age (Anderson, 2002).

Inhibition

Central to Luria's theory of EF is the concept behavioral inhibition. Prepotent response inhibition is defined as the suppression of dominant, automatic, or prepotent responses and is characterized as an EF (Miyake, Friedman, Emerson, Witzki, Howerter, & Wager, 2000). Luria's (1966) tapping test, involved remembering two rules while inhibiting a prepotent, or habitual, response to make the opposite response instead. In this situation the examinee would have to tap once when the examiner taps twice, and tap twice when the examiner taps once all while inhibiting the tendency to mimic what the examiner does. The coordination and planning of this type of task occurs under novel and complex situations.

Using confirmatory factor analysis, Miyake et al. (2000) found that three target functions inhibition, shifting between mental sets and strategies, and updating

information in working memory were distinguishable, although not completely independent. Miyake et al. (2000) went on to suggest that unity amongst EFs may be accounted for by inhibition, as all EFs involve some inhibitory processes to function properly.

Barkley (1997) defined response inhibition as the innate capacity to inhibit a 'prepotent' response that is reinforced by the environment in which one finds oneself at any given moment. This suggests the ability to consider, or delay a decision about a response, as well as the capacity to interrupt any response when feedback information reveals the response is not having the desired effect. This also implies the capacity otherwise to avoid competing responses, which act as distracters.

The second linked concept, self-regulation, includes any self-directed intervention that changes a present/future behavior so as to alter a temporarily distant, likely outcome. Luria (1966) ascribed to the prefrontal regions of the brain, those required for the programming, regulation, and verification of activity. As such, if the Supervisory Attentional System was damaged, the resulting behavior should be similar to that exhibited by patients with prefrontal lesions. Well-learned cognitive skills and cognitive procedures do not require the higher-level control system. Higher-level control becomes necessary only if error correction and planning have to be performed, if the situation is novel, or temptation must be overcome.

EFs are processes that control and regulate thought and action by suppressing overlearned responses. Barkley (1997) integrated much of the evidence on the relationship of frontal lobe dysfunction with ADHD into a comprehensive view that emphasizes the role of behavioral inhibition (i.e., inhibition of prepotent responses,

stopping prepotent responses, and controlling interference) required for 4 components of EF. Barkley conceptualizes classical ADHD symptoms as accounted for by disinhibition.

EF and IQ

The relationship between IQ and predictive validity of neuropsychological tests has been the topic of some controversy (Jung, Yeo, Chiulli, Sibbitt, & Brooks, (2000); Russell, 2001). However, the relationship between IQ and EF is not strong. Historically, neuropsychological studies proposed that IQ and EF were not related (Hebb, 1945). As such, little change was noted in IQ when lobectomies were performed (Milner, 1982). Observation of brain injured patients indicated that psychometric intelligence tests are not sensitive to frontal lobe deficits (Damasio & Anderson, 1993).

Developmental studies have found that EF tasks were uncorrelated with IQ, and yet further studies found moderate correlations between FSIQ and measures of EF (Pennington, Grossier, & Welsh, 1993). More contemporary researchers have noted that EFs may have a close relation with fluid intelligence (Salthouse, 2006).

Some researchers have posited a link between levels of intelligence and EF performance when the level of ability is taken into consideration. Ardila, Pineda, Roselli. (2000), Arffa, Lovell, Podell, & Goldberg (1998), Baron (2003) and Mahone, Hagelthorn, Cutting, Schuerholtz, Pelletier, Rawlins, et al. (2002) found that EFs are significantly related to intelligence, especially when the sample contains high IQ individuals. Ceiling effects may limit the correlation with IQ among subjects with above average IQ (Russell, 2001).

Crinella and Yu's (2000) factor analysis on a sample of children with and without ADHD produced a modest correlation between g and EF factors. Therefore, EF accounted for a statistically significant amount of the variance in g.

Assessment Issues of EF

Consensus is not present regarding what skills are actually being measured in EF assessment batteries. Often these tasks incorporate a range of lower-order skills such as expressive and receptive language (Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001). EF test scores may tap other neuropsychological skills, which may include components of attention, memory, or other cognitive processes (Fletcher, 1996). Denkla (1996) and Taylor, Schatschneider, Petrill, Barry & Owens (1996) state that EF tasks are factorially confounded, often measuring multiple cognitive functions. Fletcher, Brookshire, Landry, Bohan, Davidson, Francis, et al. (1996) developed two general conclusions: (1) EFs require careful operationalization because precise definition has not been agreed upon, and (2) although measures of EF are factorially, empirically and theoretically complex, the components can be separated and measured reliably.

Problem Statement: Need for a Developmentally Appropriate Battery

Historically, the approach to assessing neuropsychological functioning of children has been problematic because it has excessively relied on downward extensions from adult investigation (Fletcher et al., 1996). Adult derived tests historically have been of little interest or relevance to the study of children as they often lack adequate normative data necessary to differentiate normal and abnormal behavior within a developmental context (Anderson, 2002). Because adult measures elicit different skills in children, these assessments often provide inaccurate results (Fletcher et al., 1996). Further, it has yet to

be demonstrated that tasks correlated with localized dysfunction in adults can correlate in the same fashion for children (Anderson, 1998; Fletcher & Taylor, 1984). Adult EF measures are designed to study neurologic dysfunction and its manifestations in fully developed persons. This framework is inadequate in studying developmental disorders. A comprehensive, psychometrically sound and developmentally appropriate childhood EF battery will be of value to clinicians and clinical researchers.

Various neuropsychological instruments have been described as measures of “frontal lobe” functioning. However, such measures as the Wisconsin Card Sorting Test (WCST; Heaton, 1981), Trail Making Test from the Halstead-Reitan Battery (Reitan & Wolfson, 1985), and the Stroop Color Word Test (Golden, 1978) have been questioned concerning their sensitivity and specificity of frontal lobe dysfunction and the developmental appropriateness for use with children (Anderson, 2002; Anderson et al., 1991). For example, the WCST (Heaton, 1981) was found to correlate with intellectual functioning in children as it measures concept formation (Carmichael, Ris, Weber, & Schefft, 1999; Chelune & Baer, 1986; Heaton, 1981). According to Anderson (2002), concept formation is a developmentally advanced EF and is not fully mature until late adolescence. Another commonly used EF assessment is the Stroop Color Word Naming (Golden, 1978), which requires minimal levels of literacy to obtain valid results Cox, Chee, Chase, Baumbardner, Schuerholtz, Reader, et al. (1997). Cox and colleagues (1997) maintain that these tasks are not always appropriate for use in young children because of the dependence on adequate reading ability. Moreover, some measures of EF, such as the WCST (Heaton, 1981) can be cumbersome to administer and include

instructions, or a lack of instructions, that are difficult for the subject to understand (Lezak, 1997).

Further, measures of prefrontal symptoms generally have emphasized deficit symptoms, as is done in most neuropsychological tests. Neuropsychological impairment is measured by the amount of errors and response time that a subject makes on a given battery. However, classical neuropsychological descriptions of prefrontal phenomena emphasize productive symptoms such as stereotypic behavior, imitative behavior (echopraxia and echolalia), field-dependent behavior, and perseverations (Bilder & Goldberg, 1987; Luria, 1980; Stuss & Benson, 1984). Although these manifestations are frequently observed in the motor domain, Luria indicates that they are not limited to motor behaviors and can be extracted in virtually any cognitive sphere (1980).

Researchers have cautioned against defining executive function by referencing adult behaviors in children (Anderson, 2002). The ECB is a unique neuropsychological measure that is based on the work of Luria. Its emphasis on positive symptoms of EF including perseveration- uncontrolled repetition of particular response; echopraxia- imitation of action; field-dependent behavior- manipulating objects within the environmental field although this task may not be relevant; inertia- inability to begin or cease a behavior, and stereotypies- repetition of posture, movement or speech, promises to offer a rich source of developmentally appropriate manifestations of EF in children. Some of these tasks, such as Go/No-Go and behavioral sequences found in manual postures are similar to those used by Passler, Isaac, and Hynd (1985) and Levin, Eisenberg, and Benton, (1991).

Executive Control Battery

The ECB is a neuropsychological battery that is used to measure EFs. The battery is designed to assess a wide spectrum of cognitive deficits, both negative and productive, commonly found in executive deficits (Goldberg et al., 2000). The author suggests that naturalistic observation of behavior may be used to determine the level of deficits in both qualitative and quantitative measurement. The ECB contains standard procedures to elicit and document specific manifestations of executive dysfunction.

The battery is based on theoretical approaches and procedures developed by Alexander Luria and Elkhonon Goldberg while studying prefrontal lesions in Luria's laboratory (Luria, 1973). The utility of the ECB in identifying adults with focal frontal lobe lesions and "frontal lobe" like syndromes has been established (Podell et al., 1992; Podell, et al. 1993; Podell and Lovell, 1999; Podell, Wiesniewski, & Lovell, 2000).

Luria (1966) described perseverations associated with lesions of the frontal lobes in his text *Higher Cortical Functions of Man*. He referred to a type of perseveration of a hyperkinetic, graphomotor kind, in which "inertia of the nervous processes in the cortical divisions of the motor analyzer" leads to a continuous repetition of a single movement of the pencil (Luria, 1966). Goldberg & Tucker (1978) furthered Luria's work and adopted a scoring system for the Graphical Sequences Test, a subtest of the ECB, based on a taxonomy of perseveration types. According to this taxonomy, Luria's hyperkinetic, graphomotor perseverations, most often seen in bilateral lesions of the frontal lobes and basal ganglia, are classified as "hyperkinetic."

Goldberg & Tucker's (1978) taxonomy is comprised of four perseveration types arranged in a neurocognitive hierarchy. The hierarchy begins with the most basic, or

lower order, perseveration and graduates to higher level perseverations. The perseverations include: hyperkinetic or “motor” perseverations, which are at the most basic of this hierarchy, followed by perseveration of elements, reflecting the next level of disinhibition. Perseveration of features (the openness or closeness of a figure) occurs further up the hierarchy, and finally perseveration of activities (writing the name of an object replaces drawing the object) is the highest order of perseveration. According to Goldberg (1999), perseverations reflect impairment in inertia, which leads to the intrusion of previous, external or irrelevant actions on current actions. One cannot change to a new behavior, and instead relies on the previous overlearned behavior. Individuals, who perseverate, according to Luria, do not compare their actions with the task set, nor do they correct their mistakes.

The ECB is a developmentally appropriate measure of EF and distinct from many prior pediatric EF norms. The uniqueness of the ECB lies in its sampling of the full range of perseverative functions in different modalities. The study of echopraxia, and assessment of simple and complex motor sequencing is unique to the ECB and not traditionally found in EF assessments. The battery is also unique in its observation and scoring of behaviors as it combines the advantages of qualitative, phenomenological and quantitative psychometric approaches (Goldberg, 1992). Elicited behaviors are noted and described (qualitative), as well as counted (quantitative) in order to establish significance. This approach is valuable in the study of children to dissociate component behavioral processes within EF (Baron, 2004). Qualitative observations become critical and are valid in formulating hypotheses to be tested in and out of the testing environment. Goldberg (1992) argues that this approach enables one to elicit performance errors in a

standardized and quantitative manner without sacrificing phenomenal richness. As Anderson (2002) elucidates, scoring systems that incorporate both quantitative and qualitative methodologies are likely to enhance the diagnostic utility of EF tests.

Research Questions and Hypothesis

1. How much variance will be obtained when the ECB is administered to a sample of children?

Hypothesis 1: A normative analysis of the ECB will produce adequate variance on the four ECB measures.

2. Is there consistency of measurement in each ECB subtest?

Hypothesis 2: The ECB is a reliable measure. Internal consistency for each subtest will be established utilizing Cronbach's alpha.

3. Will there be concordance in the degree of agreement among raters who administer the Graphical Sequences subtest to children?

Hypothesis 3: Inter-rater reliability will be established on Graphical Sequences subtest.

4. What is the relationship between the ECB subtests and other measures of EF?

Hypothesis 4: The ECB subtests will moderately correlate with proven measures of EF such as the WCST (perseverative and non-perseverative errors) and the Stroop Color Word Test.

5. Does performance on the ECB predict outcomes on general measures of cognitive ability and achievement?

Hypothesis 5: ECB performance will be predicted by outcomes on IQ and achievement assessments.

CHAPTER II: LITERATURE REVIEW

What Are Executive Functions?

Executive Function (EF) is a construct for a set of processes that are attributed to a wide range of some very broad, as well as some very specific behaviors controlled by the prefrontal cortex. The concept of EF refers to cognitive abilities responsible for controlling and coordinating performance in complex cognitive tasks.

Difficulty arises in the definition and operationalization of EF because of the overarching nature it has on behavior. Researchers debate if the behavior is an EF, or if the behavior is a subfunction of EF. The dilemma of the functions and behaviors associated with EF often result in overlap between theoretical definitions, behavior, and tools for measurement.

General terms such as abstract reasoning and problem solving are replaced with more operationalized definitions that illuminate specific subfunctions. The specific behaviors include processes that are responsible for purposeful goal-directed behavior, the synthesis of external stimuli, formation of goals and strategies, and preparation for action, as well as the verification that plans and actions have been implemented appropriately (Luria, 1973). In general, EF includes anticipation, goal selection, planning, initiation of activity, self-regulation, mental flexibility and problem solving, deployment of attention, and utilization of feedback (Anderson, 2002). As Denckla (1989) maintains, EF requires the ability to plan and sequence complex behaviors, simultaneously attend to multiple sources of information, grasp the main idea of a complex situation, resist distraction and interference, inhibit inappropriate responses, and sustain behavior for a prolonged period of time. EF has been hypothesized as an

integrative process that calls upon more basic cognitive functions such as memory and attention, with the capacity to translate thought into action (Roberts & Pennington, 1996). From the premise that EF processes and translate thought into action, researchers have begun to study metacognition as a way to better understand EF (e.g. Dennis et al., 1996)

Executive Function Behaviors

Currently, EF's are described as multidimensional constructs consisting of several subfunctions. The specification of these subfunctions, however, is not consistent. Although EF has generally agreed upon components, the construct remains abstract and open to diverse interpretations (Baron, 2002). Most descriptions consist of regulation of arousal and vigilance, selective focusing of attention, sustained attention, and shift or dividing attention (Cooley & Lee, 1990; Klenberg, Korkman, & Lahti-Nuuttila, 2001; Mirsky, Anthony, Duncan, Ahearn, & Kellum, 1991). A variety of subdomains have been postulated, and some consistently receive more endorsement than others. Although EF is defined differently across disciplines, currently there are generally agreed on components. These include inhibiting actions, restraining and delaying responses, attending selectively, setting goals, planning, and organizing, as well as maintaining and shifting set. Most acknowledge the relationship between executive functions, attention, and working memory (e.g., Barkley, 1997; Eslinger, 1996; Pennington, Benneto, McAleer & Roberts, 1996), however these components remain debatable as to the involvement in EF. There are important theoretical and clinical distinctions that can be made for each of these subdomains.

Inhibition

A variety of forms of inhibition has been described including cognitive inhibition, interference control, and oculomotor inhibition (Barkley, 1997). Another form, behavioral inhibition, refers to the ability to inhibit a prepotent, or higher order and reflexive, response (Luria, 1973). Inhibition refers to a loss of control in which a person fails to initiate behavior. Surprisingly, a person with frontal lobe impairment can act in an inhibited or disinhibited manner. Both of which are considered inappropriate behaviors.

Inhibition mediates response selection in planning and problem solving tasks. Additionally, the act of suppressing a prepotent response, or resistance to interference, is noted to improve with development in children (Levin 2001, Pennington et al., 1996). Therefore, inhibition has become a focus of attention as investigators attempt to parcel out contributions to effective or impaired inhibitory function. Substantial data indicates that the frontal cerebral region mediates response inhibition (Stuss and Benson, 1986; Mega and Cummings, 1994) whereas orbitofrontal, inferior frontal, and gyrus rectus lesions affect inhibitory efficiency (Levin, Song, Ewing-Cobbs, & Roberson 2001).

Chelune and Baer (1986) and Levin et al. (1991) conclude in their research that perseverative behavior is common in infancy, declines during early and middle childhood, and is rare in adolescence. Although infants younger than 9 months of age have difficulty inhibiting previously learned responses, they can inhibit particular behaviors and shift to a new response set by 12 months (Anderson, 2002). The capacity to switch rapidly between two response sets emerges between 3 and 4 years of age. Diamond & Taylor (1996) concluded that 3-year-old children were able to inhibit

instinctive behaviors, however perseverative errors continued to be made on occasion. Children this age have difficulty switching sets when the rules become more complex (Epsy, 1997). At the age of seven, the ability to switch behaviors is difficult when contingent upon multiple dimensions. However, performance on multi-dimensional tasks improves greatly between the ages of seven and nine (Anderson et al., 2001). Children 9 years and older were found to monitor and regulate their actions, however, an increase in impulsivity was observed during a short period around the age of 11 (Anderson, Anderson, & Lajoie, 1996; Anderson et al., 2000).

The development of intact and proficient inhibitory function is critical to adaptive functioning. Knowledge of how response inhibition progresses in typically developing individuals helps to understand atypical response inhibition in psychiatric and behavioral disorders. Tamm, Menon, and Reiss (2002) studied the developmental trajectory of response inhibition to determine whether there is a dissociation of function in the prefrontal cortex during the development of EF and associated response inhibition abilities. In this study, 19 typical children and adults performed a Go/No-Go task while behavioral and fMRI data were collected.

The results indicate that a positive correlation between cerebral activation and age was observed in the left inferior frontal gyrus/insula/orbitofrontal gyrus. A negative correlation was found between cerebral activation and age in the left middle/superior frontal gyri. No relationship between accuracy and age emerged, but the ability to inhibit responses more quickly improved significantly with age (Tamm et al., 2002). The authors conclude that these data provide the first evidence of dissociable processes occurring in the prefrontal cortex during development of executive functions associated

with response inhibition. Younger subjects activated more extensively than older subjects in specific regions of the prefrontal cortex. This is presumably due to increased demands and inefficient recruitment of brain regions subserving EF including working memory. Older subjects demonstrated increasingly focal activation in specific regions thought to play a more critical role in response inhibition (Tamm, et al., 2002).

Clinical measures used to assess the ability to inhibit the prepotent response include the Stroop Color-Word Test (Golden, 1978), the Category Test (CT; Reitan and Wolfson, 1985), Go/No-Go tests of reciprocal motor movements and the Contingency Naming Test (Anderson, Anderson, Northam, & Taylor (2000).

Initiation and Maintenance of Set

Initiation can be observed in behavior as a latency to respond, or an inability to respond without prompting. Maintenance of set refers to the ability to continue with an activity in the face of competing stimuli. Go/No-go tasks are one way of assessing maintenance of set. Here the person is asked to first mirror a simple tapping task (“If I knock once, you knock once; if I knock twice you knock twice”). Then, the task demands switch so that the person is asked to inhibit the salient response and give the opposite response (“If I knock twice, you knock once; and if I knock once you knock twice”). Word fluency tasks can also measure initiation and set maintenance. The person is asked to name as many words as they can think of beginning with specified letters of the alphabet (i.e. F, A, S). Persons who lose set will produce words starting with letters other than the target words.

Mental Flexibility and Abstract Reasoning

Cognitive flexibility is a term used to refer to a person's ability to switch from one topic to another in thought or action, according to the demands of the new situation (Lezak, 1995). Within this construct is a demand to restrain, or inhibit one behavior, and spontaneously commence another. Two forms of cognitive flexibility have been associated with the frontal lobes. These include reactive and spontaneous flexibility. Reactive flexibility refers to the ability to change set in accordance with environmental demands (Grattan & Eslinger, 1991). Spontaneous flexibility, however, refers to the study of cognitive flexibility as a divergent thinking process.

Tests that measure these characteristics set up an automatic expectancy or routine of behavior, in a subject and then require a shift from that expectancy, or routine, in an independent manner. Mental flexibility can be assessed through sorting or categorization tasks. The Wisconsin Card Sorting Test (Grant and Berg, 1948) and the Category Test (CT; Reitan and Wolfson, 1985) are measures of mental flexibility and abstract problem solving. Measures of perseverative tendency, failure to maintain set, and categories achieved help to determine problem solving ability. The Category Test measures abstraction and concept formation ability by requiring the person to figure the concept, which must be applied within each of seven subtests in order to get the correct answer. The subject must demonstrate the ability to generate possible concepts and benefit from feedback.

The ability to conceptualize of abstract problems and execute tasks to a predetermined plan is a particularly complex set of mechanisms that can result in deficits with temporal organization, rule attainment and action selection. Deficits in task

planning are often measured with Shallice's (1982) 'Tower of London' task, which involves moving disks from an initial state to a goal state using a minimum number of moves. Subjects with executive deficits often find this task difficult. Carlin, Bonbera, Phipps, Alexander, Shapiro, & Grafman (2000) could not identify one root cause to failure, however, went on to suggest that contributing factors may be difficulty with working memory and an inability to plan. Similarly, Burgess and Shallice (1996) found frontally injured patients had problems with rule attainment problems when assessed on a measure which involves guessing the underlying rules that govern how a colored circle moves in a series of presentations.

Self-Regulation

Self-regulation is a complex construct. It has been variously defined as: "the ability to comply with a request; to initiate and cease activities according to situational demands; to modulate the intensity, frequency, and duration of verbal and motor acts; to postpone acting upon a desired object or goal; to resist temptation, and to generate socially approved behavior in the absence of external monitors (Bronson, 2000). Self-regulation is often used with the same meaning as self-control. However, Kopp (1982) distinguishes self-control and self-regulation. She suggests that control is less flexible and adaptive than regulation. A need exists, therefore, to distinguish between self-regulated goal setting and self-regulated goal attainment. Many developmental psychologists believe that at the core of self-control is the ability to inhibit one's initial impulses and compliance, or voluntary obedience to requests and commands.

Maccoby, Dowley, Hagen, & Degerman, (1965) defined four types of inhibition that children must master to gain self-control: 1. Inhibition of movement: the ability to

stop an action that one is already engaged in (“Simon-says,” “Bulb-pressing” task); 2. Inhibition of emotions: control expression and intensity of emotions; 3. Inhibition of conclusions: the ability to withhold a quick and not well-thought-out response to a difficult problem; 4. Delay of gratification (Bronson, 2000).

In a study by Kochanska, Coy, & Murray (2001) the development of self-regulation was examined in 108 individuals between 14 and 45 months. Categories of compliance were derived including: Committed compliance- children embrace maternal agenda, accept it as their own, and eagerly follow maternal directives in a self-regulated way and; Situational compliance- children are cooperative but do not appear to embrace whole-heartedly the maternal agenda. Also derived were regulatory contexts including Do contexts- sustaining an unpleasant, tedious activity; and Don’t contexts- suppressing a prohibited but pleasant activity.

Findings include gender effects. Girls were more compliant than boys; particularly, more committed compliance in the do context, which was more challenging than the don’t context. There were not many correlations across different contexts. Fearfulness was associated with committed compliance in the don’t context. Effortful control was also correlated with committed compliance in the don’t context. Committed, but not situational, compliance was correlated with internalization. The correlation between committed compliance and internalization was not affected by maternal power assertion. Committed compliance showed only modest generalizability (Kochanska et al., 2001).

Attention

Attention is the ability to focus, or allocate resources to a task or object without interference or distraction. The concept of voluntary attention has also been used to describe the directivity and selectivity of mental processes (Luria, 1973). Voluntary attention is responsible for picking up the essential elements of the stimuli that reach us, of making selections among the possible movements we could make, and among all the traces stored in memory.

Shallice similarly suggested that attention is regulated by a supervisory system, which can override automatic responses in favor of scheduling behavior on the basis of plans or intentions (1988).

Working Memory

Working memory is a relatively new and debatable subset to the construct of EF. It refers to memory for, or information processing of, materials or events in a temporary mental workspace that endures a short amount of time.

Jacobson (1935) discovered that monkey's with prefrontal lesions had difficulty holding information over a delay. This finding began a period of extensive research on delayed response paradigms. Jacobson (1935) and other researchers' work has led to the conclusion that working memory is the notion of distinguishing information that has already been presented from information that has not been presented. Fuster's (1997) theory of prefrontal functioning supports Jacobson's (1935) work as it proposes that the prefrontal area is responsible for holding information over a temporal gap until a specific behavior is required.

Pennington et al. (1996) maintain that the frontal lobes are responsible for “resolving competing action alternatives as a result of interactive processes of working memory activations and inhibitory suppressions” (p. 106). A conclusion is drawn that the interaction between the inhibition of incorrect prepotent responses and the working memory process generates the correct response. Factors that influence the ability to carry out these demands include the strength of the prepotent response and the demands placed on working memory.

Debate ensues on whether working memory is an EF, or if working memory is a process that affects the efficiency of EF. Diamond, Kirkman and Amso (2002) found in their research that young children could hold two rules in memory, but have the most difficulty with inhibiting the prepotent response. The study concluded that more time, or extra memory taxation, did not decrease responses. Therefore, inhibition was the difficulty the children experienced, not problems with working memory.

Goldman-Rakic (1987) also maintained through a study of the A not B error, a classic Piagetian task, that children’s difficulty on the task reflected one of inhibitory control when working memory components were removed from the study.

Executive Function Theorists

Luria (1973) described EF as consisting of intention and the orchestration of behaviors necessary to attain goals. He achieved this understanding through years of qualitative clinical behavioral study. Luria established a “functional system” model in which he described the executive system as one of three components that plans, organizes and monitors behavior. His assessment involved various “tasks,” which are graduated in complexity and cover a wide variety of functional domains. Luria’s model is built upon

his perception that the frontal lobe is strategically situated so as to carry out a controlling role through its multiple connections with other regions of the brain. Luria emphasized the functions of inhibition of irrelevant responses, as well as the role of internalized speech in the regulation of goal directed, “programmed behavior” (Klenberg, Korkman, & Lahti-Nuutila, 2001).

The study of frontal lobe focal lesions was used to develop conclusions about EF by Damasio (1985), Fuster (2000), Mateer & Williams, (1991), and Stuss & Benson, (1986). These researchers made conclusions about EF as result of studying brain pathology. Stuss (1986) concluded that frontal lobe pathology results in a number of information processing deficiencies. These include difficulty in shifting from one context to another, difficulty in changing a behavior, a propensity to focus on one aspect of information with problems in relating or integrating isolated details, problems in managing simultaneous or multiple sources of information, and difficulty in using acquired knowledge. Accordingly, these behaviors may be viewed in terms of three general classifications: self-regulatory abilities, the allocation of attentional resource, and the ability to act on knowledge.

Another group of researchers contends that EF’s are synergistic in nature and serve as a cognitive coordinating function. Denckla & Reader (1993) maintained that EF’s are control processes that overarch "all contexts and content domains" (p. 433). EF’s are revealed in such processes as developing plans for future actions, holding those plans and action sequences in working memory until they are executed, and inhibiting irrelevant actions (Pennington & Ozonoff, 1996). EF’s are fundamental to setting and attaining future goals (e.g., performing complex motor acts, producing oral and written

explanations, regulating affect, and controlling behavior). These are problem-solving processes that are invoked when tasks are non-automatic and novel (Hayes, Gifford, & Ruckstuhl, 1996) and in the context of other prepotent, competitive responses (Pennington & Ozonoff, 1996). EF's, therefore, are the decision-making and planning processes that are invoked at the outset of a task, and in the face of a novel challenge. These processes are directly involved with inhibition and working memory (Denckla, 1996). As such, EF's are enlisted when setting goals that are consistent with one's desires and with determining what is necessary for their attainment.

Other researchers include working memory as an integral function of EF (Baddeley, 1996; Barkley, 1997; Roberts & Pennington, 1996).

Historically, two approaches have influenced how EF is defined and measured. Cognitive neuropsychological approaches have often focused on micro-level components, such as working memory and response inhibition (e.g. Goldman-Rakic, 1987; Roberts & Pennington, 1996). In contrast, approaches based on clinical experience, focus on macrolevel constructs such as social judgment, self-regulation, planning, and problem solving (e.g. Damasio & Anderson, 1993).

Models of the Executive System

Researchers formulate working models to better delineate the complex interconnectedness of EF. These models are constructed from theoretical and clinical methodologies. A review of the existing models of EF is necessary in understanding the EF system. In recent years, interest has shifted from attention deficits to deficits in executive functioning. These functions involve such diverse processes as response

inhibition, planning, working memory and flexibility of thinking or responding. Several executive functioning models have originated from this research arena.

Behavioral Inhibition Models

Some of the most influential current executive neuropsychological models of Attention-Deficit/Hyperactivity Disorder (ADHD) emphasize the behavioral symptom of impulsiveness, hypothesizing that the primary deficit in ADHD is a failure in the executive capacity for inhibitory control e.g. (Barkley, 1998; Quay, 1997; Schachar, Tannock, & Logan, 1993; Taylor 1998). While each of these models focuses on the importance of inhibition, they vary greatly in how they formulate the primary deficit. For example, Barkley (1998) proposes that the deficit in inhibition results in secondary deficits in other EF's.

Delay Aversion Models

While it is not an executive model of ADHD, Sonuga-Barke and colleague's (1994) delay aversion model acknowledges the apparent inhibitory difficulties seen in ADHD. However, this model conceptualizes impulsivity in ADHD, not as an inability to inhibit a response, but rather as a choice to avoid delay.

Multiple Executive Deficits Models

Other researchers have proposed that the deficit in behavioral inhibition is just one of several EF deficits, and believe that these arise independently and not just as a result of inhibitory difficulties. Pennington, & Ozonoff (1996) concluded that children with ADHD showed performance deficits on 40 out of 60 different measures of EF. In particular, they performed poorer on those tasks involving inhibition, working memory, planning, and attentional set-shifting/flexibility. This broad range of performance deficits

has led some to conclude that inhibition and/or attention deficits in ADHD children are merely one component of a wider, more pervasive impairment in cognitive function (Denney, 2001).

Working Memory Models

One model of working memory that has been actively tested and modified is that of Baddeley and Hitch (1974). This model is comprised of four component parts, instead of considering working memory as a component of short-term memory. The central executive system (CES) is at the highest level and is responsible for oversight of the functions of short-term memory. This component has processes of attentional control and storage capacity that are responsible for the initiation and regulation of memory. Baddeley and colleagues (2000) assert that the CES is necessary for maintaining information in working memory, retrieving information from long-term memory, and performing divided attention tasks. Within this system, exists two separate storage systems, the phonological loop, which is responsible for verbal content, and the visuospatial sketchpad, which is a storage facility for visual and spatial information. The fourth and most recent component added to Baddeley's model is the episodic buffer, which operates as an interface between the subsystems and long-term memory. Working memory deteriorates when various events occur. These include increase in task demands, compromised CES, and increased memory load (Baddeley, 2000).

Supervisory Attention Model

Norman and Shallice conceived one of the oldest and most influential models of the executive system (1986). The supervisory system is supported by the prefrontal cortex and is assumed to operate in novel, conflicting or complex situations, when the

previously learned schemas are not able to cope with the situation (Norman and Shallice, 1986).

The model is based on the premise of loss of control. It proposes that specific routines of behavior are triggered by environmental stimuli (Baron, 2004). Contention scheduling is a concept in which a schema that is selected to represent a behavioral routine is chosen over another (Baron, 2004). Unable to handle two competing behaviors at one time, contention scheduling thus inhibits or activates the specific behavior (Baron, 2004). The Supervisory Attention System (SAS) monitors these automatic actions. Modification of the contention scheduling occurs when a novel situation is introduced and automatic behavior is not adaptive (Baron, 2004). Shallice (1988) refers to the SAS in the same way that many authors refer to as the “executive system.” According to this model, dysfunction occurs when the SAS fails and the person is bound to the environmental context that controls schemas inappropriately. This error in processing would therefore produce perseverative behavior and cue utilization, and leave a person vulnerable to distraction. These behaviors are more simply understood as an attraction towards automatic responses when given a novel situation.

Shallice and Norman’s model has been criticized for being too simplistic, as it fails to explain how behaviors are planned and organized, or more importantly, how the prefrontal cortex selects new behaviors (Baron, 2004). However, it provides a useful framework in which the process of how automatic behaviors are triggered, inhibited, and replaced by more adaptive supervised processes can be understood (Baron, 2004).

Grafman's Model

Grafman (1995) also proposed a model that utilizes the concept of schema. This model suggests that an hierarchy of schemas is stored in the prefrontal cortex, progressing from general to specific. Therefore, the executive system cannot be conceived of separate from the structure of knowledge (Baron, 2004). One advantage of Grafman's (1995) model over Norman and Shallice's (1986) is that it accounts for the disorganization of information, planning, and reasoning that is common in executive dysfunction (Baron, 2004). The disorganization of information, planning, and reasoning is derived from the destruction of such represented schemas. For example, poor planning involved in getting dressed in the morning may be the result of damage to the schematic representation of being fully clothed. Grafman's model also addresses the storage of knowledge and how this information is selected and searched (Baron, 2004).

Anderson's Model

Anderson (2002) proposed a comprehensive model of EF that takes into account developmental characteristics, which has historically been overlooked by researchers. The model utilizes four distinct domains of EF that are derived from factor analytic studies and current clinical neuropsychological knowledge (Figure 1). This model corresponds with the views of Alexander and Stuss (2000).

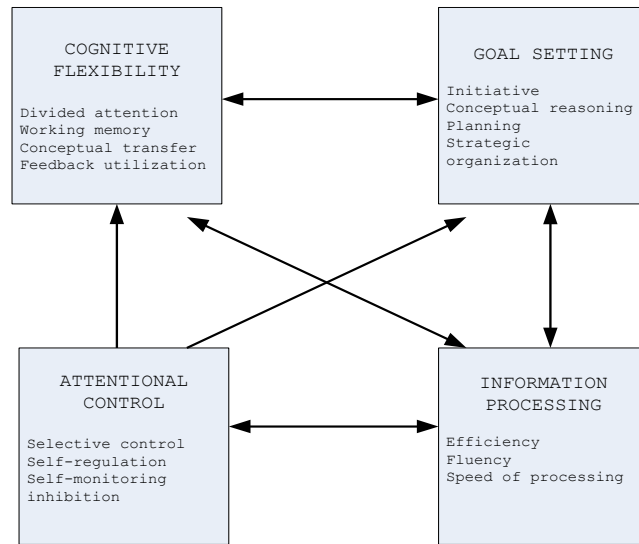


Figure 1. Anderson's Model of EF

The four executive domains that comprise the model include attention control, information processing, cognitive flexibility and goal setting. Although each is an individual and distinct process, the four domains work as an integrative system in order to complete various tasks (Anderson, 2002). Attentional control processes greatly influence the other three executive domains that are inter-related as well as inter-dependent (Anderson, 2002).

The attentional control domain includes the capacity to selectively attend to stimuli and inhibit prepotent responses, as well as the ability to control, regulate and monitor actions so that the plans are executed in the correct order (Anderson, 2002).

Accordingly, information processing refers to fluency, efficiency, and speed of output (Anderson, 2002). This domain is dependent on the integrity of neural connections and the functionality of the frontal system. Deficits in this domain include reduced output, delayed responses, hesitancy, and slowed reactions (Anderson, 2002).

Cognitive flexibility is the ability to shift between response sets, learn from mistakes, develop alternative strategies and process multiple sources of information. Within this model, working memory is included in the cognitive flexibility domain (Anderson, 2002). Therefore, a person with deficits in this domain would incur perseveration, field dependent behaviors and echopraxia. Individuals may be rigid and ritualistic, and have difficulties with novel situations and change (Anderson, 2002).

The final model domain is goal setting. This domain involves the ability to develop new concepts and initiatives, as well as the capacity to plan and organize actions in advance. Impairments that would be seen include poor organization, learning from previous strategies, disorganization, and poor conceptual reasoning.

The Cyclical Relationship Between Theoretical Orientation and Assessment

Methodology

Differing approaches to understanding brain-behavior relationships influence the measures used to assess those relationships and vice versa. Cognitive neuropsychological approaches often focus on microlevel components of EF, such as working memory and response inhibition (e.g. Goldman-Rakic, 1987; Roberts & Pennington, 1996). In contrast, approaches based on data from clinical patterns include more macrolevel constructs such as social judgment, self-regulation, planning, and problem solving (e.g. Damasio & Anderson, 1993). Approaches were developed from two historical traditions, and therefore reflect differing perspectives by which to view similar phenomena. For example, cognitive neuropsychological researchers view perseveration as an inherent by-product of breakdown in working memory and inhibition processes (e.g. Roberts & Pennington, 1996). In clinical neuropsychological approaches, lack of flexibility can be

seen as a fundamental determinant of executive dysfunction in the social arena (e.g. Damasio & Anderson, 1993).

Three main theoretical approaches exist in American neuropsychology: the Luria-Nebraska, Halstead-Reitan and Boston. Each of these approaches use differing theoretical perspectives and assessment approaches to understand brain-behavior relationships. For example, the Halstead Reitan approach hypothesizes that deficits result from CNS impairment, while the Luria-Nebraska develops hypotheses from careful behavioral observation. The Boston approach conversely focuses on the desire to understand the qualitative nature of the behavior. This approach seeks to resolve a descriptive richness with reliability and the quantitative evidence of validity. Subdomains of EF are derived from empirical studies, such as those that include factor analysis or structural equation modeling to validate the construct, or are labeled based on clinical judgment.

Development of EF

Executive processes develop throughout childhood and adolescence and have a central role in cognitive functioning, behavior, emotional control, and social interaction (Anderson, 2002). In order to develop a framework of understanding about the assessment of EF in children, it is necessary to review the current data on EF development. The current understanding of EF development is based upon a small number of developmental and normative studies (Anderson, 2002).

Research aimed at understanding the behavioral role of the frontal lobes throughout development has varied. Luria (1973) proposed that functional maturity of the frontal lobes occurs between the ages of 4 to 7, based on research on neurobiological

markers. However, Golden (1981), emphasizing the advanced organizing functions of the frontal lobe, came to believe the frontal lobes are minimally functional until adolescence (12-15) or even adulthood. Although developmental trajectories differ by task (Welsh et al., 1991), EF functions can be documented in young children if developmentally appropriate measures are administered (Baron, 2002).

Current evidence suggests that executive processes emerge in infancy, as demonstrated by neuroimaging studies (Bell & Fox, 1992), and develop into early adulthood (Anderson, 1998; Diamond & Taylor, 1996; Epsy, 1997). However, the developmental profile of these skills is still unclear (Anderson, 2002). Dennis (1991) proposed three sequential stages of EF skill development: emerging (early stage acquisition), developing (partial use of skills), and established (full skill use). The stages describe how glimpses of EF skills are apparent across development, and how insight may not be functionally apparent until the skill is developmentally fully established.

Studies have provided evidence for an evolving functional state of the frontal lobes. The development of core frontal lobe skills are apparent as early as six to nine months (Diamond & Goldman-Rakic, 1986; Goldman-Rakic, 1985), with a marked improvement observed between the ages of 3 and 5 years (Diamond, 2002), and continued development through age 15 (Chelune & Baer, 1986; Levin et al., 1991; Passler et al., 1985). Success at different frontal lobe tasks were achieved at different age levels leading researchers (Dennis, 1991; Levin et al., 1991; Mateer and Williams, 1991; Welsh and Pennington, 1988) to evolve structural and developmental models of executive behavior.

Regulatory functions, such as the ability to start and inhibit behavior at will, are seen as structurally different from planning, goal formation, and conceptual processes in all of these models. Mateer and Williams (1991) further suggest the ability to inhibit motor responses and to selectively attend are early precursors of planning, problem solving, and goal attainment.

Among the first to attempt to empirically study EF skills in children from a neuropsychological perspective were Passler, Isaac, and Hynd (1985). Passler and colleagues used measures to assess prefrontal functioning that were adapted from Luria (1973). Results of the research suggest that children between the ages of 6 and 12 years of age were able to perform behaviors associated with the prefrontal lobes with varying degrees of success. Age related changes on EF tasks. Similarly, the effects of proactive and retroactive inhibition as well as echopraxic and perseverative tendencies were observed to decrease rapidly between the ages of 6 and 8 years, with no significant changes after the age of 10.

Chelune and Baer (1986) observed similar age trend results. In their seminal study on children's performance on the WCST, found that performance on the WCST improved most significantly between the ages of 6 and 8 with no significant changes after the age of 10.

Becker, Isaac, & Hynd (1987) investigated the development of children's non-verbal abilities as a method to regulate and to inhibit motoric actions. Consistent with Passler (1987), these investigators also observed age related changes in behaviors attributed to the frontal lobes.

Welsh, Pennington, and Grossier (1991) investigated performance on a battery of EF as a function of age. It was hypothesized that rudimentary forms of prefrontal behaviors would be observed in children when given a developmentally appropriate measure. Results were also consistent with Becker et al. (1987) and with Passler and colleagues (1985) in supporting the hypothesis that emerging childhood prefrontal skills solidified in stage-like fashion throughout development. Organized planning and planful behavior was detected as early as the age of six. More complex search behavior and hypothesis testing matured by age 10, and verbal fluency, motor sequencing, and complex planning abilities had not reached adult level performance by the age of 12. The greatest increments in EF development occurred between the ages 7 and 9 years, and between 11 and 12 years (Anderson et al., 1996).

Levin et al. (1991) research obtained similar results as Welsh and colleagues. Major differences were observed between the 7-8 year group and the 9-10 year group. However, increments were evident in the 9-12 year age group and the 13 to 15 year age group. Of note in Levin's study is the use of large age bands, which may explain why significant increase were observed in the higher ages than in other studies.

Korkman, Kemp, and Kirk (2001) obtained similar results when they attempted to measure the effects of age on the NEPSY, a neuropsychological battery for children. The results of this large sample study concluded that significant age effects were observed on the NEPSY subtests in the age range of 5 to 12 years. The age effects were most pronounced in the 5 to 8 year age range than in the 9 to 12 year age range. The 10 to 12 year age range was only significant for increases in fluency subtests. The developmental investigation of EF in this study reportedly suggests that greater increase in

neurocognitive test scores occur before age nine than after (Korkman et al. 2001). Moderate increases are reported after the age of nine, however these findings are currently somewhat variable (Korkman et al. 2001).

Research has suggested that specific challenges exist in understanding EF in children. The main challenge is that the development of these skills is rapid, and the EF development is thought to occur in spurts instead of a simple linear progression (Anderson, 2002). In addition, it appears that different skills may demonstrate differing developmental trajectories as well. Because EF processes rely on the integrity of the frontal lobe, and the physical maturation of this structure goes well into adulthood, it can be concluded that EF will not completely develop until beginning adulthood. Developmental models of EF have been derived from factor analytic studies from EF test batteries (Anderson, 2002).

Recently, researchers suggest that EF development proceeds sequentially from motor inhibition and impulse control to functions of selective and sustained attention, and finally EF of fluency (Barkley, 1997; Klenberg et al., 2001). These results reinforce the conclusion made by Welsh et al. (1991) that the first subfunctions of attentional and EFs to mature are motor inhibition and impulse control beginning at the age of six. Maturation of auditory and visual attention functions occur at the age of 10 years, and continue into adolescence with the development of fluency (Klenberg et al., 2001). These developmental findings also correspond with the neurocognitive hierarchy of perseverations, established by Goldberg & Tucker (1978), which describes a progression of perseverative behaviors from lower to higher order. Each level of the hierarchy represents a more pathological perseverative response.

What Are Disorders of EF?

The frontal lobes are a fragile component of the brain due to the interconnectedness and sensitivity to insult and brain disease. In a developmental framework, the frontal lobes have one of the longest “critical periods” of formation in which insult can be disruptive. Moreover, the effect of insult may not be readily apparent until the specific skill or function is developmentally required or mature. Additionally, the prefrontal cortex depends on the adequate formation of other brain structures. Damage to the frontal lobes produces single functional, behavioral and emotional deficits as well as multiple or synergistic functional deficits. Therefore, in an attempt to understand frontal lobe functioning, it is necessary to review specific frontal lobe syndromes and symptomatology that would indicate dysfunction.

Syndromes involving incapacity in planning and organizing behavior are collectively referred to as “executive deficits” (Luria, 1973). Executive deficits are found with damage to the prefrontal regions and in certain psychiatric syndromes. These deficits are quite debilitating, especially in social, behavioral and adaptive life functions. Various syndromes result from damage to the three subdivisions of the frontal lobes.

Executive Dysfunction

Executive Dysfunction (EDF) is not a unitary disorder (Gioia, 2001). A variety of presentations is possible as EDF represents deficits in one or more elements of EF (Anderson, 2002).

Dorsolateral prefrontal syndromes produce common symptoms including personality changes, field-dependent behavior, and perseverative behavior (Baars & Gage, 2010). The person exhibits a flat affect, which is characterized by monotone

speech and a sense of indifference. Insult to this region of the brain results in impairment in the ability to initiate as well as terminate, or change behavior. Inertia of initiation and termination is observed frequently in a variety of disorders of the frontal lobe including chronic schizophrenia.

Orbitofrontal syndromes are often characterized as the opposite of the dorsolateral syndrome. Patients are observed to be both behaviorally and emotionally disinhibited. Symptoms include diminished social insight as well as emotional and behavioral changes including distractibility and stimulus-driven behavior.

The final syndrome is referred to as the apathetic type, and is secondary to insult to the mediofrontal region of the prefrontal lobe. Damage to this area can diminish spontaneity, verbalization and motor behavior. Moreover, urinary incontinence, lower-extremity weakness and sensory loss, and increased response latency are also implicated.

In children, EDF symptoms include poor impulse control, difficulties monitoring or regulating performance, planning and organizational problems, poor reasoning ability, difficulties generating and/or implementing strategies, perseveration and mental inflexibility, poor utilization of feedback, and reduced working memory (Anderson, 2002). Often these symptoms are difficult to assess within a developmental context, as most of these behaviors are appropriate during infancy and early childhood. Children exhibiting EDF show significant behavioral variability thus complicating accurate diagnosis. Some will present as apathetic, unmotivated, and unresponsive, while others may display impulsivity and argumentativeness. Children with EDF also display poor interpersonal skills and experience difficulties creating and maintaining relationships (Anderson, 2002).

Perseveration

Although perseveration is a hallmark of lesions in the ventromedial area, and a common sign of frontal lobe pathology (Luria, 1973), it cannot be considered an exclusive manifestation of frontal lobe damage (Bidler et. al, 1987). More specifically, perseverative behavior may not signify the presence of prefrontal damage, but the presence of prefrontal damage most likely implies the presence of perseveration (Bidler et. al, 1987).

In contrast with the negative symptoms of frontal lobe pathology, productive symptoms, such as perseveration, are more prevalent and severe following prefrontal damage (Bidler & Goldberg, 1987). Additionally, these symptoms are thought to be more specific to frontal syndromes than the deficit syndromes commonly measured by standard psychometric tests (Bidler et. al, 1987).

Perseveration is defined as an abnormal repetition of a specific behavior and is characterized by the continuation, or recurrence, of a purposeful response which is more appropriate to a preceding stimulus than to the succeeding one which has just been given (Ford, 1991; Stuss & Benson, 1984).

Luria (1966) classified perseverative response into two types. The first is an efferent type that is characterized by the repeated occurrence of a response. This condition is thought to be more common with subcortical frontal lobe and basal ganglia pathology. The second type is one in which a response which is elicited under an initial stimulus continues when a second stimulus is presented, and is characterized by impaired switching from one action to another (Ford, 1991). This perseverative response is associated with posteriorly situated frontal lesions.

Perseverative behaviors are reported in diverse tasks including motor acts, verbalizations, sorting tests, drawings, writing, and tracking tests. When individuals engage in activity, they may continue the activity without stopping despite negative feedback. They may only start activity when prompted by others.

Perseveration is observed in many clinical disorders from purely neurological syndromes to strongly socially conditioned behavior (Ford, 1991). These disorders include schizophrenia, Tourette Syndrome, Obsessive Compulsive Disorder, catatonia, the hyperplexias, autistic spectrum disorders, as well as Pick’s disease, Alzheimer’s disease, vascular lesions.

However, perseverative behavior and stereotypies can also be part of normal behavior. For example, echolalia is a developmentally appropriate phenomenon until after the age of 3. At this point echolalia may be a manifestation of linguistic impairment (Ford, 1991). Figure 1 depicts the age in months in which the perseverative behavior is observed and by which task.

Age in Months	Task
9	A-not-B, delayed response, object retrieval
24	Invisible displacement, spatial conflict(Simon effect) Scale models,
30	deductive card sort
36	DCCS, Day-Night, tapping game, hand game
48	Flexible Item Selection Task (FIST)
72-144	Stroop Test, Wisconsin Card Sorting Test

Figure 2. Perseveration by Age and Measure

Bilder & Goldberg (1987) note that the phenomenon of perseveration is pervasive both in the horizontal sense and the vertical sense. Because perseveration is observed in nearly every domain of behavior and cognition such as motor behavior, visual search, verbal behavior and memory, it can be described as horizontal. A vertical description of

perseveration stems from the fact that perseveration can be observed at various levels of the neurocognitive hierarchy (Goldberg, 1986; Goldberg & Tucker, 1978; Luria, 1980).

According to the hierarchy of perseveration there are four distinct levels of perseveration beginning with the simplest hyperkinesias-like motor, and moving according to developmental complexity to perseveration of elements, perseveration of features, and perseveration of activities. Motor perseveration is a perseveration of a single motor act corresponding to a simple graphical element.

Field-dependent behaviors, such as echolalia and echopraxia, occur from damage to the left prefrontal cortex. This phenomenon occurs because there is too much plasticity and not enough stability and the person utilizes environmental cues in choosing a behavior. This phenomenon would be observed in the Graphical Sequences Test, Competing Programs, Motor Sequences, Stroop, and WCST as non-perseverative error.

Damage to the right prefrontal cortex results in productive executive control symptoms such as perseveration and stereotypies. These phenomena are produced when there is not enough plasticity and the area becomes too stable. This phenomenon is observed in the GST, Competing Programs, Motor Sequences, Stroop, and WCST as perseverative error.

Measures of field dependency include Stroop Interference, Manual Postures Mirroring, Echoes in conflict and Go/No-Go. Measures of stability include Perseveration on WCST, Graphical Sequences, Stereotypies on Graphical Sequences, conflict, go/no-go, Stability/Plasticity- Dimension test.

Emotional Disturbance

EF are also indicated in the regulation of emotions. Lesions in the orbitofrontal region produce poor impulse control and stimulus bound behavior (Mesulam, 1986). These areas have interconnections with the amygdala and hypothalamus. The emotional lability shown by individuals is often misinterpreted as mania with the most disturbing behavior is impulsive and short-lived aggression (Campbell, Duffy, Salloway, 2001). Emotional disturbances include laughing or crying in situations inappropriate to the emotion. The emotional response also appears superficial and variable as the person usually has no awareness that their emotional response is incorrect or extreme.

Similarly placed lesions in the right hemisphere rarely produce aphasia. They have been associated with disturbance in modulating the affective components of language (Grattan & Eslinger, 1991). These aspects speech are reflected in the coloring, melody, and cadence of speech as well as emotional gesturing that contribute to the ability to communicate emotion. This deficit has been proposed as “motor aprosodia” following lesions to the right dorsolateral frontal lobe (Ross & Rush, 1981).

Clinical Disorders

Executive impairments have been described in numerous childhood disorders such as attention-deficit/hyperactivity disorder (Barkley, Edwards, Laneri, Fletcher, & Metevia, 2001), autism (Bishop, 1993), pervasive developmental disorder (Pennington, 1997) bacterial meningitis (Taylor et al., 1996), learning disorders (Pennington et al., 1993), head injury, frontal lobe lesions, phenylketonuria (Welsh, Pennington, Ozonoff, Rouse & McCabe, 1990) and schizophrenia (Goldberg & Podell, 1993).

Behavioral disorders are also linked to EFs. For example, conduct disorder is associated with the pseudopsychopathic syndrome of orbitofrontal lesions; attention-deficit/hyperactivity disorder (ADHD) is linked to attention disorder and hyperkinesia; autism shares similarities with the apathetic syndrome; and Tourette syndrome is analogous to an inhibition deficit (Pennington, 1997). Because of the consistent presence of EF deficits in childhood psychopathology, researchers question whether EDF is a nonspecific result of psychopathology.

EDF is a very common result of traumatic brain injury from head trauma, stroke, or tumors. In addition, subcortical structure atrophy is indicated in persons with Huntington's disease (Owen, Sahakian, Semple, Polkey, & Robbins, 1995). Symptoms are also apparent in advanced cases of Alzheimer's disease.

Behaviors associated with prefrontal lobe functioning have been studied in children with ADHD, inattentive type. Similarities were investigated between differences in neuropsychological performance between a group of children with ADHD, inattentive type and a group of matched controls (Pineda, Ardila, Rosselli, Cadavid, Mancheno, & Mejia (1998). Results revealed deficits for the ADHD, inattentive type children, but not the matched controls on tests that measured inhibitory control. Age trends were also noted on the tasks and a possible maturational lag was postulated for functioning among those with ADHD, inattentive.

EF and IQ

The relationships between EF and IQ is unclear. Researchers have sought to discern the two constructs, however, this goal is complicated by the complexity of EF.

Although subjects with frontal lobe lesions may have extensive brain injury and numerous behavioral changes, they will typically score within the normal range on IQ tests (Milner, 1982; Damasio & Anderson, 1993). The cognitive impairment associated with frontal lobe lesions involve cognitive abilities that are not measured by conventional IQ (Hebb and Penfield, 1940). In addition, the structure, organization, and cadence of traditional IQ assessments are thought to compensate for a person's deficit in EF. These include impairment of hypothesis-testing and abstract reasoning, memory disorder, attention deficits and difficulty in initiation of cognitive activity.

The relationship between IQ and predictive validity of neuropsychological tests has been the topic of some controversy (Jung et al., 2000; Russell, 2001) as the relationship between IQ and EF is not strong. Historically, neuropsychological studies proposed that IQ and EF were not related. Early studies by Hebb (1945) demonstrated that intelligence quotient (IQ) in patients with frontal lobe damage could be normal. Milner (1983) reported a mean loss of 7.2 IQ points for individuals who underwent dorsolateral frontal lobectomies. Damasio and Anderson (1993) observations of brain injured patients suggested that psychometric intelligence tests are not sensitive to frontal lobe deficits as subjects with significant insult to the frontal lobes still produced average cognitive ability on measures of IQ.

In a developmental study completed by Welsh, Pennington, and Grosier (1991), most of the EF tasks were uncorrelated with IQ. However in a later study, Pennington, Grossier, and Welsh (1993) found moderate correlations between FSIQ and measures of EF (perseverative errors on WCST, percentage correct on the CPT). It is noted that the

results were derived from a combined clinical-control population which resulted in a skewed distribution of participants concerning EF functioning.

Schmitt and Wodrich's (2004) validity study of the NEPSY found that when IQ differences were statistically controlled, differences were not significant on the attention and executive domains on the NEPSY. Further, Hutton, Wilding, and Hudson (1997) found that measures from the Tests of Everyday Attention did not have significant correlations with IQ.

Murji & DeLuca (1998) found that full scale IQ from the WISC-III was not a factor in overall performance on the Tower of London when administered to a group of children aged 6 to 15 years with FSIQ greater than 80. Additionally, tests measuring IQ have correlations between .20 and .40 with measures of higher-level EF tests (Ardila, Pineda, & Rosselli, 2000). This suggests that about 4-16% of the variance for EF tests is accounted for by measures of IQ and basic level achievement (Delis, Kaplan, & Kramer, 2001). Ardila et al. (2000) found that performance on the WCST is not highly correlated with performance on the WISC-R. Their conclusions support the notion that IQ tests are not sensitive to executive control and planning.

More contemporary researchers have suggested that EFs may have a close relation with fluid intelligence (Salthouse, 2006). It was noted that EF had little discriminant validity because the variance common to EF variables was very strongly related to fluid reasoning (Salthouse, 2006). Some researchers argue that fluid intelligence may be more preserved from insult in adults and contend that certain EFs are related to IQ. Friedman, Miyake, Corley, Young, DeFries, Hewitt (2006) concluded that updating and working memory was most related to intelligence. These abilities involve

maintain attention to incorporate relevant information while disregarding irrelevant information.

Ardilla, Pineda & Roselli (2000) found that select components of IQ measures correlate with EF measures. Verbal fluency tests were found to correlate about 0.30 with Verbal Intelligence Quotient (IQ) and Full Scale IQ. The WCST Perseverative Errors negatively correlated with Verbal IQ and Full Scale IQ. Additionally, significant correlations were found with WISC-R Vocabulary subtest and Trails making Tests A, and Performance IQ correlated with Trail Making Tests B Time. The authors note that the results support the assumption that traditional intelligence tests are not appropriately evaluating executive functions.

Other researchers have posited a link between levels of intelligence and EF performance. Dodrill (1997; 1999) observed that while IQ scores below the average range are often correlated with a variety of neuropsychological measures, the same relationship is not present for individuals with above average IQ. In contrast to IQ tests, most neuropsychological tests measuring EF's were designed to measure deficits. Ardila, Pineda, Roselli. (2000), Arffa, Lovell, Podell, & Goldberg (1998), Baron (2003) and Mahone, Hagelthorn, Cutting, Schuerholtz, Pelletier, Rawlins (2002) found that EFs are significantly related to intelligence, especially when the sample contains high IQ individuals. A factor considered in this discussion is that neuropsychological measures are designed to reveal deficits. As such, ceiling effects may limit the correlation with IQ among subjects with above average IQ (Russell, 2001).

Salthouse et al. (2006) suggests that many variables thought to assess EF in adults are more directly related to reasoning and perceptual speed cognitive abilities. Further,

although nearly all of the EF variables were negatively related to age, statistical independence did not exist between age-related influence of EF and age-related influences on cognitive abilities (Salthouse et al, 2006). Crinella and Yu (2000) factor analysis on a sample of children with and without ADHD produced a modest correlation between g and EF factors. Therefore, EF accounted for a statistically significant amount of the variance in g.

Assessment Issues of EF

A major problem with the research on the development of attentional and executive functions is the lack of conceptual clarity (Klenberg, Korkman and Lahti-Nuutila, 2001). Test of EF tend to be chosen based on face validity (Kafer and Hunter, 1997), although construct validity data does not always support such a decision. The concepts of attention, executive function and memory overlap which makes the terminology confusing (Fletcher, 1998). This overlap becomes even more evident in a review of the research literature, including factor analytic studies, and in clinical assessment descriptions based on focused behavioral sampling (Baron, 2002). As a result, Baron (2002) claims that EF cannot always be discretely dissociated from other constructs, such as attention, information processing speed, or memory. This overlap between EF and other cognitive domains can seriously confound child clinical evaluation conclusions (Baron, 2002).

As Denkla (1996); Levin et al., (1991); and Taylor et al. (1996) demonstrate, EF tasks are factorially confounded, often measuring multiple cognitive functions. Simply ascribing factorially complex tasks to the frontal lobes does not convey the complexity of the tasks or the measure described as one of EF. The task complexity has led some

investigators to attempt to garner greater theoretical accuracy in the definition and operationalizing of tasks and constructs, often relying on the cognitive sciences such as developmental psychology, cognitive neuroscience, and neuropsychology (Dennis (1991), Roberts & Pennington, (1996). Other investigators have taken approaches that are more empirical, defining through conventional factor analysis (Levin et al. 1991, Taylor et al. 1996) or through clinical experience (Denckla, 1986). These practices result in two very general conclusions as illuminated by Fletcher (1996): (1) In the course of conducting research, EF require careful operationalization because precise definition has not been agreed upon, and (2) although measures of EF are factorially, empirically, or theoretically complex, the components can be separated and measured reliably, accurately, or adequately, for useful interpretation.

Also complicating the assessment of EF is the reliance of EF assessment measures on negative symptomatology.

Review of Factor Analytic Studies

A review of factor analytic studies helps to elucidate the variability in measures of EF. Welsh and colleagues (1991) revealed three similar factors: a speeded response factor termed Fluid and Speeded Response, an impulse control factor referred to as Hypothesis Testing and Impulse Control, and a third factor referred to as Planning. Similarity can be seen in comparison of Response Speed and the Focus-Execute factor proposed by Mirsky et al. (1991); Response Inhibition factor and their Encode factor; and Planning-Sequencing and their Shift factor (Taylor et al., 1996).

A variety of results are apparent in applying executive measures. Tasks such as the Tower of London (TOL) and WCST are multifactorial tasks that measure a variety of cognitive skills, not all of which are executive in nature (Fletcher, 1996).

In the previous decade, many investigators described problems with neuropsychological approaches to children that reflected excessive reliance on investigation of adults and the need to develop hypotheses and databases on disorders specific to children (Dennis, 1987; Fletcher & Taylor, 1984). The applications are driven by hypothetical models of cognition derived from research on the cognitive development of children. In other words, the tasks are not derived from tests created and normed on adults (Fletcher, 1996).

The Executive Control Battery

The battery consists of four subtests that can elicit appropriate functions of EF. The subtests are Graphical Sequences, Competing Programs, Manual Postures, and Motor Sequencing. The Graphical Sequences Test (GST) requires the subject is to draw graphical representations following verbal commands under time constraints. The test is designed to elicit four types of graphomotor perseverations. Hyperkinetic, or “motor” perseverations, is defined as the inability to stop a single elementary graphomotor component such as drawing a circle. The perseveration of elements category of includes the substitution, or addition, of a previously occurring part of an element, an entire element, or group of elements, for the current one. The intrusion may involve the incorporation of a component from a previous element with a current element, or it may involve complete replacement of an element with a previous element. The previous element or group of elements may have occurred earlier within an item, or in a preceding

item. The intrusion may be measurable in single units, or in stereotypic units or “strings”. It may involve the simple substitution of correct elements for incorrect ones, or it may result in the production of excessive elements reflecting interminability.

Perseveration of features occurs when specific features of a previous stimuli intrude upon the current response. For example, geometric figures have parameters of openness/closeness or straightness/curvedness and these features may be continued onto the next design. Perseveration of Activities is the highest level of the neurocognitive hierarchy in which there is an intrusion between semantic categories such as drawing pictures versus geometric designs or writing letters and words (Goldberg and Tucker, 1979). Each of these perseverations can be manifested in up to three different ways: simple, interminability, and stereotypic. This task takes 15 to 20 minutes to administer.

Competing Programs (CP) consists of executing various responses following commands whose physical characteristics are “in conflict” with desired responses (Goldberg, et. al., 1992). Two types of sequences are employed: a) simple conflict visual version and b) simple “go/no-go” version. The tendency of subjects with executive deficits is observed in the difficulty to inhibit responding (Goldberg, et. al., 1992). After responding in an imitative manner to the first command, the subject may tend to respond to the second command by imitation. This behavior is synonymous to echopraxia, which is appropriate in the first command, but inappropriate in response to the second. The subtest instructions require that task directives are repeated if an error is made. This subtest is designed to elicit various types of echopraxia and behavioral stereotypes (Luria, 1980). This task takes 12 to 15 minutes to administer.

Motor Sequencing (MS) requires rapid alteration of both simple uni-manual and bimanual motor sequences. Six types of sequences are employed including uni-manual two-stage movement, uni-manual two-stage movement reversal, uni-manual three-stage movement, bi-manual (reciprocal) coordination-distal, bi-manual (reciprocal) coordination- proximal, bi-manual (reciprocal) coordination- mixed (Goldberg, et. al., 2000). The task is designed to elicit various types of motor perseverations, stereotypes and other deficits of sequential organization (Luria, 1980). The breakdown of the kinetic organization of motor acts occurs when an individual is incapable of successfully transitioning between differing motor acts (Podell, 2008). The task takes 10 to 15 minutes to administer.

The final subtest is the Manual Postures (MP). This task is a more elaborate variant of the test developed by Henry Head (Luria, 1980, pp. 418-420) and involves imitations by the subject of various asymmetric static manual postures (both uni-manual and bi-manual) produced by the examiner who is facing the subject (Goldberg, et. al., 1992). The task assesses the subject's ability to relate egocentric and allocentric spaces (Goldberg, et al., 1992). Rosenkilde (1979) demonstrated that this ability is severely impaired following dorsolateral prefrontal lesions in monkeys. Luria (1980) describes this task as being designed to elicit various types of echopraxia and "mirroring" behavior.

The Manual Postures Test is reportedly a systematic examination of the phenomenon of echopraxia (Goldberg, 2000). The analysis of errors and the variety of task complexity creates the opportunity to delineate between the echopraxia and the visual-spatial impairment seen in parieto-occipital lesions (Goldberg, 2000). Testing of elemental functions, such as left-right discrimination, as well as thorough and

standardized retraining procedures have been incorporated to establish the specificity of task performance to frontal lobe functions. The authors note that persons with frontal lobe syndrome will be unable to apply retraining procedures and to maintain echopraxic-free performance for the duration of the test. The retraining procedures adopted in this test were designed to increase its specificity.

Performance, reportedly, may also be disrupted following damage to the callosal fibres, despite intact uni-manual performance. These tasks may additionally be sensitive to lateralized dysfunctions, in which case the hand contralateral to the dysfunction may lag behind the other or show isolated impairments. This task takes approximately 10 to 15 minutes to administer.

Each of the four subtests is designed to provide partial sampling of the same construct, but with different sensitivity/specificity ratios and somewhat different relationships to different variants of the executive dyscontrol syndrome (Goldberg, et. al., 1992). The ECB can assess a broad range of hierarchically ordered, positive indices of frontal lobe function, and therefore is preferable to the previously reviewed isolated experimental tasks and clinical instruments.

Perseveration in the ECB

A common sign of frontal lobe pathology is perseveration (Luria, 1973). Perseveration is defined as an abnormal repetition of a specific behavior and is characterized by the continuation, or recurrence, of a purposeful response which is more appropriate to a preceding stimulus than to the succeeding one which has just been given (Ford, 1991; Stuss & Benson, 1984). Perseverative behaviors are reported in diverse tasks including motor acts, verbalizations, sorting tests, drawings, writing, and tracking

tests. Bilder & Goldberg (1987) state that the phenomenon of perseveration is pervasive both in the horizontal sense and the vertical sense. Perseveration is observed in nearly every domain of behavior and cognition such as motor, visual search, verbal and memory behavior; it can be described as horizontal. A vertical description of perseveration stems from the fact that perseveration can be observed at various levels of the neurocognitive hierarchy (Goldberg, 1986; Goldberg & Tucker, 1978; Luria, 1980).

According to this hierarchy, there are four distinct levels of perseveration beginning with the simplest hyperkinesias-like motor, and moving according to developmental complexity to perseveration of elements, perseveration of features, and perseveration of activities. Motor perseveration is a perseveration of a single motor act corresponding to a simple graphical element.

Field-dependent behaviors, such as echolalia and echopraxia, occur from damage to the left prefrontal cortex (Goldberg, 1986). This phenomenon occurs because there is too much plasticity and not enough stability and the person utilizes environmental cues in choosing a behavior. This phenomenon would be observed in the Graphical Sequences Test, Competing Programs, Motor Sequences, Stroop, and WCST as non-perseverative error.

Damage to the right prefrontal cortex results in productive executive control symptoms such as perseveration and stereotypies (Goldberg, 1987). These phenomena are produced when there is not enough plasticity and the area becomes too stable. This phenomenon is observed in the GST, Competing Programs, Motor Sequences, Stroop, and WCST as perseverative error.

Measures of field dependency include Stroop Interference, Manual Postures Mirroring, Echoes in conflict and Go/No-Go. Measures of stability include Perseveration on WCST, Graphical Sequences, Stereotypies on Graphical Sequences, conflict, go/no-go. Stability/Plasticity- Dimension test.

Luria (1980) credits Head with the observation that frontal lobe persons “mirror” the movements of an examiner sitting opposite when instructed to copy their movements. This situation creates a conflict between the visual image and the verbal instructions, which require a crossing over of the visual input (i.e. the positions of the subject’s right hand must be the same as that of the examiner’s right hand). Correct performance thus requires the inhibition of a motor response followed by the recoding of the visual signal prior to response execution (Goldberg, 1986).

Impairment in this behavior can also be associated with lesions of the parieto-occipital area; however the nature of the error is different (Goldberg, 1986). In the case of parieto-occipital lesions, responses tend to break down at much more fundamental levels; i.e. vertical, horizontal, distal and proximal directions are confused leading to complex errors. Impairments associated with the frontal syndrome are specifically and almost exclusively seen as mirroring or echopraxia (Goldberg, 1986). The visual image is so compelling, and the recoding or complex spatial analysis required poses such an insurmountable problem, which an echopractic person fails to correct their mirror response patterns even after a detailed analysis of his errors is provided. Training is reportedly of little help. People with a mild impairment may adopt a strategy of verbal recoding which reduces the apparent severity of the syndrome.

ECB Data in Adults

The ECB was originally normed on an adult clinical population with diagnoses of schizophrenia, focal frontal lesions, traumatic brain injury and healthy controls. Of the 133 subjects, 43 were females and 90 males. Podell et al. (2000) have established that both echopraxia, or field dependency, and perseveration are highly prevalent in chronic schizophrenics. They argue that EC deficits are multidimensional, consisting of several behavioral components.

Table 1 represents the demographic variables for the healthy control (HC) and clinical populations. The HC group consisted of individuals without a history of neurological disorder, TBI, psychiatric symptoms/treatment or ETOH/substance abuse (DSM-III criteria). The schizophrenic group was diagnosed using DSM-III criteria and

Table 1. Mean and standard deviation for subject demographic variables for The Executive Control Battery in adults

Male	n	Age	Education	Full Scale IQ*
Healthy Control	23	32.0 (6.2)	12.5 (1.4)	101.5 (11.2)
Left Frontal	7	41.1 (12.1)	12.3 (3.3)	82.4 (7.1)
Right Frontal	6	63.8 (8.4)	11.3 (2.9)	83.0 (8.7)
Bifrontal	4	35.5 (12.4)	15.7 (4.5)	89.5 (19.2)
Schizophrenic	21	31.7 (6.8)	12.5 (2.0)	89.9 (8.8)
TBI	29	28.7 (11.3)	12.0 (1.9)	91.2 (12.5)
Female				
Healthy Control	9	30.3 (6.6)	12.8 (2.2)	98.3 (14.7)
Left Frontal	4	32.2 (10.9)	13.5 (3.0)	89.3 (17.7)
Right Frontal	4	32.2 (5.0)	13.5 (3.0)	94.5 (9.5)

Schizophrenic	8	34.6 (6.1)	11.4 (1.6)	73.1 (10.9)
TBI	18	28.1 (9.9)	13.1 (2.4)	95.1 (18.3)

*Wechsler Adult Intelligence Scale- Revised prorated four subtest Full Scale IQ.

consisted of both chronic, institutionalized and outpatient adults. All schizophrenic subjects were reportedly without focal neurological disorder or significant TBI (Goldberg, et al., 2000). The TBI group included individuals admitted to a large urban trauma center for TBI, with and without loss of consciousness. All TBI subjects were tested within 48 hours of injury. The frontal focal lesion group consisted of subjects with MRI and CT scans demonstrable adult onset parenchymal lesions involving either dorsolateral or orbitofrontal prefrontal cortex (anterior to motor cortex). Frontal focal lesion subjects were without histories of psychiatric symptoms/treatment prior TBI, neurologic disorder or ETOH/substance abuse (Podell et al. 2000).

Table 2. Mean and Standard Deviation for Executive Control Battery Subtest Error Scores in healthy control, focal frontal, schizophrenic, and traumatic brain injured male and female subjects.

	n	Graphical Sequences Perseveration	Manual Postures Mirroring	Competing Programs Mirroring	Competing Programs Perseverations
Male					
Healthy Control	23	2.5 (2.1)	1.4 (1.8)	0.5 (0.1)	0.1 (0.3)
Left Frontal	7	15.3 (5.2)	4.1 (3.8)	3.4 (3.3)	1.0 (1.4)
Right Frontal	6	8.7 (9.4)	9.0 (7.1)	4.8 (7.5)	0.3 (0.5)
Bifrontal	4	5.8 (4.2)	4.3 (4.3)	0.5 (1.0)	0.3 (0.5)
Schizophrenic	21	9.1 (7.1)	4.9 (3.9)	5.6 (7.4)	1.1 (1.0)
TBI	29	5.2 (5.6)	4.3 (4.0)	4.4 (5.0)	0.8(0.81)

Female					
Healthy Control	9	3.7 (2.0)	0.7(0.7)	.02 (0.4)	0.0 (0.0)
Left Frontal	4	5.0 (11.8)	3.0 (3.2)	4.3 (7.5)	2.0 (2.0)
Right Frontal	4	6.8 (3.7)	1.8 (1.3)	2.0 (1.7)	2.0 (1.9)
Schizophrenic	8	15.6 (11.1)	9.0 (1.9)	7.2 (6.1)	0.8 (0.8)
TBI	18	2.9 (2.5)	3.7 (3.9)	4.2 (4.2)	0.8 (1.1)

Table 2 displays the mean and standard deviation of subtest perseverations. Podell (2009) notes that the healthy controls made very little errors. Additionally, the means were often close to the standard deviations suggesting that not all subjects had productive errors.

Measures on the ECB have demonstrated good discrimination between healthy controls and various adult clinical groups. Podell et al. (1992) found the number of perseverative responses from the Graphical Sequence Subtest (GST) was as accurate as the WCST in discriminating healthy control versus persons with frontal focal lesions or schizophrenia. The GST, number of perseverative responses, was 83.3% accurate in discriminating between healthy control and a focal frontal lesion and schizophrenia groups. The WCST perseverative responses were 83.3% and 81.5% correct when discriminating between groups. Although GST and WCST were highly similar in classification rates, GST was 100% accurate in classifying healthy control subjects while the WCST perseverative responses were not.

In a related study (Podell et al., 1993), the four measures from the ECB were grouped into perseverative responses on the GST and Competing Programs subtest and field-dependent responses (mirroring errors on Manual Postures and Competing

Programs Subtests). Both the frontal focal and schizophrenic groups made significantly more perseverative and field-dependent responses than the healthy controls. To show that the four measures from the ECB were dissociable and comprised perseverative and field-dependent domains, they were submitted to confirmatory factor analysis using a predicted two-factor model. The factor loading, using varimax rotation, reportedly shows a distinct dissociation between variables considered perseverative and field-dependent. Factor 1, perseveration, loaded .89 around Graphical Sequences and .76 around Competing Programs, whereas it loaded .08 around Manual Postures and .26 around Motor Sequences.

The Manual Postures Test (MP) has demonstrated to be a highly sensitive test of executive deficits in clinical populations including focal frontal lesions, schizophrenia and traumatic brain injury. Podell and Lovell (1999) demonstrated that mirroring errors on MP were greater in persons with focal frontal lesions or schizophrenia compared to healthy controls, but did not differ from each other. In addition, MP mirroring errors were as accurate as perseverative errors on the WCST in discriminating between healthy controls and either frontal focal lesions or schizophrenia. Overall, MP was 80% accurate in classification and WCST was 81.3% accurate. Furthermore, discriminability between the healthy controls and the two clinical groups improved when both mirroring errors on the MP and perseverative responses on WCST were combined (84.1% classification accuracy).

Podell et al., (2000) furthered this research and confirmed that persons with traumatic brain injury exhibited significant field-dependency (and perseveration) as part of their executive control deficit. Their study concluded that: 1) the traumatic brain

injury group was more field-dependent than they were perseverative; and 2) the number of mirroring deficits on Manual Postures Subtests, utilizing step-wise linear regression, was the most, and highly accurate measure of field-dependency (2000).

Goldberg, et al. (1999) maintains that discrimination between schizophrenia and frontal focal lesions has historically been poor. Because executive dyscontrol is prevalent in a variety of clinical CNS and psychiatric disorders, a priori differences on test performance were not expected (Goldberg et al., 1999). The schizophrenic group tended to be the most impaired, however, this may be due to the severity and chronicity of the sample. Perfect discernability was reportedly not expected between healthy control and clinical groups as not all subjects, especially in mild traumatic brain injury, experienced executive deficits. Goldberg et al. (1999) maintain that the fact that Type I errors, or false positives, were minimal indicates that impaired performance on the ECB variables strongly implies the presence of true executive control deficits.

Lamar et al. (1997) conducted an additional study utilizing the GST on elderly subjects with Alzheimer's Dementia and ischemic cerebrovascular dementia. Significant graphomotor perseveration was demonstrated in both groups.

Test-retest studies were not performed with any of the ECB subtests. Goldberg and colleagues contend that the inherent variability in the expression of executive dyscontrol will artificially decrease the correlation and therefore render it meaningless (2000). The possibility of practice effect is strong which would render such correlation useless. These types of analysis are not common among tests of executive dyscontrol.

Basic inter-rater reliability studies were performed for GST and MP. The inter-rater reliabilities for the total number of perseverative errors on GST for the two sets of

trained raters were reported to be Cronbach alpha = 0.94 and 0.98 (Jaeger et al., 1987). However, it is noted that the inter-rater reliability was not as high for classifying type of perseveration. Inter-rater reliability for echopraxic errors on MP was perfect ($r=1.0$) between two raters assessing 15 persons in the elderly groups.

CHAPTER III: METHOD

Participants

The existing data set includes subjects that have been sampled from seven different public and private schools in metropolitan Pittsburgh (Falk School, Moon Township Middle School, Baldwin-Whitehall Elementary School, Mt. Lebanon Elementary School, St. James, St. Joseph's, and Immaculate Conception). The database and all associated procedures for data entry have been approved by the Institutional Review Board of Allegheny General Hospital. Parents completed informed consent procedures for assessment prior to the initiation of evaluation. Identifying information was removed from all data prior to entry into the database.

Equal numbers of male and females were sampled including low, average, above average and superior intellectual ranges in each age range from 5-16. With a minimum of 5 subjects per age group, 158 subjects were collected.

Demographics gathered included parent's occupation and educational level, and child history variables including history of medical and neurological problems, emotional problems, physical disability, and history of special education. Any child suspected of central nervous system disease, a history of severe emotional or education problems, or with a physical disability interfering with the ability to master the tasks were excluded. Children with IQ's below 80 were not included in the study as this may suggest central nervous system dysfunction.

Measures

The Wechsler Intelligence Scale for Children-III (WISC-III)

The Wechsler Intelligence Scale for Children-III (WISC-III, Wechsler, 1991) was administered to all subjects to assess IQ. This version of the WISC is standardized for children from age 6 to 16.

The test is divided into two main sections. The Verbal Scale measures language expression, comprehension, listening, and the ability to apply these skills to solving problems. The examiner gives the questions orally, and the child gives a spoken response. The Performance Scale assesses nonverbal problem solving, perceptual organization, speed, and visual-motor proficiency. Included are tasks like puzzles, analysis of pictures, imitating designs with blocks, and copying.

Within the Verbal Scale are the following subtests and what they measure: Information measures a child's range of factual information; Similarities- ability to categorize; Arithmetic- ability to solve computational math problems; Vocabulary- ability to define words; Comprehension- ability to answer common sense questions; Digit Span- short-term auditory memory. Within the Performance Scale are the following subtests and what they measure: Picture Completion- identifying what is missing in various pictures; Coding- learning a code through visual rote learning; Picture Arrangement- story sequencing; Block Design- pattern construction skills – or similar; Object Assembly- construction skills using puzzles.

The normative sample for the WISC-III was large (N = 2,200) and reportedly representative of 1988 U.S. Census data. Subtest reliabilities (expressed as internal consistencies for all but the speeded subtests of Symbol Search and Coding) are

considered moderate to excellent (.61 to .92). The consistency of IQs and Indexes is reportedly very good to excellent (.80 to .97). Subtest stability coefficients, based on 353 children subdivided into three age groups, are adequate (.56 to .89). IQ and Index stability is reportedly generally good to excellent (.74 to .95; only one coefficient is below .80). The adequacy of the instrument is conveyed by the technical data provided by the manual. Inter-rater reliabilities for selected Verbal Scale subtests are reportedly excellent (all greater than .92).

The WISC-III boasts a substantial body of research addressing its validity. WISC-III distinguishes normal from clinical populations i.e. neurologic and TBI. Three categories of validity reviewed are factorial validity, convergent-divergent validity, and predictive validity.

The WISC-III factor structure is largely congruent with a four-factor hierarchical model (i.e., Full Scale IQs estimate broad intelligence, with Verbal Comprehension (VC), Perceptual Organization (PO), Freedom From Distractibility (FFD), and Processing Speed (PS) subfactors). Factor analyses using orthogonal rotation or confirmatory procedures from the normative sample (Wechsler, 1991) support the four-factor "Index" model. However, hierarchical factor analyses cast doubt on the composition, stability, and uniqueness of indexes (Carroll, 1993). The confirmatory factor analyses presented in the manual are not entirely consistent in yielding a four-factor solution.

The manual reports strong correlations between WISC-III metrics and comparable metrics from the WPPSI-R, WISC-R, WAIS-R, Otis-Lennon School Ability Test, and

Differential Ability Scales (correlations between WISC-III IQ's and comparable composites range from .59 to .92).

Studies reported in the manual describe lower correlations among noncomparable metrics (e.g., the WISC-III PS and the Peabody Picture Vocabulary Test--Revised). Taken together, these data attest to the convergent and divergent validity of the WISC-III.

Studies presented in the manual and subsequent publications support the ability of the WISC-III to predict related outcomes. The most important of these is academic achievement in children. The WISC-III manual reports appropriate correlations with achievement (pp. 204-209), and studies published since test publication also report appropriate IQ-achievement correlations in children representing normal (Weiss, Prifitera, & Roid, 1993) and learning disabled (Slate, Jones, Graham, and Bower, 1994).

Wide Range Achievement Test

The WRAT-3 is a brief screening measure of academic achievement that measures reading recognition, spelling, and arithmetic. There are three alternate forms to administer and corresponding norms for each. The manual notes that the WRAT-3 takes 15 to 30 minutes to administer. It contains very easy beginning items (letter reading, basic counting, and dictation of letters) followed by spelling, pronouncing words, and written math problems.

A national stratified sample design was employed. The test makers gathered 4433 participants from 23 age groups across 4 regions of the United States. Ethnicity of participants included 71.1% White, 13.6% Black, 10.7% Hispanic (English speaking), and 3.9% Other. The test authors attempted to match the 1990 census data.

Four measures of internal consistency were obtained on the WRAT3. The median test coefficient alphas range from .85 to .95 across the 9 WRAT3 subtests. For the three combined subtests, the reported range is from .92 to .95.

Alternate forms correlation was also explored with an alternate form for each of the academic tests. Correlations over the 23 age groups produced a reading correlation of .87 to .99 with a median correlation of .92. The arithmetic range is .82 to .99 with a median of .89. The alternate form correlations for the WRAT3 suggest overall reliability of the instrument. Stability of the WRAT3 was measured utilizing test-retest reliability. Corrected stability coefficients range are .91 or better on a relatively sample of 142 individuals.

Test validity indicates that raw scores increase with age. Additionally, reading and spelling are highly correlated, and arithmetic correlates poorly with the other two measures. Reading and spelling correlate .65 to .72 with WISC III Verbal IQs. Correlations with Vocabulary are .64. Arithmetic correlates .65 to .74 with WISC III FSIQ, VIQ, and PIQ. Correlation with Arithmetic is only .66 with WISC III. WAIS III correlations are notably weaker. Correlations to other achievement tests are in the .50s to .70s (California Achievement Test and Stanford Achievement Test) and .60s to .80s (California Test of Basic Skills)

Wisconsin Card Sorting Test

The Wisconsin Card Sorting Test (WCST; Heaton, 1981) is one of the most notable assessments for EF and was developed as a measure of “flexibility in thinking” (Berg, 1948). It is widely recognized as a measure of concept generation, cognitive set shifting, the ability to inhibit prepotent responses, attribute identification, abstract

reasoning, hypothesis testing, problem solving and selective attention (Barone, 2004).

The WCST has been established as a measure of frontal lobe function.

The WCST consists of four stimulus cards and two sets of 64 response cards that depict four forms (circle, crosses, triangles, and stars), four colors (red, yellow, blue, and green), and four numbers (one, two, three, and four). Adequate performance on the test requires that the examinee determine the correct sorting principle and maintain that set across changing stimulus conditions. Failure to maintain the set or perseveration on an older, and ineffective, principle is taken into consideration in the scoring. The criterion is six complete sorts or until all 128 cards are attempted. Scoring is comprised of perseverative responses, perseverative errors, and failure to maintain set. The procedures for administering the test are standardized, and the same instructions are considered adequate for children and adults. The authors, however, suggest that examiners introduce the test as a "game" to young children.

Chelune and Baer (1986) developed normative data with children and concluded that children's performance on the test was indistinguishable from adults by the time they reached ten years of age. Although studies have demonstrated the WCST's effectiveness in identifying frontal lobe dysfunction in adults (Milner, 1963), studies with children have demonstrated mixed results. Developmental variables make adult measures difficult to apply to children.

Although the WCST is one of the standard, clinical measures of EF, there are disadvantages in its clinical application. The first disadvantage is that it requires lengthy administration, especially for severely impaired persons, and can be stressful for the examinee receiving continuous negative feedback. Secondly, the WCST only measures

negative deficits, and is also at times difficult to interpret and correctly score responses. The examinee may also have difficulty understanding the directions or lack thereof. The WCST has received criticism for its use with children because it is a downward extension of an adult test.

The revised Wisconsin Card Sorting Test was normed on a group of 899 "normal" subjects between the ages 6.5 to 89 years (Heaton, 1978). The 899 subjects were drawn from six distinct samples. To correct for irregularities in the distribution of scores, continuous norming was used to derive norms for a census-matched sample of the entire normative group. Regression analysis showed a significant quadratic effect for age on all WCST variables. Scores improved with age between ages 6.5 and 19 and then tended to be stable throughout most of adulthood. Performance declines after age 60.

Gender was not significantly related to performance. According to the manual, the majority of subjects in the norming groups were selected from the southeastern and southwestern-Rocky Mountain regions of the United States. Data pertaining to race were reported in only one sample, a group of 379 children from an urban setting in the southeast. No race data were provided for the remaining subjects, and no socioeconomic data were included for any subjects. Gender data were provided, and for the most part, evenly distributed. Age and education data were also provided; however, the mean age of the child and adolescent samples was not given.

The mean age of the 384 adult subjects (i.e., 20 years and older) was noted to be 49.89 with a standard deviation (SD) of 17.94. The data were compared to the 1995 census data and showed an underrepresentation of younger adults, and an overrepresentation of older adults. The analyses of the normative data showed that the

demographic variable with the greatest relationship to WCST performance was age. The data indicate that individuals with higher levels of education perform better on the WCST.

Reliability data reported in the manual pertain to inter-scorer and intra-scorer agreement for the child-adolescent and adult samples, and generalizability coefficients and standard error of measurement values for the child and adolescent data only. The inter-scorer and intra-scorer reliability studies reported in the manual were conducted with 30 adult psychiatric inpatients. The first study used experienced clinicians and showed a range of inter-scorer reliability between .88 and .93 and a range of intra-scorer coefficients between .91 to .96. Coefficients found for novice examiners were also adequate (i.e., coefficients ranged from .75 to .97 for both inter- and intra-scorer data). Similar data were obtained for a sample of children and adolescents. With the exception of the Learning to Learn score, inter-scorer coefficients ranged from .90 to 1.00 (the Learning to Learn coefficient was .66). Intra-scorer coefficients for the same set of data ranged from .83 to 1.00.

Reliability was further evaluated through a study design based on Cronbach's generalizability theory (Cronbach, Glaser, Nanda, and Rajaratnam, 1972). Generalizability coefficients, intended to assess how well the instrument measures a subject's true score, were calculated for the child and adolescent data only. Subjects were 46 children and adolescents tested twice over the span of a month. Based on a single test administration, generalizability coefficients ranged from .39 to .72, with a mean of .57 and median of .60. Previous authors had suggested that coefficients of .60 or better are considered good. Using this criterion, most of the WCST scores showed good reliability

evidence. Scores for the Percent Perseverative Responses and Percent Perseverative Errors had lower reliability estimates. Standard errors of measurement are provided for most WCST scores, but only for this subsample.

Standard errors of measurement (SEM) were also calculated for the child and adolescent "reliability sample." These data are provided in the manual for each of the WCST standard scores (i.e., scores with a mean of 100 and SD of 15). Because the sample was "normal," further data are needed to determine what the SEMs would be for a clinical group of children and adolescents, as well as for a clinical and normal group of adults.

A number of validity studies, in particular, correlational and discriminant function analyses were described in the manual. The data from these studies support the use of the WCST for a variety of neurological and psychological problems, and with a variety of populations. Studies of adults with closed head injuries, demyelinating diseases, seizure disorders, and schizophrenia, and children with traumatic brain injuries (TBI), seizures, learning disabilities (LD), and attention deficit hyperactivity disorders (ADHD) indicate that the WCST may be useful in assessing "executive functions" in these groups. Data provided in the manual and in the research literature suggest that the WCST is also sensitive to dysfunction in other areas of the brain.

Stroop Color-Word Test

The Stroop Color Word Test (SCWT; Golden, 1978) is a brief measure of selective or focused attention, the ability to shift from one perceptual set to another as test requirement change, and the ability to inhibit responding (Barone, 2004). The Stroop

procedure requires the child to inhibit a pre-potent, well learned verbal response when faced with a novel one.

The Stroop Color Word Test (SCWT; Golden, 1978) is a three-color version (blue, red, green). There are three 100 item pages, one each for three 45-second trials of word reading of black typed words, color naming of “XXXX” in randomized color sequences, and color naming when the words are printed in nonmatching colored ink: the word “red” is printed in green ink, and the correct response is “green.” The child reads down columns of stimuli on each trial. If the last column is completed before

Construct validity is confounded by multiple demands inherent in the task such as response inhibition, response shifting, sustaining attention, selective visual attention reading level, and naming ability (Baron, 2004). The Stroop Interference Test is clearly a verbal measure and as Cox et al. (1995) found in their study among adults, reading and word identification skills influenced the interpretation of Stroop interference scores. Reading proficiency has been found to affect the construct validity of the Stroop interference score. Therefore, as Denkla (1996) posits, levels of literacy are crucial to making meaningful statements about the ability to inhibit responses on the Stroop test.

Reliabilities are reported for both the group form and individualized form of the Stroop, and generally range from a low of .69 to a high of .89. No significant differences are reported between administration formats. Test-retest reliability was .90, .83, and .91, respectively, for each of the three parts (word reading, color naming, color-word interference) when a 1-month interval existed between tests (Spren and Strauss, 1998). The Stroop effect has been documented in the literature as being a valid and reliable factor associated with a multitude of cognitive and behavioral domains.

Research Design

The research battery was structured utilizing a counterbalanced design in order to avoid confounding of order and presentation of task. Reliability studies were completed utilizing Cronbach's alpha for internal consistency and intra-class correlation coefficient for inter-rater reliability. This study also utilized a hierarchical multiple regression research design to determine convergent and divergent validity. The dependent variable is the total perseverative errors on Graphical Sequences, Competing Programs, Manual Postures, and Motor Sequences. The independent variable is WCST Perseverative Errors Scaled Score, Stroop Color Standard Score, Word Standard Score, and Color Word Standard Score, Full Scale IQ, and WRAT-R Reading Standard Score, and Arithmetic Standard Score.

Procedure

Data was entered into SPSS 17.0 for windows. Descriptive statistics (i.e., means, standard deviations, frequencies, and percentages) were calculated for demographic data and research variables. Reliability was computed using Cronbach's alpha as well as intra-class correlation coefficients. Inferential statistics were computed using multiple regression to determine convergent and predictive validity. The assumptions of regression, linearity, constant variance, and multicollinearity were assessed.

Research Questions and Hypothesis

The first research question explored a normative analysis and creation of tables of the study data. (1a) *How much variance will be obtained when the ECB is administered to a sample of children?* The mean and standard deviations of perseverative errors were

examined. It was hypothesized that the developmental progression of EF will result in adequate variance of the ECB in a sample of children.

The second research question addressed the reliability of the ECB scoring. (2a) *Is there consistency of measurement in each ECB subtest?* Utilizing Cronbach's alpha, internal consistency was established for each subtest of the ECB. Adult literature on the ECB noted that test-retest studies were not performed with any of the ECB subtests. Goldberg and colleagues maintain that the inherent variability in the expression of executive dyscontrol will artificially decrease the correlation and therefore render it meaningless (2000). The possibility of practice effect is strong which would render such correlation useless.

The third research question determined inter-rater reliability on the Graphical Sequences subtest. (3a) *Does Graphical Sequences have adequate inter-rater reliability? Will there be concordance in the degree of agreement among raters who administer the Graphical Sequences subtest to children?* The reported inter-rater reliabilities for the total number of perseverative errors on GST for the two sets of trained raters were reported to be .94 and .98 (Jaeger et al., 1992). However, it is noted that the inter-rater reliability was not as high for classifying type of perseveration. It was hypothesized that adequate agreement will be established among raters who administer the Graphical Sequences Test to children.

The fourth research question seeks to establish convergent validity with the four ECB subtests and other measures of EF (WCST perseverative and nonperseverative errors and Stroop). (4a) *What is the relationship between the ECB subtests and other measures of EF?* Through the use of a hierarchical multiple regression analysis, it was

hypothesized that the subtests of the ECB will moderately correlate with established measures of EF (WCST and Stroop Color Word).

The final research question sought to explore the predictive validity of the ECB. *(5a) Does performance on the ECB predict outcomes on general measures of cognitive ability and achievement.* Again, a multiple regression analysis was conducted with the four subtests of the ECB and FSIQ, and reading and math achievement scores. It was hypothesized that the performance on the ECB will be negatively correlated with IQ and achievement- that is; children of higher cognitive, reading and mathematics ability will make a lower percentage of perseverative errors. Additionally, one would contend that intact EF would be necessary to obtain a high level of cognitive and academic ability.

CHAPTER IV: RESULTS

This chapter presents the findings of statistical analyses that were conducted to examine this study's five research questions. The primary objective of the research study is to examine normative data of the ECB and its four respective subtests in children. This was accomplished by determining if adequate variance was obtained on the four ECB subtests. Next, reliability data were examined through internal consistency and inter-rater reliability analyses. Finally, the ECB subtests were compared to other measures of EF (Stroop, WCST) as well as non-EF measures (WISC-III, WRAT-R) via multiple regression. Prior to running these analyses, descriptive statistics were obtained and preliminary analyses were conducted in order to evaluate statistical assumptions.

Descriptive Statistics

Demographic and frequency data are presented in Table 3 and Table 4. Participants are closely divided between sex with 48.1% male, and 51.9% female participants. The sample is 97% Caucasian. The age range for the sample is 5 years to 16 years. The ages of 8 to 12 account for 67.8% of the sample with the overall mean age as 10.53 years.

Table 3. Descriptive Statistics

Sex	Frequency	Percent
Male	77	48.1
Female	83	51.9

Ethnicity		
Caucasian	154	96.3
African-American	1	.6
Other	5	3

Table 4. Age in Years for Entire Sample

Age	Frequency	Percent
5	1	.6
6	13	8.2
7	10	6.3
8	18	11.3
9	28	17.6
10	22	13.8
11	19	11.9
12	21	13.2
13	13	8.2
14	11	6.9
15	2	1.2
16	1	.6

Table 5. Parent Education

Father

Education	Frequency	Percent
Did not graduate HS	1	.7
Completed HS	27	18.4
Some College	25	17.0
Completed College	37	25.2
Some Graduate School	7	4.8
Masters Degree	18	12.2
Advance Degree	32	21.8

Mother

Education	Frequency	Percent
Did not graduate HS	3	2.0
Completed HS	14	9.9
Some College	31	21.2
Completed College	38	26.0
Some Graduate School	11	7.5
Masters Degree	23	15.7
Advance Degree	25	17.1

Parent education data as reported in Table 5 indicates 59.2% of the subject's fathers completed college and obtained an advance degree. Further, 58.8% of the subject's mother's completed college and also obtained an advanced degree.

Preliminary Analysis for Statistical Assumptions

Preliminary analysis assures that any potential third variables that significantly associate with the primary dependent variables are identified prior to running the main analysis (Tabachnick & Fidell, 2001). Therefore, the total numbers of parent demographics were examined in order to identify possible correlations with the dependent variables. The examined demographic variables are: parent ethnicity (African American, Caucasian, or Other), education level of father/mother (Did not graduate high school, Completed high school, Some college, Completed college, Some graduate school, Masters degree, or Advance Degree), and parent marital status.

Because the demographic information is categorical, Phi correlation analysis was used for intercorrelations among categorical variables and Point-biserial for correlations between continuous and dichotomous variables. Table 6 presents the results.

Demographic data do not significantly correlate with any of the dependent variables.

Amongst the demographic variables, there are two significant correlations at the $p < .01$ level. Parent Education of Father correlates significantly with Parent Education of Mother. A significant negative correlation was observed between Parent Education of Father and Parent Marital Status.

There are five significant correlations present when examining the dependent variables at the $p < .01$ level. Graphical Sequences correlates with Manual Postures, Competing Programs and Motor Sequences Total Errors. Manual Postures correlates with Motor Sequences, and Competing Programs correlates with Motor Sequences. Competing Programs correlates with Manual Postures at the $p < 0.05$ level. Additionally, significant negative correlations were present at the $p < .01$ level between age and

Table 6. Point-Biserial and Phi Correlations of Demographics and Dependent Variables: Total Errors on ECB Subtests

	Parent Ethnicity	Parent Ed. of Father	Parent Ed. of Mother	Parent Marital Status	GST	MP	CP	MS	Age
Parent Ethnicity	1	.134	-.127	.055	.017	-.017	-.092	-.084	-.014
Parent Ed. of Father		1	.360**	-.414**	.093	.027	.115	-.029	-.103
Parent Ed. of Mother			1	-.049	.077	.067	-.084	.042	-.046
Parent Marital Status				1	.167	-.052	-.067	-.078	-.031
GST Total Errors					1	.313**	.367**	.366**	-.224**
MP Total Errors						1	.199*	.310**	-.234**
CP Total Errors							1	.270**	-.236**
MS Total Errors								1	-.157
Age									1

Note. * Significant at the 0.05 level (2-tailed), ** significant at the 0.01 level (2-tailed). Parent Ed. of Father = Parent Education of Father, Parent Ed. of Mother = Parent Education of Mother, GST= Graphical Sequences Test, MP= Manual Postures, CP= Competing Programs, MS= Motor Sequences.

Graphical Sequences Total Errors, Manual Postures Total Errors, and Competing Programs Total Errors. Age did not correlate with Motor Sequences.

Missing Data

Participants and their parents met with research evaluators and were required to sign consent and assent forms. The informed consent forms and discussion clearly delineated that participants may choose to end participation at any time during the assessment. Therefore, it is likely that not all subtests were given to study participants. In addition, giving children lengthy assessment batteries can be difficult and frustrating for the subject. The research evaluators were instructed to discontinue testing if subject burden, or fatigue, appeared to affect assessment results. This condition will also likely contribute to possible missing data.

The missing data is considered missing at random. A counterbalanced design was employed so that variables were not confounded due to order of presentation. Table 7 displays missing data for both independent and dependent variables. The missing data were managed by listwise deletion during analysis.

Table 7. Missing Data for Dependent and Independent Variables

<u>IV</u>	<u>n</u>	<u>% Missing Data</u>
Wisconsin Card Sorting # Perseverative Errors	112	27
Stroop Color	144	7
Stroop Word	144	7
Stroop Color Word	144	7
WISC-III FSIQ	144	7
WRAT-R Reading	133	13

DV	n	% Missing Data
WRAT-R Arithmetic	130	15
Graphical Sequences Total Errors	143	8
Manual Postures Total Errors	124	19
Competing Programs Total Errors	103	33
Motor Sequences Total Errors	98	36

Statistical Assumptions

The assumption of normality was examined to determine the extent to which all observations in the sample for a given variable are normally distributed. In an inspection of scatterplots, if variables are normally distributed and linearly related, the shape of the scatter plot will be elliptical (Mertler & Vannatta, 2005). A visual inspection of the relationship between ECB scores indicates that perseverations are neither normal nor linear (Figure 3). Inspection of histograms for ECB total errors reveals a positive skew with a long tail to the right. This pattern indicates a greater frequency of lower scores on all variables (Figure 4).

Additionally, more formal skewness and kurtosis statistics were obtained. Table 8 provides a summary of score ranges, skewness, kurtosis and standard error for each of the dependent variables. Skewness characterizes the degree of asymmetry of a distribution around its mean. The skewness statistic for all subtests are positive and range from Manual Postures = 1.061 to Motor Sequences = 2.85. Kurtosis characterizes the relative peakedness or flatness of a distribution compared to the normal distribution.

Table 8 illustrates that the positive kurtosis statistic results in a relatively peaked, or leptokurtic, distribution on the four ECB subtests.

Research sought to explore the ECB's relationship to IQ and achievement. Descriptive statistics were examined for the independent variables of IQ and WRAT-R Reading and Arithmetic (Table 9). The mean IQ for the sample was 122.5, with a SD of 13.87. The range of full scale IQ scores was 84 to 150. Skewness and kurtosis statistics suggest that the distribution is relatively peaked and slightly to the right. WRAT-R Reading standard score (M =113.09, SD = 14.47) ranged in the sample from 68 to 155.00. The sample produced a WRAT-R Arithmetic standard score (M =110.18, SD = 15.39) range of 48 - 155.00.

To determine if variance is consistent across variables, scatterplots of residuals around the regression line were examined. Data points should be equally distributed around the regression line indicating that variance is consistent, or that the assumption of homoscedasticity is satisfied.

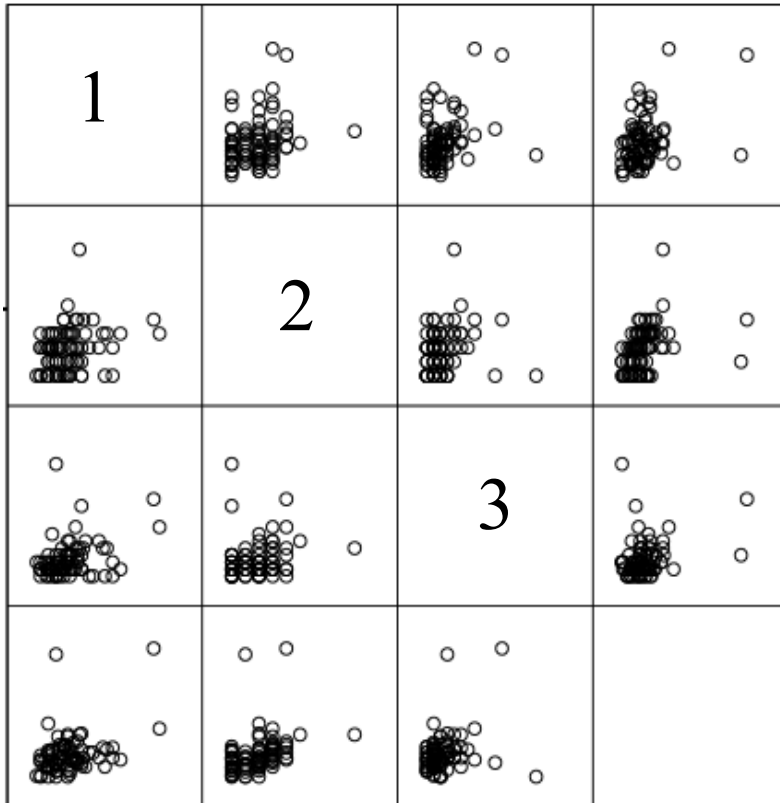
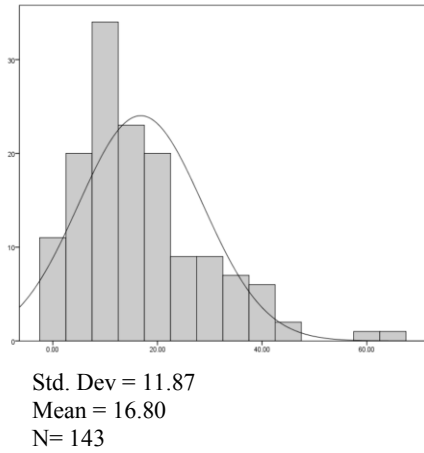
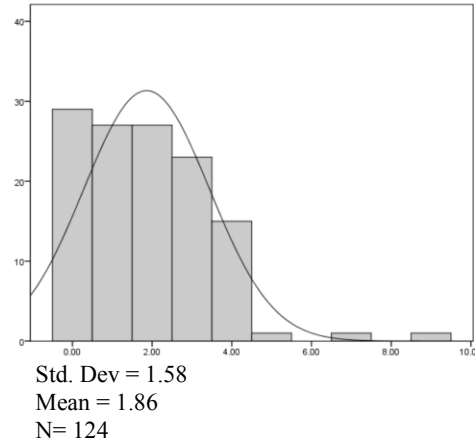


Figure 3. Matrix scatterplots of dependent measures 1 = Graphical Sequences; 2 = Manual Postures; 3 = Competing Programs; 4 = Motor Sequences.

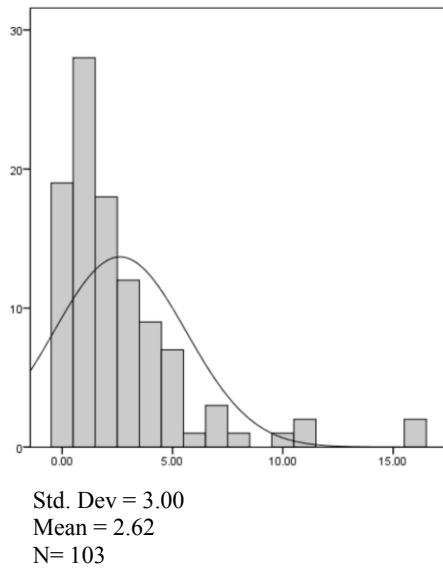
Graphical Sequences Total Errors



Manual Postures Total Errors



Competing Programs Total Errors



Motor Sequences Total Errors

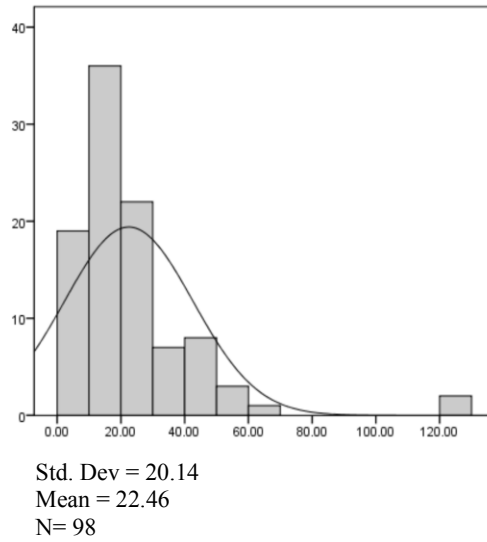


Figure 4. Error distributions for ECB dependent measures

The Point bi-serial and Phi correlation matrix presented in Table 5 was further examined for collinearity among dependent variables. Tabachnick and Fidell (2007) suggest either omitting the variable with the highest variance proportion or computing the average of the collinear variables when correlations are high (.90 and higher). Although

the DV's are significantly related ($r = .367, p < .01$), the relation is not to a degree that would signify redundancy and therefore require computation of collinear variables.

Table 8. Mean, Standard Deviation, Range, Skewness, and Kurtosis for Dependent Measures

Measure	Mean	SD	Range	Skew	Std. Error	Kurtosis	Std. Error
GST Total Error	16.80	11.87	0 - 63.0	1.158	.203	1.672	.403
MP Echopraxia	1.86	1.58	0 - 9.00	1.061	.217	2.561	.431
CP Total Error	2.62	3.00	0 - 16.0	2.39	.238	7.17	.472
MS Total Error	22.46	20.14	0 - 128.0	2.85	.244	12.38	.483

Note. GST = Graphical Sequences; MP = Manual Postures; CP = Competing Programs; MS = Motor Sequences

Table 9. Mean, Standard Deviation, Range, Skewness, and Kurtosis for IQ and WRAT-R

Measure	Mean	SD	Range	Skew	Std. Error	Kurtosis	Std. Error
WISC-III, Full Scale	122.51	13.87	84 - 150	-.512	.202	.557	.401
WRAT-R Reading SS	113.09	14.47	68 - 155.00	-.122	.210	-.087	.417
WRAT-R Arithmetic SS	110.18	15.39	48 - 155.00	-.078	.212	2.091	.422

Note. WRAT-R Reading SS= WRAT-R Reading Standard Score, WRAT-R Arithmetic SS=

WRAT-R Arithmetic Standard Score

Research Question One Results

The first research question is to determine how much variance will be obtained when the ECB is administered to a sample of children. Table 8 displays descriptive statistics for each ECB subtest according to error type by age. Visual inspection of mean perseverations on the Graphical Sequences Test reveals a decrease in errors as age increases. This is also observed on the Manual Postures, Competing Programs, and Motor Sequences subtests. Additionally, inspection reveals that mean errors on the GST decrease as the hierarchy of perseverations increase. As such, children in the sample were more likely to make lower order perseverations than higher order, or more pathological, perseverations as described by Goldberg & Tucker (1978). Outliers were not managed statistically. Outliers within the sample possibly represent subjects with executive deficits that were not identified by the study's exclusionary criteria.

Table 10. Descriptive Statistics for Graphical Sequences Subtest by Age and Error Type

Age	n	<u>TP</u> M	SD	<u>HO</u> M	SD	<u>ESSO</u> M	SD	<u>ESSR</u> M	SD	<u>ESIO</u> M	SD	<u>ESIR</u> M	SD	<u>ESSO</u> M	SD
6	13	18.77	11.20	-	-	6.77	3.94	7.61	5.78	.23	.60	.92	3.04	.08	.28
7	10	24.80	13.21	1.30	4.11	7.30	5.10	5.90	4.98	.90	.99	1.40	1.35	.40	.97
8	17	13.76	8.76	-	-	4.29	3.35	4.70	4.43	.76	1.15	.82	1.33	.23	.75
9	25	21.16	13.68	-	-	7.28	4.26	8.12	5.70	1.04	2.05	1.16	2.39	.24	.83
10	20	14.80	7.98	-	-	5.40	3.07	5.70	3.37	.4	.75	.40	.75	.05	.22
11	15	22.27	15.76	-	-	7.60	5.77	9.87	9.24	.67	1.11	.80	1.42	.20	.56
12	19	13.05	8.68	-	-	4.58	2.97	4.74	3.01	.68	1.49	.89	2.13	.37	.83
13	12	10.67	12.15	-	-	4.25	4.86	4.42	5.19	.33	.65	.42	.79	.08	.08
14	8	12.37	8.89	-	-	4.25	3.77	4.37	4.03	.37	.74	.37	.74	-	-
15	2	7.00	-	-	-	3.50	.71	3.50	.71	.50	.71	.50	.71	-	-
16	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Note. TP= Total Perseverations; HO= Hyperkinetic Occurrences; ESSO = Elements, Single Units, Simple Occurrences; ESSR = Elements, Single Units, Simple Repetitions; ESIO = Elements, Single Units, Interminability Occurrences; ESIR = Elements, Single Units, Simple Repetitions; ESSO = Elements Stereotypy Simple Occurrences

Table 10

Descriptive Statistics for Graphical Sequences Subtest by Age Cont.

<u>Age</u>	<u>n</u>	<u>ESSR</u>		<u>ESIO</u>		<u>ESIR</u>		<u>FO</u>		<u>FR</u>		<u>AO</u>		<u>AR</u>	
		M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
6	13	.08	.28	.15	.37	.15	.37	.92	1.44	1.38	2.18	.23	.60	.23	.60
7	10	.40	.97	.40	.97	.70	1.64	.40	.52	1.90	4.01	.30	.67	3.50	10.72
8	17	.29	.84	.06	.24	.12	.48	.59	.87	.82	1.13	.18	.39	.88	2.91
9	25	.40	1.26	.20	.50	.32	.80	.56	.71	.80	1.22	.44	.71	.60	1.04
∞	10	.05	.22	.45	.89	.70	1.38	.40	.60	.55	.10	.35	.93	.35	.93
11	15	.47	1.35	.53	.64	.67	1.05	.47	.74	.60	.98	.20	.41	.20	.41
12	19	.37	.83	.05	.23	.05	.23	.47	.90	.74	1.56	.05	.23	.05	.23
13	12	.08	.29	.17	.39	.17	.39	.25	.62	.50	1.17	-	-	-	-
14	8	-	-	.37	.52	1	1.41	.37	.74	1.00	2.45	.12	.35	.12	.35
15	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Note. ESSR = Elements, Stereotypy, Simple Repetitions; ESIO = Elements Stereotypy, Interminable Occurrences; ESIR = Elements, Stereotypy, Interminability Repetition; FO= Features, Occurrences; FR= Features, Repetitions; AO= Activities, Occurrences; AR= Activities, Repetitions

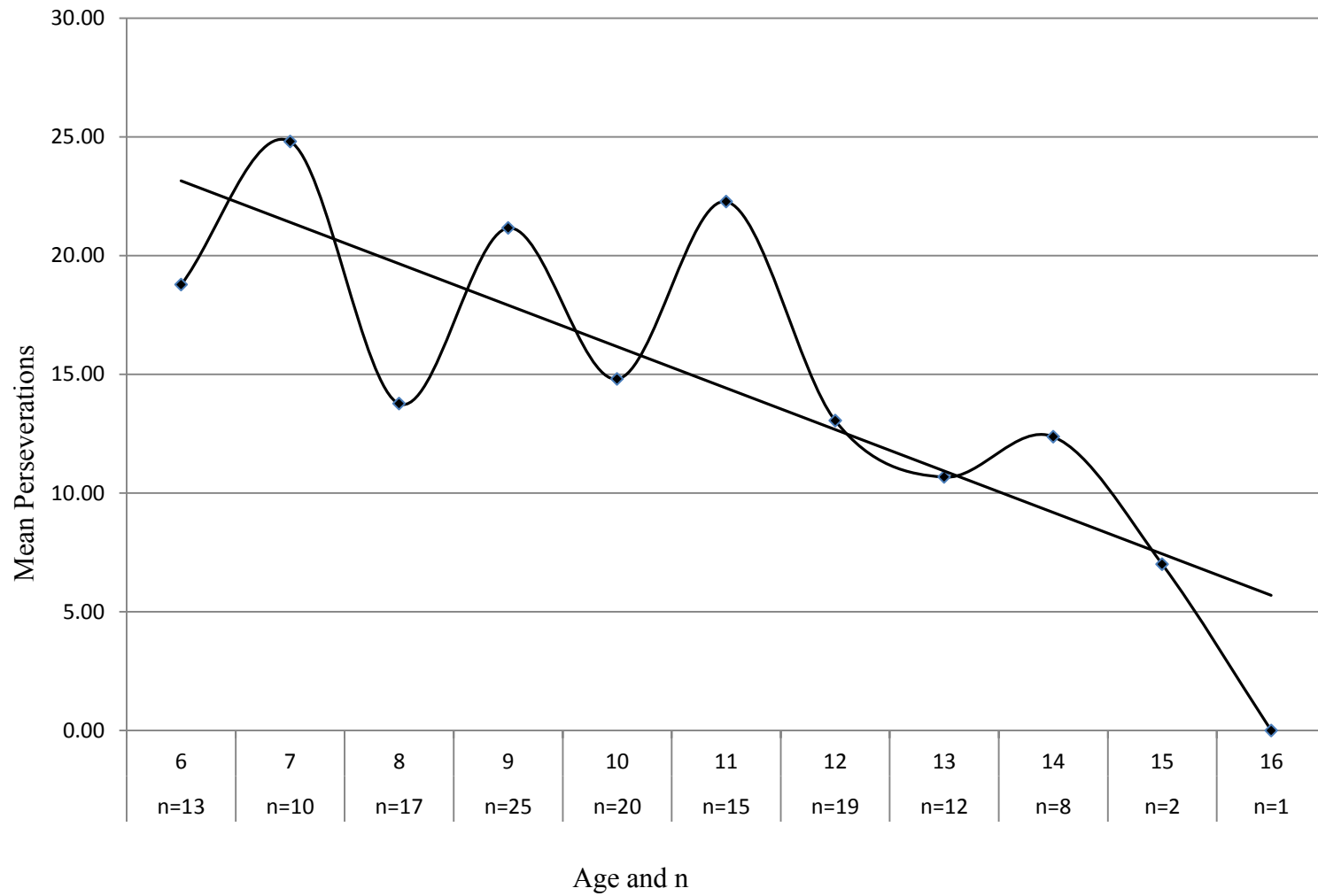


Figure 5. Graphical Sequences mean perseverations by age.

Table 11. Descriptive Statistics for Manual Postures Subtest by Age and Error Type

<u>Age</u>	<u>n</u>	<u>E</u>		<u>UE</u>		<u>BE</u>	
		M	SD	M	SD	M	SD
6	7	1.57	1.72	.43	.79	1.14	1.07
7	8	3.37	2.44	.37	.52	2.12	.83
8	11	1.54	1.63	.45	.69	1.09	1.22
9	23	2.56	1.24	.74	.86	1.83	1.11
10	16	1.19	1.22	.37	.81	.81	.75
11	18	2.33	1.78	.67	.84	1.67	1.41
12	19	1.84	1.17	.37	.76	1.42	.90
13	11	.73	.90	.18	.40	.54	.93
14	9	.89	1.17	.22	.44	.78	.97
15	2	.5	.71	.50	.71	-	-

Note. E= Echopraxia; UE= Uni-Echo ; BE= Bi-Echo

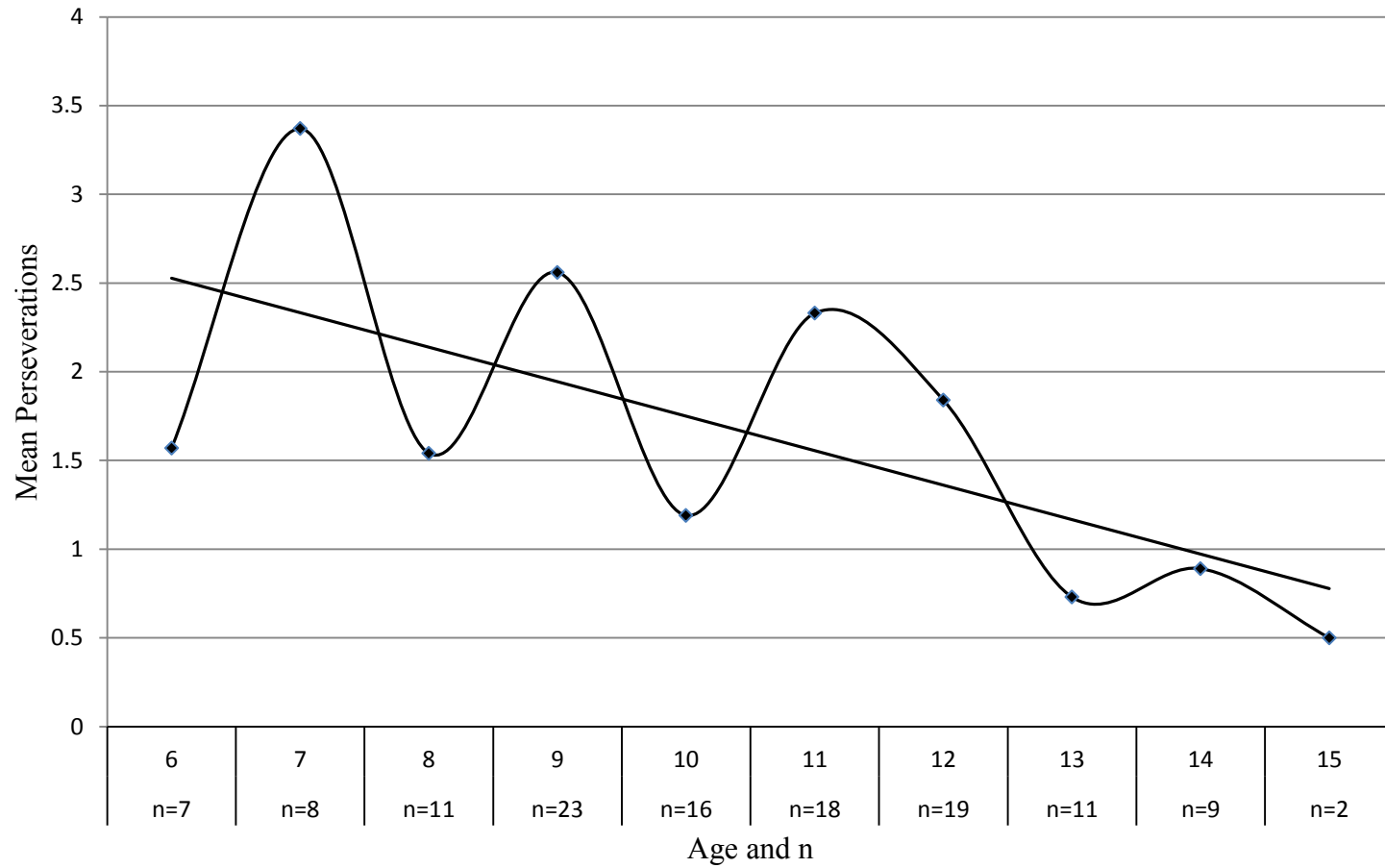


Figure 6. Manual Postures mean perseverations by age.

Table 12. Descriptive Statistics for Competing Programs Subtest by Age and Error Type

<u>Age</u>	<u>n</u>	<u>TE</u>		<u>CE</u>		<u>ST</u>	
		M	SD	M	SD	M	SD
6	3	1.67	1.53	.33	.58	.33	.58
7	5	4.20	2.49	.40	.55	.40	.55
8	8	4.12	4.97	.50	.53	.50	.53
9	19	3.31	3.40	.95	1.18	.95	1.18
10	15	3.53	3.72	.60	.63	.60	.63
11	16	3.00	2.92	.75	1.00	1.25	1.84
12	19	1.05	1.08	.26	.56	.21	.53
13	10	.90	.87	.40	.52	.40	.52
14	6	3.00	1.55	.67	.82	.67	.82
15	2	1.00	1.41	-	-	-	-

Note. TE= Total Errors; CE= Critical Errors; ST= Stereotypy Total

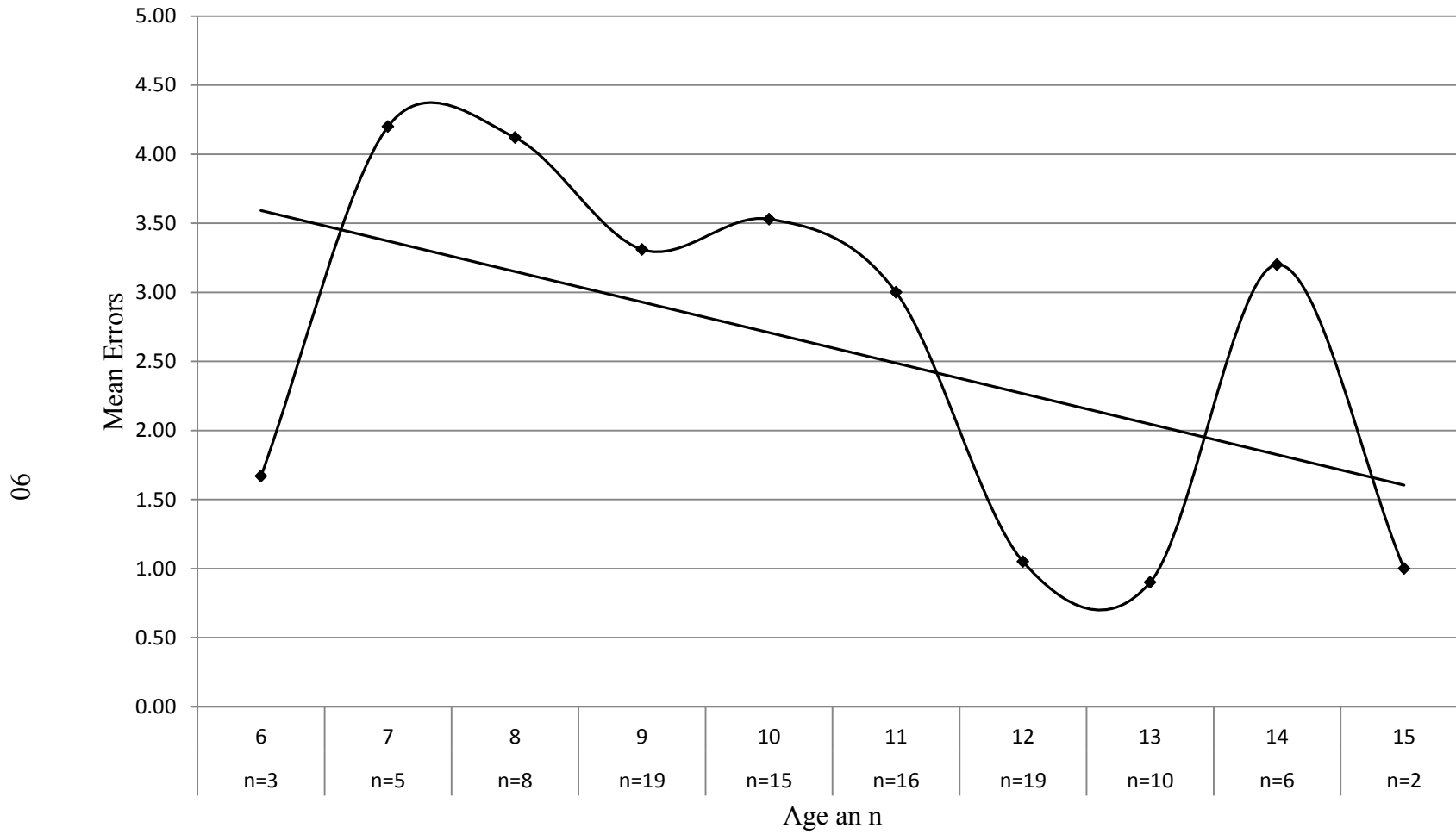


Figure 7. Competing programs mean perseverations by age

Table 13. Descriptive Statistics for Motor Sequences Subtest by Age and Error Type

Age	n	<u>TE</u>		<u>UM</u>		<u>BM</u>		<u>2SRI</u>		<u>2SRC</u>		<u>2SLI</u>		<u>2SLC</u>	
		M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
6	4	21	14.16	8.25	5.68	12.75	9.21	3.00	4.69	2.50	5.0	3.5	5.20	3.25	4.72
7	6	38.83	25.36	18.17	9.54	20.67	17.36	.25	.50	5.25	8.62	-	-	1.0	1.15
8	10	21.10	16.34	13.00	11.18	8.10	5.86	.22	.44	-	-	.11	.33	-	-
9	19	32.68	26.65	14.89	15.18	17.79	14.87	-	-	.21	.92	.16	.50	.31	.67
10	14	22.86	29.82	8.43	7.19	14.43	24.48	.36	.93	.07	.27	.07	.27	.21	.58
11	16	28.50	30.85	13.87	18.57	14.62	14.23	1.28	4.05	.14	.53	.21	.58	.43	1.34
12	16	20.06	12.77	9.56	6.61	10.50	8.57	-	-	-	-	1.56	5.00	.12	.50
13	11	12.36	9.26	6.82	6.19	5.54	3.72	.18	.60	-	-	-	-	-	-
14	8	15.37	10.38	.37	7.25	8.12	7.34	-	-	-	-	.25	.71	-	-
15	2	16.00	-	-	11.50	4.50	.71	-	-	-	-	-	-	-	-

Note. TE= Total Errors; UM= Uni-Manual; BU= Bi-Manual; 2SRI= 2 Stage Right Imitation, 2SRC= 2 Stage Right Continuation; 2SLI= 2 Stage Left Imitation; 2SLC= 2 Stage Left Continuation

Table 12

Descriptive Statistics for Motor Sequences Subtest by Age and Error Type, Cont.

<i>Age</i>	<i>n</i>	<u>3SRI</u>		<u>3SRC</u>		<u>3SLI</u>		<u>3SLC</u>		<u>2SRC</u>		<u>2SLI</u>		<u>2SLC</u>	
		M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
6	4	5.75	6.40	4.50	6.35	7.25	8.50	6.00	9.38	2.50	5.0	4.14	3.81	6.00	9.38
7	6	4.25	1.71	3.50	1.29	3.25	2.63	4.25	1.71	5.25	8.62	3.44	2.24	4.25	1.71
8	10	4.22	3.07	4.22	6.10	3.44	2.24	2.22	1.64	-	-	3.58	4.14	2.22	1.64
9	19	3.89	3.51	3.37	3.82	3.58	4.14	3.21	4.23	.21	.92	2.14	1.87	3.21	4.23
10	14	2.71	2.33	1.50	1.56	2.14	1.87	1.50	1.40	.07	.27	3.50	4.99	1.50	1.40
11	16	3.21	4.19	3.14	5.19	3.50	4.99	4.50	5.60	.14	.53	2.75	1.84	4.50	5.60
12	16	2.50	1.59	1.69	1.40	2.75	1.84	2.37	2.58	-	-	1.45	1.51	2.37	2.58
13	11	2.27	1.35	1.82	1.89	1.45	1.51	1.73	1.68	-	-	1.37	1.41	1.73	1.68
14	8	2.75	1.98	1.25	2.37	1.37	1.41	1.62	1.77	-	-	3.50	.71	1.62	1.77
15	2	4.0	1.41	-	-	3.50	.71	-	-	-	-	-	-	-	-

Note. 3SRI= 3 Stage Right Imitation; 3SRC= 3 Stage Right Continuation; 3SLI= 3 Stage Left Imitation; 3SLC= 3 Stage Left Continuation; 2SRC= 2 Stage Right Continuation; 2SLI = 2 Stage Left Imitation; 2SLC= 2 Stage Left Continuation

Descriptive Statistics for Motor Sequences Subtest by Age and Error Type, Cont.

<i>Age</i>	<i>n</i>	<u>BFPI</u>		<u>BFPC</u>		<u>BPSI</u>		<u>BPSC</u>		<u>BMI</u>		<u>BMC</u>	
		M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
6	4	2.00	2.16	2.25	2.87	1.75	2.36	1.50	1.29	2.75	1.89	2.50	1.73
7	6	1.7	2.06	6.50	9.15	.75	1.50	2.25	2.63	5.75	2.50	.75	1.50
8	10	.33	.50	.78	1.71	.89	1.05	1.11	1.27	2.78	1.79	10.50	7.14
9	19	1.37	2.09	1.74	3.16	1.58	1.95	2.53	4.19	4.95	3.61	5.58	5.29
10	14	1.86	4.02	1.78	3.47	1.71	4.68	1.57	4.09	4.14	5.14	3.28	4.48
11	16	2.64	4.34	2.36	2.02	.71	1.49	2.36	5.24	3.50	3.80	2.50	1.70
12	16	.81	1.86	1.00	1.50	.50	.89	.12	.34	4.12	2.06	3.75	4.57
13	11	.45	.82	.82	1.47	.27	.65	.27	.47	1.82	1.33	2.00	1.84
14	8	.37	.74	.50	.92	.25	.71	.50	.75	1.37	1.68	5.12	6.77
15	2	-	-	-	-	.50	.71	-	-	-	-	-	-

Note. BFPI= Bi-Manual Fist/Palm Imitation; BFPC= Bi-Manual Fist/Palm Continuation; BPSI= Bi-Manual Pron/Sup Imitation; BPSC= Bi-Manual Pron/Sup Continuation; BMI= Bi-Manual Mixed Imitation; BMC= Bi-Manual Mixed Continuation

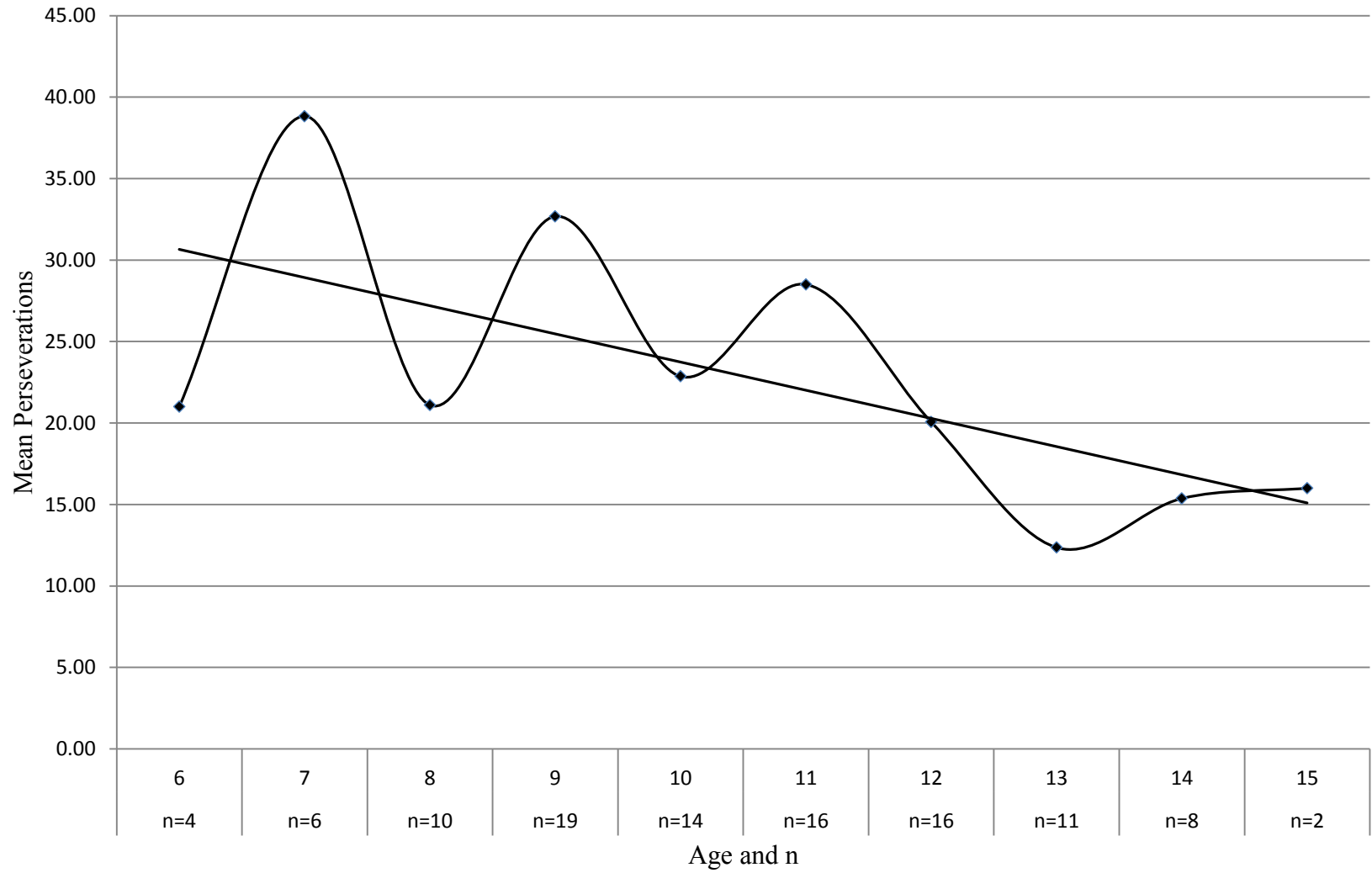


Figure 8. Motor Sequences mean perseverations by age.

Research Question Two Results

Internal consistency was established on the four subtests utilizing Cronbach's alpha. Due to the varying degree of perseverative errors elicited by each subject and the relatively heterogeneous variance on the Graphical Sequences Test, the use of standardized variables was considered more appropriate (Cronbach, 1951). As it is, the procedure output has an overall alpha of .716 which is adequate considering that .70 is considered a satisfactory value of alpha (Nunnally, 1978). Graphical Sequences test items number 2, 4, 6, 7, and 14 were removed from the analysis as they have low item-total correlations ($<.15$). The Manual Postures Subtest has adequate internal consistency ($\alpha = .752$). The Competing Programs has an alpha of .814. Items number 2, 9, 11, 16, 17, 20, 23, 28, 32, and 33 were removed from the analysis because they had low item-total correlations. Motor Sequences has an adequate internal consistency ($\alpha = .889$) when low-item correlations are removed (items 2, 5, 8, 13, 18, 23, 26, 30).

Research Question Three Results

The third research question was to establish inter-rater reliability on the Graphical Sequences subtest and determine if there is concordance in the degree of agreement among raters who administer the Graphical Sequences subtest to children. Intra-class correlation coefficient measures the proportion of variance of an observation due to between-subject variability in the true scores (Bland & Altman, 1986). The ICC is an improvement over Pearson's r and Spearman's ρ , as it takes into account the differences in ratings for individual segments, along with the correlation between raters. The single measure intra-class correlation coefficient between rater 1 and rater 2 is .961.

Inter-rater agreement of perseverative errors among individual items is included in Table 13. Item 1 had a substantial level of agreement among raters. Items 3, 4, 8, 9, 11, 13 and 14 demonstrated an outstanding level of agreement amongst the two raters ($k=1.0$). Items 2, 5, 6, 7, 10, and 12 could not be calculated. Items 2, 6, and 7 were not calculated because total rater 1 and total rater 2 are constants (Error = 0). Items 5, 10, and 12 Kappa statistics could not be computed because they require a symmetric 2-way table in which the values of the first variable match the values of the second variable.

Table 14. Inter-rater Agreement of Perseverative Errors per Item

Item #	Kappa Statistic	Level of Significance
1.	.759	$p = .003$
2.	-	-
3.	1.000	$p < .001$
4.	1.000	$p < .001$
5.	-	-
6.	-	-
7.	-	-
8.	1.00	$p < .001$
9.	.906	$p < .001$
10.	-	-
11.	1.00	$p < .001$
12.	-	-
13.	1.00	$p < .001$
14.	1.00	$p < .001$

Note. Items 2, 6, and 7 were excluded because total rater 1 and total rater 2 were constants (Error=0) Items 5, 10 and 12 did not have a symmetric 2-way table in which values 1 matched value 2.

Table 14 displays the inter-rater reliability of the 13 unique types of perseverative errors on the Graphical Sequence Test. Kappa statistics could not be computed for Hyperkinetic Occurrences; Elements, Stereotypy, Simple Occurrences; Elements,

Stereotypy, Simple Repetitions, Perseveration of Activities, Occurrences, Perseveration of Activities, Repetitions because the Rater 1 and Rater 2 scores were constants (Score = 0). Kappa statistic could not be computed for Elements, Single Units, Simple Occurrences and Elements, Single Units, Simple Repetitions because they require a symmetric 2-way table in which the values of the first variable match the values of the second variable.

Table 15. Inter-Rater Reliability of Perseverative Errors

Error Type	Kappa Statistic	Significance Level
Hyperkinetic Occurrences	-	-
Elements, Single Units, Simple Occurrences	-	-
Elements, Single Units, Simple Repetitions	-	-
Elements, Single Units, Interminability Occurrences	.868	$p < .001$
Elements, Single Units, Interminability Repetitions	.868	$p < .001$
Elements, Stereotypy, Simple Occurrences	-	-
Elements, Stereotypy, Simple Repetitions	-	-

Elements, Stereotypy, Interminability Occurrences	1.00	p< .001
Elements, Stereotypy, Interminability Repetitions	1.00	p< .001
Perseveration of Features Occurrences	1.00	p< .001
Perseveration of Features Repetitions	1.00	p< .001
Perseveration of Activities Occurrences	-	-
Perseveration of Activities Repetitions	-	-

Research Question Four Results

The fourth research question was to establish convergent validity with the four ECB subtests with two measures of EF (WCST and Stroop). A hierarchical multiple regression analysis was computed utilizing the enter method.

A hierarchical multiple regression was conducted to determine which independent variables (WCST perseverative errors, scaled score, WCST failure to maintain set, Stroop Color Word Test Word standard score, Stroop Color Word Test Color standard score, and Stroop Color Word Test Color Word standard score) were related to perseverative errors on the Graphical Sequences Test. The model summary, ANOVA table, and coefficient table are presented in Tables 15 and 16 respectively. Tolerance among the IVs is adequate since coefficients for all IVs included and excluded are above .1. Regression

results indicate an overall model of one predictor (Stroop Color Word Standard Score) that significantly explains Graphical Sequence Errors, $R^2 = .285$, $R^2_{adj} = .211$, $F(5, 48) = 3.380$, $p < .005$. This model accounted for 28.5% of variance in Graphical Sequence Total Errors. A summary of the regression model is presented in Table 15. In addition, bivariate and partial correlation coefficients between each predictor and the dependent variable are presented in Table 16.

Table 16. Model Summary of the Relation of WCST Perseverative Errors Scale Score, WCST Failure to Maintain Set, Stroop Color Word Test Color Word Standard Score to GST

Step	R	R ²	R ² _{adj}	ΔR ²	F _{chg}	p	df ₁	df
WCST	.160	.026	-.013	.026	.669	.517	2	51
Stroop	.534	.285	.211	.260	5.811	.004*	3	48

Table 17. Coefficients for Final Model

	<i>B</i>	<i>β</i>	<i>t</i>	Bivariate <i>r</i>	Partial <i>r</i>
WCST Perseverative Errors	.048	.042	.291	-1.00	.042
WCST Failure to Maintain Set	-.543	-.033	-.231	-.071	-.033
Stroop Word Standard Score	.197	.132	.785	-.185	.113
Stroop Color Standard Score	.000	.000	.000	-.351	.000
Stroop Color Word Standard Score	-.596	-.600	-3.004*	-.519	-.367

Note: * Indicates significance at $p < .001$

A hierarchical multiple regression was conducted to determine which independent variables (WCST Perseverative Errors, Scaled Score, WCST Failure To Maintain Set, Stroop Color Word Test Word Standard Score, Stroop Color Word Test Color Standard

Score, and Stroop Color Word Test Color Word Standard Score) were related to errors on the Competing Programs Test. The model summary, ANOVA table, and coefficient table are presented in Tables 17 and 18 respectively. Tolerance among the IVs is adequate since coefficients for all IVs included and excluded are above .1. Regression results do not indicate a predictor that significantly explains Competing Program Errors, $R^2 = .184$, $R^2_{adj} = .112$, $F(5, 62) = 2.565$, $p < .037$. This model accounted for 18.4% of variance in Competing Programs Total Errors. A summary of the regression model is presented in Table 17. In addition, bivariate and partial correlation coefficients between each predictor and the dependent variable are presented in Table 18.

Table 18. Model Summary of the Relation of WCST Perseverative Errors, Scaled Score, WCST Failure to Maintain Set, Stroop Color Word Test Word Standard Score, Stroop Color Word Test Color Standard Score, and Stroop Color Word Test Color Word Standard Score to CP.

Step	R	R ²	R ² _{adj}	ΔR ²	F _{chg}	P	df ₁	df
WCST	.155	.024	-.009	.024	.738	.482	2	60
Stroop	.429	.184	.112	.160	3.716	.016	3	57

Table 19. Coefficients for Final Model

	<i>B</i>	β	<i>t</i>	Bivariate <i>r</i>	Partial <i>r</i>
WCST Perseverative Errors	-.002	-.007	-.050	-.134	-.007
WCST Failure to Maintain Set	.556	.144	1.075	.121	.141
Stroop Word Standard Score	.138	.405	2.585	.148	.324
Stroop Color Standard Score	.016	.060	.323	-.071	.043
Stroop Color Word Standard Score	-.112	-.506	-2.679	-.217	-.334

Note: * Indicates significance at $p < .001$

A hierarchical multiple regression was conducted to determine which independent variables (WCST perseverative errors, scaled score, WCST failure to maintain set, Stroop Color Word Test Word standard score, Stroop Color Word Test Color standard score, and Stroop Color Word Test Color Word standard score) were related to Manual Postures Echopraxia. The model summary, ANOVA table, and coefficient table are presented in Tables 19 and 20 respectively. Tolerance among the IVs is adequate since coefficients for all IVs included and excluded are above .1. Regression results do not indicate a predictor that significantly explains Manual Postures Echopraxia, $R^2 = .121$, $R^2_{adj} = .045$, $F(5, 63) = 1.594$, $p < .176$. This model accounted for 12.1% of variance in Manual Postures Echopraxia. A summary of the regression model is presented in Table 19. In addition, bivariate and partial correlation coefficients between each predictor and the dependent variable are presented in Table 20.

Table 20. Model Summary of the Relation of WCST Perseverative Errors, Scaled Score, WCST Failure to Maintain Set, Stroop Color Word Test Word Standard Score, Stroop Color Word Test Color Standard Score, and Stroop Color Word Test Color Word Standard Score to MP

Step	R	R ²	R ² _{adj}	ΔR ²	F _{chg}	P	df ₁	df
WCST	.216	.047	.015	.047	1.48	.234	2	61
Stroop	.348	.121	.045	.074	1.633	.192	3	58

Table 21. Coefficients for Final Model

	<i>B</i>	<i>β</i>	<i>t</i>	Bivariate <i>r</i>	Partial <i>r</i>
WCST Perseverative Errors	-.014	-.132	-.945	-.185	-.123
WCST Failure to Maintain Set	-.105	-.063	-.457	-.039	-.060
Stroop Word Standard Score	.024	.167	1.056	-.032	.137
Stroop Color Standard Score	.001	.012	.062	-.153	.008
Stroop Color Word Standard Score	-.033	-.350	-1.828	-.289	-.233

Note: * Indicates significance at p<.001

A hierarchical multiple regression was conducted to determine which independent variables (WCST perseverative errors, scaled score, WCST failure to maintain set, Stroop Color Word Test Word standard score, Stroop Color Word Test Color standard score, and Stroop Color Word Test Color Word standard score) were related to Motor Sequences Total Errors. The model summary, ANOVA table, and coefficient table are presented in Tables 21 and 22 respectively. Tolerance among the IVs is adequate since coefficients for all IVs included and excluded are above .1. Regression results suggest that WCST Perseverative Errors moderately explains Motor Sequences Errors, $R^2 = .265$, $R^2_{adj} = .191$,

F(5, 55)= 3.601, $p<.007$. This model accounted for 20% of variance in Motor Sequencing Errors. A summary of the regression model is presented in Table 21. In addition, bivariate and partial correlation coefficients between each predictor and the dependent variable are presented in Table 22.

Table 22. Model Summary of the Relation of WCST Perseverative Errors, Scaled Score, WCST Failure to Maintain Set, Stroop Color Word Test Word Standard Score, Stroop Color Word Test Color Standard Score, and Stroop Color Word Test Color Word Standard Score to MS

Step	R	R ²	R ² _{adj}	ΔR ²	F _{chg}	P	df ₁	df
WCST	.450	.203	.176	.203	6.744	.002*	2	53
Stroop	.515	.265	.191	.062	1.403	.253	3	50

Table 23. Coefficients for Final Model

	<i>B</i>	<i>β</i>	<i>t</i>	Bivariate <i>r</i>	Partial <i>r</i>
WCST Perseverative Errors	-.618	-.425	-2.971*	-.436	-.387
WCST Failure to Maintain Set	-2.703	-.112	-.802	.063	-.113
Stroop Word Standard Score	.435	.206	1.299	-.062	.181
Stroop Color Standard Score	-.325	-.198	-1.063	-.246	-.149
Stroop Color Word Standard Score	-.227	-.162	-.820	-.313	-.115

Note: * Indicates significance at $p<.001$

Research Question Five Results

The final research question explored the predictive validity of the ECB. Does performance on the ECB predict outcomes on general measures of cognitive ability and achievement? A multiple regression analysis was conducted with the four subtests of the

ECB and FSIQ, and reading and math achievement scores. The mean FSIQ for the sample was 122.51 and the standard deviation was 13.88. The mean WRAT-R Reading Standard Score was 113.10, SD= 14.47. WRAT-R Arithmetic mean was 110.18, SD= 15.39.

A hierarchical multiple regression was conducted to determine which independent variables (WISC-III, Full Scale IQ, WRAT-R Reading Standard Score, WRAT-R Arithmetic Standard Score) were related to Graphical Sequences Total Errors. The model summary, ANOVA table, and coefficient table are presented in Tables 23 and 24 respectively. Tolerance among the IVs is adequate since coefficients for all IVs included and excluded are above .1. Regression results suggest that there is no significant relationship between Graphical Sequences, Full Scale IQ, WRAT-R, Reading or Arithmetic, $R^2 = .023$, $R^2_{adj} = -.007$, $F(2, 98) = .779$, $p < .509$. This model accounts for 2.3% of variance in Graphical Sequence Errors. A summary of the regression model is presented in Table 23. In addition, bivariate and partial correlation coefficients between each predictor and the dependent variable are presented in Table 24.

Table 24. Model Summary of the Relation of GST to FSIQ, WRAT-R Reading and Arithmetic

Step	R	R ²	R ² _{adj}	ΔR ²	F _{chg}	p	df ₁	df ₂
FSIQ	.459	.002	.008	.002	.240	.625	1	100
WRAT-R	.153	.023	-.007	.021	1.048	.509	2	98

Table 25. Coefficients for Final Model

	<i>B</i>	β	<i>t</i>	Bivariate <i>r</i>	Partial <i>r</i>
WISC-III FSIQ SS	.021	.024	.189	-.049	.019
WRAT-R Reading SS	-.138	-.167	-1.323	-.150	-.132
WRAT-R Arithmetic SS	.007	.009	.067	-.076	.007

Note: * Indicates significance at $p < .001$

A hierarchical multiple regression was conducted to determine which independent variables (WISC-III, Full Scale IQ, WRAT-R Reading Standard Score, WRAT-R Arithmetic Standard Score) were related to Manual Postures Echopraxia Errors. The model summary, ANOVA table, and coefficient table are presented in Tables 25 and 26 respectively. Tolerance among the IVs is adequate since coefficients for all IVs included and excluded are above .1. Regression results suggest that there is no significant relationship between Manual Postures, Full Scale IQ, WRAT-R, Reading or Arithmetic, $R^2 = .067$, $R^2_{adj} = .035$, $F(3, 85) = 2.048$, $p < .113$. This model accounts for 6.7% of variance in Manual Postures Echopraxia Errors. A summary of the regression model is presented in Table 25. In addition, bivariate and partial correlation coefficients between each predictor and the dependent variable are presented in Table 26.

Table 26. Model Summary of the Relation of WISC-III, Full Scale IQ, WRAT-R Reading Standard Score to MP

Step	R	R^2	R^2_{adj}	ΔR^2	F_{chg}	<i>p</i>	df ₁	df ₂
FSIQ	.006	.000	-.001	.000	.004	.952	1	87
WRAT-R	.260	.067	.035	.067	3.074	.113	3	85

Table 27. Coefficients for Final Model

	<i>B</i>	β	<i>t</i>	Bivariate <i>r</i>	Partial <i>r</i>
WISC-III FSIQ SS	.009	.074	.566	-.006	.061
WRAT-R Reading SS	-.033	-.316	-2.406	-.231	-.253
WRAT-R Arithmetic SS	.009	.091	.617	-.054	.067

Note: * Indicates significance at $p < .001$

A hierarchical multiple regression was conducted to determine which independent variables (WISC-III, Full Scale IQ, WRAT-R Reading Standard Score, WRAT-R Arithmetic Standard Score) were related to Competing Programs Total Errors. The model summary, ANOVA table, and coefficient table are presented in Tables 27 and 28 respectively. Tolerance among the IVs is adequate since coefficients for all IVs included and excluded are above .1. Regression results suggest that there is no significant relationship between Competing Programs, Full Scale IQ, WRAT-R, Reading or Arithmetic, $R^2 = .023$, $R^2_{adj} = -.015$, $F(3, 77) = .607$, $p < .613$. This model accounts for 2.3% of variance in Competing Programs Errors. A summary of the regression model is presented in Table 27. In addition, bivariate and partial correlation coefficients between each predictor and the dependent variable are presented in Table 28.

Table 28. Model Summary of the Relation of WISC-III, Full Scale IQ, WRAT-R Reading Standard Score, WRAT-R Arithmetic Standard Score to CP

Step	R	R^2	R^2_{adj}	ΔR^2	F_{chg}	<i>p</i>	df ₁	df ₂
FSIQ	.115	.013	.001	.013	1.058	.307	1	79
WRAT-R	.152	.023	-.015	.010	.389	.679	2	77

Table 29. Coefficients for Final Model

	<i>B</i>	β	<i>t</i>	Bivariate <i>r</i>	Partial <i>r</i>
WISC-III FSIQ SS	-.042	-.174	-1.219	-.115	-.138
WRAT-R Reading SS	-.013	-.063	-.445	-.053	-.051
WRAT-R Arithmetic SS	.025	.143	.882	-.002	.100

Note: * Indicates significance at $p < .001$

A hierarchical multiple regression was conducted to determine which independent variables (WISC-III, Full Scale IQ, WRAT-R, Reading Standard Score, WRAT-R Arithmetic Standard Score) were related to Motor Sequencing Total Errors. The model summary, ANOVA table, and coefficient table are presented in Tables 29 and 30 respectively. Tolerance among the IVs is adequate since coefficients for all IVs included and excluded are above .1. Regression results indicate that there is a significant relationship between Motor Sequencing, Full Scale IQ, WRAT-R, Reading and WRAT Arithmetic, $R^2 = .173$, $R^2_{adj} = .138$, $F(3, 72) = 5.016$, $p < .003$. This model accounts for 17% of variance in Motor Sequencing Errors. A summary of the regression model is presented in Table 29. In addition, bivariate and partial correlation coefficients between each predictor and the dependent variable are presented in Table 30.

Table 30. Model Summary of MS relation to WISC-III, Full Scale IQ, WRAT-R, Reading Standard Score, WRAT-R Arithmetic Standard Score

Step	R	R^2	R^2_{adj}	ΔR^2	F_{chg}	<i>p</i>	df ₁	df ₂
FSIQ	.176	.031	.018	.031	2.353	.129	1	74
WRAT-R	.416	.173	.138	.142	6.182	.003*	2	72

Table 31. Coefficients for Final Model

	<i>B</i>	β	<i>t</i>	Bivariate <i>r</i>	Partial <i>r</i>
WISC-III FSIQ SS	.197	.125	.914	-.176	.107
WRAT-R Reading SS	-.163	-.121	-.886	-.301	-.104
WRAT-R Arithmetic SS	-.463	-.400	-2.658	-.396*	-.299

Note: * Indicates significance at $p < .001$

CHAPTER V: DISCUSSION

The objective of this study was to examine normative data of the Executive Control Battery in children. This chapter will address the findings of the current study within the context of relevant theoretical background and current literature. Implications and recommendations for future research will be discussed.

Summary of Results

Research Question One

The first research question was to determine if adequate variance would be produced on the ECB when administered to children. It was hypothesized that the ECB would produce adequate variance when studying a sample of children. The creation of descriptive statistics tables of the mean and standard deviation of errors on the four ECB subtests, organized by age and error type, demonstrated adequate variance. Inspection of the data indicates that the total perseverative errors decreased as age increased. This age trend has been established in EF developmental literature (Welsh, Pennington, and Grossier, 1991; Gerstadt, Hong & Diamond, 1994; Diamond & Taylor, 1996; Epsy, 1997; Anderson, 1998; Levin et al., 1991; Korkman, Kemp, and Kirk, 2001; Anderson, 2002). Developmental theory suggests that EF's emerge during the first several years of life (Diamond, 1988) and continue to develop in spurts, rather than a linear progression, into late childhood and early adolescence (Luna et al., 2004). Adult levels of performance on some tasks were achieved by approximately 12 years of age (Anderson et al., 2001; Chelune & Baer, 1986; Welsh, Pennington, & Grossier, 1991; Zelazo & Muller, 2003).

Additionally, subject mean errors decreased as the complexity of error type,

according to the hierarchy of perseverative errors established by Goldberg (1999), increased on the GST. Although perseveration is a common phenomenon of normal development, the findings suggest that more pathological perseveration is less frequent in the childhood sample.

Examination of histograms as well as skewness and kurtosis statistics indicates that the sample produced little perseverative errors on the ECB subtests. This finding is relatively comparable to those measured in adults (Podell, 2009; Goldberg et al. 2000). The error pattern suggests that the ECB functions as a cut-score assessment that would differentiate between those with intact EF and those with EF deficits. Additionally, subjects who demonstrated a high number of errors (outliers), when compared to the sample, may have EF deficits. It is also interesting to note that the mean errors derived from the childhood sample were greater than the clinical and control adult mean errors. This supports the EF developmental literature that suggests that EF continues to develop in children until approximately the age of 20. A higher rate of perseverative behavior would be anticipated from children who have not reached full neurological maturity. Moreover, it supports claims that adult norms and measures are not appropriate when utilized in children (Fletcher et al., 1996; Anderson, 1998; Fletcher & Taylor, 1984).

Research Question Two

The purpose of question two was to establish internal consistency on the four ECB subtests utilizing Cronbach's Alpha. The hypothesis of establishing internal consistency was confirmed. Adequate internal consistency was established on the GST ($\alpha = .716$), CP ($\alpha = .814$), MP ($\alpha = .752$), and MS ($\alpha = .889$) tests. Cronbach's alpha generally increases as the intercorrelations among test items increase, which results in an

established internal consistency estimate of reliability of test scores. Because intercorrelations among test items are maximized when all items measure the same construct, Cronbach's alpha is assumed to indirectly indicate the degree to which a set of items measures a single unidimensional latent construct (Cronbach, 1951). Robust alpha scores on each subtest suggest that the ECB items measure a similar construct. Correlations between the individual tests were also significant. The Graphical Sequences Test was correlated to Manual Postures, Competing Programs, and Motor Sequences at the $p < .01$ level. Manual Postures was correlated to Competing program at the $p < .05$ level, and Motor Sequences at the $p < .01$ level, and Competing Programs was correlated with Motor Sequences at the $p < .01$ level.

Research Question Three

Inter-rater reliability studies were performed on GST to determine concordance in the degree of agreement among raters who administer and score the GST to children. Single item intra-class correlation coefficient was found to be .961 when two raters scored 10% of the sample $n=15$. Inter-rater agreement in this current study is commensurate with the adult normative studies which reported inter-rater reliability for the total number of perseverative errors on the GST at $\alpha = .94$ and $.94$ (Jaeger et al. 1992). This study also examined inter-rater reliability of identifying perseverative errors on each individual item of the GST utilizing the Kappa statistic. Seven of the fourteen items demonstrated an outstanding level of agreement between two raters, while one item had a substantial level of agreement. Additionally, inter-rater agreement was measured on the specific type on perseverative error. Of the 13 types of perseverative errors, 6 were found to be significantly in agreement among the two raters. Much like the current study

results, the normative study of the ECB in adults noted that although agreement was reached regarding the number of perseverative errors, agreement was not as high on the specific type of perseverative error. On average the study data suggests that the raters were able to reliably identify both quantitative and qualitative features of perseverative errors on the GST.

Research Question Four

Convergent validity was explored to determine if the ECB was related to two established measures of EF. The research hypothesis predicted that the ECB would moderately correlate to the WCST and Stroop Color Word Test. These measures are known to measure inhibition and perseverative behavior (Barone, 2004) which are hallmark characteristics of the ECB. Multiple regression was utilized to compare the ECB to WCST perseverative errors, scaled score, WCST failure to maintain set, Stroop Color Word Test Word standard score, Stroop Color Word Test Color standard score, and Stroop Color Word Test Color Word standard score. Analysis indicated a significant negative correlation between Stroop Color-Word Standard Score and GST perseverative errors. This suggests that subjects with higher standard scores on the Stroop Color Word test produced less perseverative errors on the GST. The Stroop Color Word standard score predicted a significant amount of variance in Graphical Sequences Test (28.5%). WCST perseverative errors was also significantly and negatively correlated to Motor Sequences total errors. The WCST perseverative errors predicted a significant amount of variance in Motor Sequences Test (20%). There were no other significant interactions between independent and dependent variables. This provides evidence that the Graphical

Sequences Tests is an adequate measure of inhibition. However, the other nonsignificant findings suggest other cognitive processes are accounting for the subtests variation.

Research Question Five

Predictive validity was explored by comparing the ECB subtests to outcomes on non-EF tests. It was hypothesized that performance on the ECB would be negatively correlated with IQ and achievement. As such, subjects who demonstrate a higher cognitive and academic ability would produce less perseverative errors on the ECB. Regression results indicate that the overall model of three IV's significantly predicts perseverative errors on the Motor Sequences test. However, review of the beta weights specify WRAT-R Arithmetic significantly contributed to the model.

These findings suggest that the ECB's unique system of eliciting perseverations is independent of IQ. Studies have found that measures of EF correlate with concept formation and fluid reasoning (Salthouse, 2006; Chase-Carmichael, et al. 1999; Chelune & Baer, 1986; Heaton, 1981) which often confounds measurement of cognitive skills. The study results suggest that the ECB does not measure fluid reasoning or concept formation and therefore remains an independent measure of EF according to this definition. Moreover, higher IQ scores do not significantly predict lower perseverative errors on the ECB subtests. This finding also supports the EF literature that contends that EF deficits do not impair IQ (Milner, 1982; Demasio & Anderson, 1993).

A significant negative relationship was observed between Motor Sequences and WRAT-R Arithmetic subtest. Results suggest that fewer errors on the Motor Sequences test predict higher performance on the WRAT-R Arithmetic. Motor Sequences is designed to elicit various types of motor perseverations, stereotypes and other deficits of

sequential organization (Luria, 1980). It is hypothesized that the sequential demands of the Motor Sequences administration is sensitive to working memory. The role of working memory in mathematic performance has been established (Bull & Scerif 2001; Passolunghi & Siegal, 2004; Hitch, 1978). Students with a disability in mathematics were found to have general working memory deficits, specifically in the central executive component (Baddeley, 1996) and primarily in the ability to inhibit irrelevant information (Passolunghi & Siegal, 2004). On a continuum of passive and active memory tasks, digits forward is closer to the short-term memory process, while digits backward involves more active working memory components as information is manipulated while held in mind (Passolunghi & Siegal, 2004). Therefore, the WISC-III may not offer enough working memory loading (digits backward and arithmetic) to adequately correlate with the Motor Sequences Test. Bull and Scerif (2001) also found that children of lower mathematical ability demonstrate difficulty on tasks that measure the ability to inhibit both prepotent information (Stroop interference) and learned strategies (WCST perseverative responses).

Conclusions

The current study explored normative data in the ECB. Hypothesized results of research questions were met with mixed findings. The ECB demonstrated adequate variance when administered to a sample of children. A developmental progression was observed when inspecting mean errors according to age. Much like adult findings, descriptive statistics indicate a low number of errors on the ECB subtests. This suggests that the ECB may be a “cut score” measure that distinguishes between intact and deficient EF in children. Additionally, the ECB was reliably scored when administered

to children and excellent internal consistency data suggests that the all items of each subtest measures the same latent variable (Cronbach, 1951). Each ECB subtest significantly correlated to each other. Moreover, as found in adult studies, the complexity of perseverative error types in the Graphical Sequences Test reduced perseverative error identification accuracy, but not to a significant degree. Validity measures conclude that the Graphical Sequences Test moderately correlates with the Stroop Color Word Test and Motor Sequences correlates with WCST Perseverative Errors. Predictive validity did not find any interaction between the ECB and IQ. Friedman's (2006) work also concluded that inhibition and shifting were not related to intelligence unlike updating. Interestingly, a significant relation was found between Motor Sequences and arithmetic as MS errors was found to be predicted by performance on WRAT-R Arithmetic. The relation to the task demands of the MS subtest and mathematic achievement is hypothesized to be working memory.

Limitations

There are a number of limitations that should be considered when discussing the results of this study. First, a preexisting dataset from a previous study was utilized. Thus, the sample was already established and included individuals primarily from the same geographical area. Additionally, the data set does not contain the most current measures of cognitive ability and academic achievement, which makes conclusions concerning current research challenging. Moreover, the newest versions of these assessments would contain updated norms that would likely influence the outcome of the analysis.

Second, the sample used in the study has specific limitations. Although the size of the overall sample was adequate, missing data contributed to a modest decrease in the number of children included in the multivariate regression. This lowered the overall power of the analysis and subsequently increased the likelihood of Type II error.

Third, the participants were recruited from private and suburban schools in southwestern Pennsylvania. The sample was primarily Caucasian and the overall mean IQ was measured in the High Average range. Therefore, results of this study are not generalized to all groups of children. Future studies should obtain a more complete data set and focus on a wider demographic in an effort to increase generalizability.

Implications

The findings of the current study suggest that the ECB is a developmentally appropriate, reliable, and valid measure of EF in children. As the authors contend, the ECB elicits perseverative behavior by utilizing novel motor tasks. Traditional EF assessments are often confounded by measuring cognitive factors such as concept formation and fluid reasoning (Salthouse, 2006; Chase-Carmichael, et al. 1999; Chelune & Baer, 1986; Heaton, 1981). This study did not produce any significant relation between IQ and the ECB. As the ECB is a measure of EF based on the concept of inhibiting a prepotent response, these findings are consistent with Friedman et al. (2006) who found that inhibition was unrelated to IQ. Therefore, clinicians and researchers will have a developmentally appropriate measure of EF that is free of shared variance with IQ. Additionally, the relation of Motor Sequences and WRAT-R Arithmetic furthers the discussion and implications of the role EF plays in academic achievement.

Directions for Future Research

Research on EF's in children has increased significantly in the past decade. Although the current study revealed adequate results, the ECB should also be studied in a clinical population to determine its efficacy in differentiating between intact and deficient EF in childhood. Further correlational and factorial analysis may prove noteworthy. The examination of the constructs of EF measured by each subtest will assist in more accurate measurement. Due to the motoric nature of the subtests, a comparison with measures of visual motor integration may be of value.

Based on this study's limitations reported above, future research should focus on the use of a larger and more geographically and diagnostically diverse sample that would allow for greater generalizability and a more complete picture of reporting trends.

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APPENDIX



DUQUESNE UNIVERSITY
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Dr. Paul Richer
Chair, Institutional Review Board
Human Protections Administrator
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November 16, 2010

Dr. Jeffrey Miller
School of Education
Duquesne University
Pittsburgh PA 15282

Dear Dr. Miller:

Re: Norming of the executive control battery in children (Protocol # 10-132)

Thank you for submitting the research protocol from your student, Mr. John Thorton, to the IRB.

Based on the review of Dr. David Delmonico, IRB Representative, and my own review, your study is approved as **Exempt** based on 45-Code of Federal Regulations-46.101.b.4, regarding data without identifiers extracted from existing records.

This exempt approval pertains strictly to the research described in the protocol. If you and Mr. Thorton intend to make a change in the research, you must submit a formal amendment for review before proceeding. In addition, you should inform the IRB if any adverse events or procedural problems occur impacting subjects. In correspondence about the research, please refer to the protocol number shown after the title above.

Once the study is complete, provide our office with a short summary (one page) of your results for our records.

Thank you for contributing to Duquesne's research endeavors.

Sincerely yours,

Paul Richer, Ph.D.

C: Mr. John Thorton
Dr. David Delmonico
IRB Records