EXAMINATION OF COGNITIVE FLEXIBILITY OVER TIME IN RESPONSE TO A COGNITIVE REHABILITATION PROGRAM IN PEDIATRIC TRAUMATIC BRAIN INJURY PATIENTS

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DEDICATION

For my parents, Wale and Moni Alade, who have always called me "Dr. K" since elementary school. For my siblings, Lola and Bola who have continued to encourage me and remind me that I'm built to achieve any goal that I want to accomplish. For my mother- and father-in-law, Judy and Sergio, who remind and encourage me to celebrate every small victory along the way. For Noble, Andrea, and Joe. I am proud and lucky to call you family. For my nephews, Elijah and Liam, and my niece, Isa, who remind me that anything can be done with a smile and a lot of fun. For my close friends who have continued to stay in my corner and encourage me throughout this process. I consider you as family as well.

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ABSTRACT

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EXAMINATION OF COGNITIVE FLEXIBILITY OVER TIME IN RESPONSE TO A COGNITIVE REHABILITATION PROGRAM IN PEDIATRIC TRAUMATIC BRAIN INJURY PATIENTS

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Traumatic brain injury (TBI), one of the leading health concerns in the United States, can affect the functioning and development of many children and adolescents. These brain injuries can result in deficits in a variety of neuropsychological skills, particularly in executive functioning. Executive functioning is a difficult neuropsychological construct to define since it is often thought to be an overarching umbrella of various neurocognitive skills. One specific executive skill is cognitive flexibility, the mental ability to switch between thinking about two different concepts and discerning multiple concepts simultaneously. Cognitive flexibility relates to various areas of functioning such as academic, social, behavioral, and adaptive abilities. Cognitive rehabilitation, which has been a standard practice since the 1980s, is a commonly used intervention to enhance functioning of those who have sustained a TBI, particularly in outpatient settings. Assessment of executive functioning and cognitive flexibility has also evolved with more focus on the pediatric population, especially with the development of the Delis-Kaplan Executive Function System (D-KEFS) and the Comprehensive Trail-Making Test (CTMT). The purpose of this study is to examine cognitive flexibility skills over time with exposure to a hospital outpatient cognitive rehabilitation program for TBI-affected children and adolescents. Another main goal of this study is to examine longitudinal effects of the program among TBI-affected groups based on the previous program participation and whether patients were receiving speech, occupational, and/or physical therapy. This study will also attempt to examine the effectiveness of the cognitive rehabilitation program compared to exposure to therapy at a longitudinal time point. Patients completed neuropsychological tasks at three different time points: before the start of the program, immediately after discharge, and a final point of evaluation between 6 and 13 months after the time of injury. This process was designed to examine possible effects of cognitive rehabilitation on specific skills over time. Repeated-measures ANOVA and one-way ANOVA were used for data analyses.

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CHAPTER I

INTRODUCTION

Traumatic brain injury (TBI), one of the leading public health concerns in the United States, affects the functioning and development of many children and adolescents. It has an annual incidence of 500 in 100,000 individuals (Georges & Booker, 2020). According to the Centers for Disease Control and Prevention (CDC; 2020) in 2014, there were 837,000 TBI-related emergency department visits, hospitalizations, and deaths in the United States in children and adolescents younger than the age of 18. One glaring concern of TBI is the number of incidents that are likely not reported because symptoms are frequently underestimated and not monitored appropriately, which has led to this injury being known as a "silent epidemic." In order to measure the severity of a TBI, the Glasgow Coma Scale (GCS) is used to classify whether a TBI is mild, moderate, or severe. The GCS uses a point system that consists of three components of arousal to assess for severity. Mild TBIs are the most common severity, comprising of 80% of reported cases, while moderate and severe TBIs each account for 10% of the TBI population (Iverson & Lange, 2011a; Iverson & Lange, 2011b).

TBI and Executive Functioning

A TBI is an injury that is caused by a bump, blow, or jolt to the head that disrupts the normal function of the brain (CDC; 2020). These brain injuries can result in deficits in a variety of neuropsychological skills. A vital neuropsychological construct that can be negatively affected is executive functioning. Executive functioning is often thought to be an overarching umbrella of a multitude of neurocognitive skills, which makes it difficult to specifically define. One of the skills that falls under this umbrella is cognitive flexibility, which is the mental ability to switch between thinking about two different concepts as well as discerning multiple concepts simultaneously. As a specific area of executive functioning, this construct theoretically can be classified into more specific categorizations such as verbal and visual cognitive flexibility (Miller & Maricle, 2019). The center of executive functioning is in the frontal lobe of the brain, specifically the prefrontal cortex (Schoenberg & Scott, 2011). Within the prefrontal cortex, the dorsolateral prefrontal cortex is the neurological substrate that is responsible for abilities in cognitive flexibility. Sustaining a TBI in these areas of the brain affects an individual's executive skills, which in turn affects various areas of life functioning.

Cognitive Flexibility

Cognitive flexibility is sometimes referred to as task-switching or set-shifting. It is the ability to shift attention from one task to another. It also requires response inhibition, which refers to the ability to stop a response that may be irrelevant or incorrect. When an individual is able to inhibit prepotent responses, this demonstrates a capability to track multiple requirements during a task. This may also show that the individual is able to monitor his or her own internal thoughts in social interaction. Active skills of cognitive flexibility involve cycles of thought generation and thought suppression that emerge and dissipate while an individual adjusts to changing factors in the environment. Cognitive flexibility is considered one of the three main executive functions (Zelazo, 2020).

Cognitive flexibility is important in solving problems. It allows individuals to think about things in multiple ways and therefore plays an important role in academic, social, emotional, behavioral, and adaptive learning. Cognitive flexibility also allows individuals to come up with alternative ways to approach a problem when their initial attempt is unsuccessful. This is commonly seen in problem solving academic tasks but it is also extremely important in social understanding. The ability to understand your own point of view coupled with the ability to take someone else's view on the same situation demonstrates good cognitive flexibility skills. However, a child who struggles with this may have difficulty understanding that a peer would like a turn during an activity or may have trouble realizing that a peer does not like the same video games as they like. Therefore, they are likely to appear rigid or inflexible in their behavior even if they are getting feedback that suggests that they should change. A common term people use to describe struggles with cognitive flexibility is when children get "stuck" during a social, emotional, or behavioral situation.

Cognitive Rehabilitation

Cognitive rehabilitation is an intervention that is used to enhance functioning for individuals who have suffered a TBI. This treatment intervention dates back to the mid-19th century when Paul Broca hypothesized that patients with aphasia could regain abilities with the use of cognitive training (Prigatano, 2018). Since the 1980s, a multitude of studies in cognitive rehabilitation have helped this intervention grow as standard treatment in clinical and hospital settings around the world. Cognitive training has also been shown to have positive longitudinal effects in adults with brain injury such as overall improved cognitive functioning, verbal memory, executive functioning, and adaptive skills (Hallock et al., 2016). Common types of interventions in cognitive rehabilitation programs include art-based activities, problem-solving activities, clinician-led information sessions, behavioral and cognitive interventions, family or social support interventions, online interventions, and multi-component interventions (Lindsay et al., 2015). There are also specific evidence-based interventions that focus on certain neurocognitive skills during this type of rehabilitation training. However, much of the integration of standard cognitive rehabilitation is practiced in the clinical setting but is lacking in the school setting.

Historical Foundations of Assessment

Neuropsychological assessment of children and adolescents began from downward extensions of common adult batteries. Two of the first downward extensions of adult neuropsychological batteries were developed in the mid-1970s; the Halstead-Reitan Neuropsychological Test Battery for Older Children and the Reitan-Indiana Neuropsychological Test Battery (Miller & Maricle, 2019). In the 1980s, the first psychometrically sound standardized online neuropsychological battery extending to the child population was developed, and was known as the Cambridge Neuropsychological Test Automated Battery (CANTAB; Bogaczewicz et al., 2015). The Wisconsin Card Sorting Test (WCST), one of the most utilized instruments to assess executive functioning and specifically cognitive flexibility, is another standardized downward extension to the child population (Delis et al., 2001). As research improved and the need to evaluate children and adolescents increased throughout the years, new instruments continued to surface and be developed. More modern neuropsychological batteries that are commonly used today include the Developmental Neuropsychological Assessment, Second Edition (NEPSY–II) and the Delis-Kaplan Executive Function System (D-KEFS). The first edition of the NEPSY was developed in 1998, while the second and latest edition was developed in 2007. It is a commonly used neuropsychological assessment battery today. There is currently only one edition of the D-KEFS, which was developed in 2001, and it is a commonly used battery to assess different areas of executive functioning. It uses a variety of standalone subtests consisting of multiple conditions within each subtest. The conditions measure different neurocognitive skills that lead up to a main condition that measures cognitive flexibility.

A classic and popular neuropsychological test of cognitive flexibility is the Trail Making Test, which assesses skills in visual scanning and processing speed. This test was originally part of the Army Individual Test Battery, developed in 1944 and was subsequently added to the Halstead-Reitan Battery in 1955 (Reynolds, 2002; Tombaugh, 2004). As this test was primarily used to assess the adult population, standardization and use for the child and adolescent populations were lacking. It was not until 2001 when a version of the original Trail Making Test was included as a subtest in the D-KEFS tailored towards the younger population, but also included more conditions within the subtest compared to the original. Shortly after the D-KEFS was published, the Comprehensive Trail-Making Test (CTMT) was published in 2002, and draws many comparisons with the Trail Making subtest on the D-KEFS. Research in adults has shown dorsolateral and medial frontal activity during the more demanding portion of the Trail Making Test (Zakzanis et al., 2005).

Another classic test of cognitive flexibility is the Stroop task, which also measures an individual’s ability to suppress impulses and incorrect responses on a habitual task. This task was named after John Ridley Stroop in 1935 as he used three tasks to eventually find the “Stroop effect” (Leon-Carrion et al., 2004). He did this by having individuals initially name color patches, then read words of the colors, and concluded by having them name color words that were incongruently printed in a different colored ink. Subsequent research, development, and standardization of this task focused on adult populations before the focus turned to children and adolescents. Multiple versions of the Stroop task now exist, including the Color-Word Interference test on the D-KEFS that adds a fourth and more cognitive demanding task that requires the examinee to read the ink color if the word is not placed in a box and to read the actual word if it is in a box. Task-switching elements of the original Stroop test and Color-Word Interference tasks have blended with other skills to assess different areas of cognitive flexibility, particularly through multiple subtests on the D-KEFS.

Statement of the Problem

Problems in cognitive flexibility are demonstrated through difficulties in decision making, trouble understanding and exhibiting empathy as well as coming up with ways to calm when upset or emotionally dysregulated. Children who struggle with cognitive flexibility are likely to have trouble understanding the perspectives of others, such as taking turns during a game, or may only focus on their own interests in conversations instead of normal back and forth flow between preferred interests. These students can often have difficulty changing their behavior even with corrective feedback from teachers during school assignments and social interactions with peers. TBIs are often associated with these types of behavioral manifestations.

TBI in the pediatric population not only affects clinical settings and services, but greatly affects services, accommodations, and performance in school. If a brain injury directly affects the corresponding neurological areas of the brain, executive functioning and cognitive flexibility skills are directly affected and therefore may negatively influence academic functioning. Even though special education law began to evolve during the 1960s and 1970s, TBI did not become a disability condition for school-aged youth until 1990 in order to receive special education services in the public school system (Vaughn, 2014). Declines in school classroom performance are associated with TBI-affected students (Taylor et al., 2002). Behavioral adjustment has been shown to be difficult for students who have had a TBI and as a predictive factor for increased likelihood of educational interventions (Yeates & Taylor, 2006). The severity of the TBI can be predictive of the degree of academic difficulties. Ewing-Cobbs, Barnes et al. (2004) found that school-aged children with severe TBI had persistent academic deficits compared to those of mild and moderate severity.

As previously stated, cognitive rehabilitation is common in the practice of improving neuropsychological skills for individuals who have sustained a TBI. Frontal lobe dysfunction, which came to be the basis of how executive functioning is studied, began to be studied in the 1960s as Hans-Lukas Teuber published “The Riddle of Frontal

Lobe Function in Man” (Bigler, 2009). Throughout the years, new theories and hypotheses on executive functioning have been created and have extended from previous theories. Through this, the construct of cognitive flexibility emerged as a specific area of executive functioning that has received more research attention. The intent of the current study is to add to the knowledge of executive functioning within the specific area of cognitive flexibility. While cognitive flexibility is assessed through neuropsychological tasks, it is important to be cognizant of how this construct affects various areas of functioning. In regard to academic functioning, deficits in cognitive flexibility have been shown to relate to reading, writing, and math (Hooper et al., 2002; Protopapas et al., 2007; Purpura et al., 2017). Social and behavioral deficits related to cognitive flexibility include difficulties in modifying strategies during daily activities and adapting to others’ perspectives (Coulacoglou & Saklofske, 2017). Adaptive behavior and daily living skills can also be negatively affected by a TBI (Yeates & Brooks, 2018). Incorporating potential positive effects of a cognitive rehabilitation program with children and adolescents who have sustained a TBI can potentially improve academic, social, behavioral, and emotional functioning, which are all areas that school-aged youth are asked to navigate throughout their educational experience.

Purpose and Significance of the Study

The purpose of this study was to examine cognitive flexibility skills over time with exposure to a hospital outpatient cognitive rehabilitation program for TBI-affected children and adolescents. Another main goal of this study was to examine longitudinal effects of the program among TBI-affected groups based on the previous program participation and whether patients were receiving speech, occupational, and/or physical therapy. The effectiveness of the cognitive rehabilitation program compared to exposure to therapy at a longitudinal time point was also examined. Adding to the research and knowledge of cognitive therapy following a TBI is warranted due to the scarcity of studies similar to this one. The cognitive rehabilitation program and data taken was designed to examine and monitor neuropsychological skills over time. Research in the improvement of neurocognitive skills after the course of a day-to-day cognitive rehabilitation treatment program is also scarce along with the tracking of these skills longitudinally. This study hoped to provide insight into treatment interventions for the pediatric TBI population and how positive effects on cognitive flexibility can improve life functioning. This study was designed in attempt to highlight potential long-lasting effects of cognitive training interventions compared to controls and hypothesize appropriate duration of these types of interventions in the future. Also, insight into bridging the gap between clinical and school intervention may be provided as a result of cognitive rehabilitation practice for TBI-affected students.

A total of seven measures of performance from three subtests of the D-KEFS (i.e., Trail Making, Verbal Fluency, Color-Word Interference) and one condition from the CTMT were used for analysis to assess cognitive flexibility. Scaled scores and z-scores were used for analysis to concisely describe and compare performance.

A repeated-measures analysis of variance (ANOVA), otherwise known as a within-subjects design, was utilized to examine performance before the start of the program, immediately after discharge, and at a final point of evaluation between 6 and 13 months after the time of the TBI. In order to investigate possible long-lasting effects of the cognitive rehabilitation program, levels of TBI-patient performance were compared among those who participated in the program and whether they were receiving therapy at a post-injury time point. Performance across each of the seven measures were analyzed and compared at the final time point between the two groups by the use of one-way ANOVA.

Hypotheses

The seven assessment measures of cognitive flexibility used in the study included 1) D-KEFS Trail Making: Number-Letter Sequencing and CTMT Trail 5, 2) D-KEFS Verbal Fluency: Switching Correct, 3) D-KEFS Verbal Fluency: Switching Accuracy, 4) D-KEFS Color-Word Interference: Inhibition Time, 5) D-KEFS Color-Word Interference: Inhibition Errors, 6) D-KEFS Color-Word Interference: Inhibition/Switching Time, and 7) D-KEFS Color-Word Interference: Inhibition/Switching Errors. The following hypotheses were proposed:

1. Comparisons between performance before the start of the program (Initial), performance immediately after the program (Discharge), and a subsequent time-point between 6 and 13 months post-TBI (Post-Injury).
    a. It was hypothesized that there would be a statistically significant difference between the three time points for each of the seven cognitive flexibility measures.
    b. Pairwise comparisons were hypothesized to demonstrate that performance at Discharge and Post-Injury would each be significantly improved

compared to the Initial testing for each of the seven cognitive flexibility measures.

c. Pairwise comparisons were hypothesized to demonstrate that there would not be a significant difference between Discharge and Post-Injury performance for each of the seven cognitive flexibility measures.

2. Comparisons at Post-Injury between two levels of program participation, two levels of exposure to therapy, and four levels of previous program participation intersected with exposure to therapy at this time point. The two program participation groups are: 1) Program (P) and 2) No Program (NP). The two therapy groups are: 1) Therapy (T) and 2) No Therapy (NT). The four groups are: 1) No Program, No Therapy (NPNT); 2) No Program, Therapy (NPT); 3) Program, No Therapy (PNT); and 4) Program, Therapy (PT).

    a. It was hypothesized that there would be a statistically significant difference within the four groups for each of the seven cognitive flexibility measures.

        i. It was hypothesized that the PT group would have statistically significant higher performance than the NPNT group.

        ii. It was hypothesized that the PT group would have statistically significant higher performance than the PNT group.

        iii. It was hypothesized that the PNT group would have statistically higher significant performance than the NPT and NPNT groups.

b. It was hypothesized that the P group would have statistically significant higher performance than the NP group.

c. It was hypothesized that the T group would have statistically significant higher performance than the NT group.

CHAPTER II

LITERATURE REVIEW

TBIs are one of the leading public health concerns in the United States due to a variety of neurocognitive abilities that are affected as well as affecting various aspects of daily life such as adaptive skills, social functioning, and academic achievement. With such a high incidence of TBI-related events that are reported, TBI is often referred to as a "silent epidemic" because symptoms are frequently underestimated and not monitored appropriately.

Executive functioning is difficult to outline with a common definition because it involves so many different skills. Many researchers have provided a multitude of theories regarding the definition of executive functioning. Stuss and Alexander (2000) posited that there is no unitary executive function but describes this construct as functioning of the prefrontal cortex. Baron (2004) stated that while executive function is heterogenous, her common definition of overlap is that this construct emphasizes the "metacognitive capacities that allow an individual to perceive stimuli from his or her environment… utilizing these capacities to serve a common purposive goal" (p. 135). Strauss et al. (2006) described executive functioning as the ability to develop new strategies and monitor effectiveness when confronted with novel or complex circumstances. A simpler definition is suggested by Koehler et al. (2011) stating that it is a "set of integrated cognitive processes necessary to perform or accomplish everyday life activities" (p. 137).

One of the specific skills intertwined in executive functioning is cognitive flexibility. It refers to the ability to shift attention between task sets, attributes of a stimulus, responses, perspectives, or strategies (Miyake et al., 2000). Basically, it can also be described as the mental ability to switch between thinking about multiple concepts simultaneously. Cognitive flexibility has more of a specific definition than executive functioning regarding how it is exhibited in neuropsychological tasks. However, this construct is continuing to be explored and how it links to various areas of life functioning. An individual who is able to inhibit prepotent responses shows that he or she is capable of tracking multiple requirements during a task and can monitor his or her internal thoughts in social interactions.

Cognitive rehabilitation is an intervention that attempts to enhance functioning and independence in patients with cognitive impairments as a result of brain damage or disease, most commonly following TBI (Koehler et al., 2011). It can be used in conjunction with physical, occupational, and speech therapy. Pertinent research is reviewed in terms of an evolving definition of cognitive rehabilitation. Additional aspects such as evidence-based practice, multidisciplinary teams who provide this service, and the systems in which this intervention is provided are discussed.

TBI undoubtedly has various effects on cognitive functioning, particularly in executive functioning and cognitive flexibility. The center of executive functioning is in the frontal lobe of the brain, where cognitive flexibility is occupied. However, it is important to consider adjacent areas of the brain and their interaction with the frontal lobe. This chapter reviews the neurological aspects of cognitive flexibility and task switching along with the theoretical models that contribute and lead to subsequent research. Aspects of executive functioning are also addressed due to the nature of cognitive flexibility and task switching falling under this wide umbrella. Developmental aspects of cognitive flexibility are discussed with much of the focus being on school-aged youth. Assessment of cognitive flexibility is a vital part of this study and therefore this review discusses the aspects of evaluating cognitive flexibility skills within the parameters and characteristics in evaluating executive functioning. The focus then shifts to TBI research of children and how cognitive flexibility is intertwined. Lastly, relative research in evidence-based practices regarding cognitive rehabilitation and cognitive training are reviewed.

Defining Executive Functioning

As previously mentioned, executive functioning is difficult to define since it encapsulates so many cognitive abilities. Therefore, it is sometimes easier to examine specific skills within this broad construct. In addition to cognitive flexibility, terminology and skills associated with executive functioning include problem solving, concept generation, abstract reasoning, planning, organization, goal setting, initiation, working memory, inhibition, regulation, and self-control. Ewing-Cobbs, Prasad et al. (2004) speak to the wide umbrella of executive functioning stating that core functions of inhibition, shifting set, and updating information in working memory are partially distinguishable but are not completely independent.

The study of executive functioning was propelled by the pioneering work of Alexander R. Luria. Through his experience with brain injured survivors of World War

II, Luria understood the importance of connecting the brain's processes with observable behavior. Luria would eventually come to be known as the father of neuropsychology and his theoretical foundations propelled modern neuropsychological assessment (Morrison & Lang, 2011). Domains within the broad umbrella of executive functioning such as cognitive flexibility and task switching have continued to evolve and warrant current active research.

Behavioral manifestations are just as important and can help explain strengths and weaknesses in the area of executive functioning. Chavez-Arana et al. (2018) separated executive functions into two categories: hot executive functions and cold executive functions. Cold executive function is described as more of a pure form and includes skills such as the manipulation of abstract concepts, cognitive flexibility, inhibition, working memory, and problem-solving. Children with deficits in cold executive functions tend to forget instructions, misplace school supplies, have difficulties concentrating during homework, make careless mistakes, and try a solution repeatedly even if it is not useful. Hot executive functions are referred to as the affective aspects of these cognitive skills such as behavioral regulation, emotional regulation, affective decision making, social functioning, and theory of mind. Impairments in these affective aspects of executive functions can negatively impact children's self-esteem, family functioning, and social adaptation. For example, a child who dominates conversations among peers, such as talking loudly about his own interests without noticing that his peers are annoyed, is likely to be a manifestation of lagging social executive functioning skills.

Skills in executive functioning undoubtedly relate to school performance and achievement ability. Different academic activities in reading, math, and writing involve different combinations of specific executive function skills, including cognitive flexibility. For example, an individual who demonstrates strong cognitive flexibility skills is likely able to consider and use alternative ways to solve academic problems when his or her initial attempt is unsuccessful. Research has continuously investigated the causal relationship between executive functioning and academic performance which is discussed later.

Defining Cognitive Flexibility

One of the hallmark executive functions attributed primarily to the frontal lobes is cognitive flexibility, which allows an individual to abandon a previous response in order to generate a novel response. Through this unique skill, humans are given the mental freedom to engage in creative thought (Delis et al., 2001). Cognitive flexibility has also been defined as an ability to change one's behavior in response to situational demands (Whiting et al., 2017) as well as the ability to shift between response sets and process multiple sources of information simultaneously (Catroppa et al., 2009). The mental ability to switch between thinking about two different concepts and to think about multiple concepts at the same time extends outside of the assessment and testing environment. It relates to how individuals perform academically, social, behaviorally, and emotionally. Active skills of cognitive flexibility involve cycles of thought generation and thought suppression that emerge and dissipate while an individual adjusts to changing factors in the environment. An example of how this is manifested socially and behaviorally is a child's ability to exhibit empathy towards others or having a good ability to think hypothetically. Cognitive flexibility is sometimes referred to as task switching or set shifting, the ability to shift attention from one task to another. An aspect of cognitive flexibility is the ability to suppress habitual or learned responses while tracking a different requirement and providing a response based on that specific requirement. People who have difficulties with cognitive flexibility and task switching may also be concrete and perseverative in their thinking as they continue to provide the same response regardless of the situational demand.

Inhibition and set-shifting, key aspects of cognitive flexibility, are important in ignoring irrelevant information as well as moving from one task to another (Best et al., 2009). Inhibition refers to "the stopping or overriding of a mental process, in whole or in part, with or without intention" (MacLeod, 2007, p. 5). Behaviorally, a student with robust cognitive flexibility skills is able to exhibit good self-control when frustrated with a difficult school assignment, for example. The student is also likely able to consider alternative ways to solve problems on this assignment. Children with poor cognitive flexibility skills are often rigid and concrete thinkers, which makes it difficult for them to come up with alternative solutions. For example, a student missing the bus on the way home from school may have difficulty thinking of other solutions in how to get home such as asking for a ride from a friend. Difficulties in cognitive flexibility can also affect students' social functioning at school, particularly in their ability to exhibit empathy. Children who struggle with cognitive flexibility problems are likely to have trouble understanding the perspectives of others, such as taking turns during a game, or may only focus on their own interests in conversations instead normal back and forth flow between preferred interests. Students can often have difficulty changing their behavior even with corrective feedback from teachers during school assignments and social interactions with peers. Regarding specific academic skills, Purpura et al. (2017) provided evidence of response inhibition and cognitive flexibility significantly relating to math achievement in preschool children. They found that response inhibition related to basic math skills, such as counting, and more complex math skills, such as story problems. They also found that cognitive flexibility related to more abstract and complex math concepts, such as number order and grouping concepts. In terms of reading ability, deficits in inhibition have been shown in children diagnosed with dyslexia as inhibition was also associated with slower reading fluency (Protopapas et al., 2007). Difficulties in being able to stop prepotent responses may exacerbate problems related to reading disabilities, especially since the phonological approach in reading requires careful tracking of how letters and symbols are segmented and blended. In relation to writing abilities, research has shown that difficulties with set shifting in fourth and fifth grade children were significantly related to poor performance on a narrative written expression task (Hooper et al., 2002). Overall, facilitating the development of executive functioning and cognitive flexibility skills in the school environment is needed due to the relationship it has with academic performance. It is logical to conclude that these neurocognitive skills are foundational for school readiness and subsequent performance.

Theoretical Models of Executive Functioning and Cognitive Flexibility

In order to fully understand executive functioning and cognitive flexibility, it is important to recognize the theoretical underpinnings and developmental neurobiology of these neuropsychological constructs. The maturation of these skills relates to how the whole brain organizes and establishes connections across neural space over time in order to understand and make sense of the increasingly automatic and controlled responses that emerge (Hunter et al., 2012).

History and Models of Executive Functioning

In 1964, Hans-Lukas Teuber published "The Riddle of Frontal Lobe Function in Man," providing a comprehensive review of known neuropsychological problems of frontal lobe function during that time (Bigler, 2009). His research designs and neuropsychological thinking set the stage for various hypotheses for future research that would subsequently provide more understanding of executive functioning. Alexander Luria then described a syndrome of disinhibited and impulsive behavior, calling it frontal lobe syndrome (Canavan et al., 1985). He further explained that individuals are unable to follow sequential instructions and have difficulty holding back tendencies towards fixed repetition of movement as a result of this syndrome. Luria examined many patients who shared these symptoms and behaviors, stating that the dissociation of verbal and motor reactions is typical. It was not until 1974 that executive functioning as a term was widely used when Alan Baddeley and Graham Hitch proposed a model of working memory (Baddeley & Della Salla, 1996). Within their model, they proposed a central executive system that is responsible for controlling the flow of information to and from various systems of conscious thought such as planning, attention, and strategy selection. In the 1980s, Donald A. Norman and Tim Shallice (1986) presented their model of the supervisory attentional system, which assumes that two complementary processes operate in the selection and control of action. The basis of the model is contention scheduling, which automatically controls routine activities without conscious control or attentional resources. For nonroutine situations that require more novel or difficult actions, the conscious activation supervisory attention system is implemented. They proposed that individuals with executive functioning deficits have limited supervisory attentional systems. Research in non-brain injured disorders, such as ADHD, picked up more speed in the 1990s. Barkley (1997) proposed a model of executive dysfunction in ADHD that initially indicated a core deficit in behavioral inhibition. However, as research has advanced and improved, he has switched and focused on executive attention being the core deficit instead of behavioral inhibition. His original model configures four core executive functions that bring motor control, fluency, and syntax under the control of internally represented information. His four functions include working memory, self-regulation, internalization of speech, and reconstitution. Models of the broad construct of executive functioning were precursors to models of cognitive flexibility.

Transitioning to Models of Cognitive Flexibility

Theoretically, the construct of cognitive flexibility emerged from models and hypotheses of executive functioning. Anderson's (2002) model suggests that attentional control is the precursor to three factors of executive functioning, one of the factors being cognitive flexibility. A school neuropsychological model proposed by Daniel Miller in

2017 described cognitive flexibility as a second-order classification of executive functioning (Miller & Maricle, 2019). While infants are able to exhibit forms of executive functioning within the first year of life (Holmboe et al., 2008), children begin to demonstrate skills in cognitive flexibility as young as the age of three (Anderson, 2002). These skills continue to develop but advance at a slower rate after the age of 9 years and at an even slower rate around the age of 12 years. Anderson states that this skill typically is fully established during mid-adolescence or early adulthood.

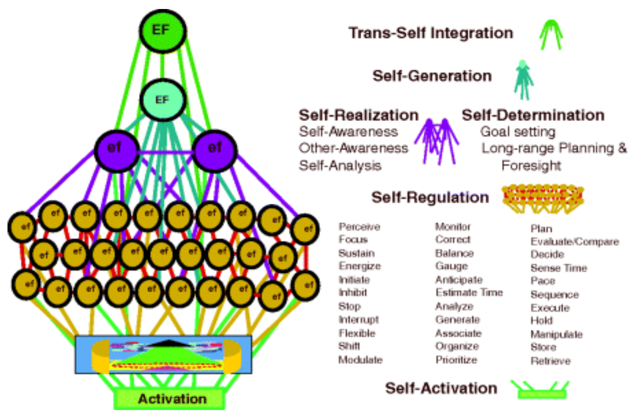
Cognitive flexibility as a specific skill began to take shape when executive functioning became a more widespread and well researched neuropsychological construct. Miyake et al. (2000) proposed a "unity and diversity" view of executive functions through their original study using a confirmatory factor analysis to test their model. They examined the performance of 137 young adults on nine different executive functioning tasks. The analysis extracted three correlated variables from the tasks, representing three components that each contribute differently to executive functioning: updating, inhibition, and shifting. Updating relates to continuous monitoring and coding incoming information by replacing irrelevant information with newer, more relevant information. Updating is closely related to the construct or skill of working memory. Inhibition refers to the ability to deliberately inhibit dominant, automatic, and prepotent responses when necessary. Many inhibition tasks also have significant working memory requirements (Best & Miller, 2010). Shifting relates to an individual's cognitive flexibility to switch between different tasks, operations, or mental sets. Being able to differentiate dissimilar domains of executive functioning can allow for more specificity and therefore more research on brain functioning during the use of these skills.

Anderson (2002) proposed a four-factor developmental model of executive functioning with one of the factors being cognitive flexibility. His model describes these four factors as discrete functions that are likely to be related to frontal lobe systems while still being able to operate in an integrative manner. In addition to cognitive flexibility, the factors include attentional control, information processing, and goal setting. Attentional control is labeled as the biggest influence and foundation of the other three and is therefore a precursor to cognitive flexibility. Attentional control includes skills in selective attention, self-regulation, and inhibition. Cognitive flexibility includes abilities in divided attention, working memory, conceptual transfer, and feedback utilization. Evidently, it is logical to see how all skills from these two factors overlap when analyzing cognitive flexibility as a whole.

McCloskey et al. (2009) proposed a much different but more specific model of executive functions that included many different variables of cognitive flexibility. They proposed a multidimensional holarchial model of executive functions. McCloskey viewed executive functioning as an overarching measure of brain intelligence, comparing it to a conductor of an orchestra. Within this large domain, he differentiates executive functioning from executive skills. He defines executive functioning as the part of the brain network responsible for cueing and directing while executive skills are responsible for the ability to carry out the directives. In his model, there are 33 self-regulation executive skills, many of which relate to cognitive flexibility and task switching. The 33 skills can be consolidated into seven clusters: attention, engagement, optimization, efficiency, memory, inquiry, and solution. Engagement is the cluster that most relates to cognitive flexibility, including skills such as energize, initiate, inhibit, stop, pause, flexible, and shift. It is important to be cognizant that cognitive flexibility tasks are not limited to these executive skills and can include other skills in other clusters such as monitor, sequence, manipulate, and others. McCloskey's model is illustrated in Figure 1.

Figure 1

McCloskey's Holarchial Model of Executive Functions



Note. Reprinted from "Ten interventions for students with executive skills and executive function difficulties," by G. McCloskey, C. Gilmartin, & B. S. Vitanza, 2012, (https://www.oreilly.com/library/view/essentials-of-planning/9781118417355/c10.xhtml)

Neuropsychological Assessment in the School Setting

The use of neuropsychological batteries for assessment in the public school system for special education referrals are generally under-utilized or not used at all. This is possibly due to a misconception that neuropsychological assessment should only be used in clinical, hospital, or private practice settings. School personnel who frequently perform the cognitive and achievement testing in the public schools often do not have the requisite training to administer neuropsychological batteries. As a result, executive functioning skills are often not thoroughly assessed in school evaluations. If a school or caregiver finds an outside neuropsychologist to assess executive functioning, the evaluation is often expensive and there may be a long wait time to complete the assessment (Miller & Maricle, 2019). However, theoretical models that integrate a school-based lens with a neuropsychological approach are becoming more prevalent. This is due to the increase of doctoral-level school psychologists practicing in the school setting, which can be credited to George Hynd who is noted as the first school psychologist advocate for doctoral school psychologists to be trained in clinical neuropsychology.

An integrative model can also be beneficial to practitioners who work in clinical, hospital, and private practice settings but have training and familiarity in school psychology. Daniel Miller introduced a school neuropsychological model in 2007, which has since been revised into the Integrated SNP/CHC (2013, 2019) including an updated library of neuropsychological constructs (Miller & Maricle, 2019). Miller's model identifies broad neurocognitive classifications and then organizes more narrow neuropsychological constructs into second-order classifications and third-order classifications. One broad classification he defines is executive processes which closely relates to the fluid reasoning (*Gf*) domain in Cattell-Horn-Carroll theory. The second-order classification of note extending from executive processes is cognitive flexibility. Verbal cognitive flexibility, visual cognitive flexibility, and verbal and visual cognitive flexibility are the three third-order classifications that extend from this second-order classification.

Neurological Aspects of Executive Functioning and Cognitive Flexibility

Understanding neurological aspects of how cognitive functioning is effectively manifested is important in explaining this neuropsychological construct. Much of the overlap neurologically falls under the umbrella of executive functioning. However, there are differences and nuances in the brain that relate primarily to cognitive flexibility. Executive functioning has historically been linked to the frontal lobe of the brain, specifically the prefrontal cortex. The frontal lobe represents the cerebral cortex anterior of the central sulcus and accounts for approximately one-third of the entire human neocortex (Schoenberg & Scott, 2011). It is thought to be the primary locus of human creativity and higher-level executive functions (Delis et al., 2001). Obviously, solely looking at the size of the frontal lobe relative to the whole brain speaks to its importance but the function of the lobe speaks of great significance as well. Goldberg (2001) described the frontal lobe as the part of the brain that defines who an individual is, one's identity, and encapsulates personal drives, ambitions, and personality. Overall, it is described as the individual's essence. The center of executive function falls within the prefrontal cortex, which is composed of the dorsolateral, orbitofrontal, and medial frontal areas (Schoenberg & Scott, 2011). These three areas of the prefrontal cortex contribute and pertain to the high levels of cognition, behavior, and emotional aspects of human behavior. Damage to the frontal lobes of the brain has traditionally been associated with impairments in the executive functions that are closely linked to the concept of flexibility

(Whiting et al., 2017). There is an abundance of knowledge and research regarding the structure of the frontal lobe but the irony is that this part of the brain may be understood the least because of the complexity of skills that are manifested through this area of the brain, particularly with executive functioning being such a broad term and concept.

There are excitatory and inhibitory pathways that begin in the subcortical regions of the brain and project to the frontal cortex. A 5-circuit scheme has been used to describe these pathways of executive functioning consisting of the skeletomotor, oculomotor, dorsolateral prefrontal, orbitofrontal, and anterior circulate circuits. The skeletomotor circuit regulates large and fine muscle movements. The oculomotor circuit is responsible for regulating eye movements. The dorsolateral prefrontal circuit is described as the "executor of the brain" (Miller & Maricle, 2019, p. 355). Impairments in this pathway can lead to decreased verbal and nonverbal retrieval, abnormal motor programming, difficulties with set shifting, poor use of feedback in task performance, and difficulties in attention. The orbitofrontal circuit accounts for the integration of emotional information into contextually appropriate behavioral responses. Exhibiting impulsivity, antisocial behavior, inappropriate feelings under normal circumstances, and irritability is seen when this pathway is negatively impacted. The anterior circulate circuit is responsible for the allocation of attentional resources, initiation of behavior, and mechanisms of motivation. Damages in this area typically cause limited spontaneous speech, poor response inhibition, problems with attention, and indifference to pain, thirst and hunger (Miller & Maricle, 2019).

When executive functioning is narrowed down to the construct of cognitive flexibility, the neurological substrate of focus is the dorsolateral prefrontal cortex. Specific functions of the dorsolateral prefrontal cortex include concrete thinking, environmental dependency, perseveration, poor set-shifting, poor sequencing, and lack of self-monitoring or self-correction. The orbitofrontal area is linked more with behavioral and social manifestations of cognitive flexibility such as an ability to inhibit verbal outbursts, ability to engage in socially appropriate behavior, and the ability to show empathy for others. Patients with lesions only in the orbitofrontal regions may perform normally on most traditional neuropsychological tests (Schoenberg & Scott, 2011). Sometimes behavioral observations and reports from reliable informants, such as caregivers and teachers, provide information about children's behavioral and emotional display of their cognitive flexibility skills. However, it is important to consider the subjective nature of observations or rating scales from a normal human bias standpoint. The medial frontal area is the least implicated in cognitive flexibility tasks and behavior but is responsible for the ability to initiate responses (Schoenberg & Scott, 2011).

Zakzanis et al. (2005) used functional MRI readings of adults who completed the Trail Making Test, which is widely used as an assessment of cognitive flexibility and task switching. Part A of this test assesses more attentional and visual scanning skills while Part B requires more cognitive resources and is considered as the cognitive flexibility and task switching component. They found distinct left-sided dorsolateral and medial frontal activity was revealed while participants completed Part B when compared to when they completed Part A (Zakzanis et al., 2005). Another study that looked into the neuroimaging of adults during a cognitive flexibility task was conducted by Kim et al. (2011). Their results demonstrated a functional organization of prefrontal cortex functioning based on the level of abstraction during tasks of cognitive flexibility. They found that highly abstract cognitive set switches recruited anterior prefrontal cortex regions, moderately abstract response switches recruited mid prefrontal cortex regions, and highly constrained stimulus switches recruited posterior prefrontal cortex regions. (Kim et al., 2011).

It is important to keep in mind that adding a language component to cognitive flexibility tasks implicates other brain regions such as the temporal and parietal lobes in the left hemisphere. On verbal fluency tasks, Broca's area is implicated due to the expressive language component of the task. When cognitive switching is incorporated in a verbal fluency task, the left-sided dorsolateral prefrontal activity is expected in conjunction with Broca's area. A verbal fluency task of this nature is explained and subsequently examined later in this study. Tasks that incorporate motor movements and cognitive flexibility are also examined. The basal ganglia serve as a relay station to the frontal lobe and are involved in the initiation and execution of movements. Eslinger and Grattan (1993) conducted a study that focused on the basal ganglia as a possible player in cognitive flexibility. Their findings suggested that the frontal lobe and basal ganglia participate differently in the neural substrate of cognitive flexibility, stating that the frontal lobe appears to mediate spontaneous flexibility. They concluded that while both the frontal lobes and basal ganglia are involved in response-shifting, the basal ganglia are less implicated in broader cognitive flexibility involving divergent thought and fluency.

Developmental Aspects of Cognitive Flexibility

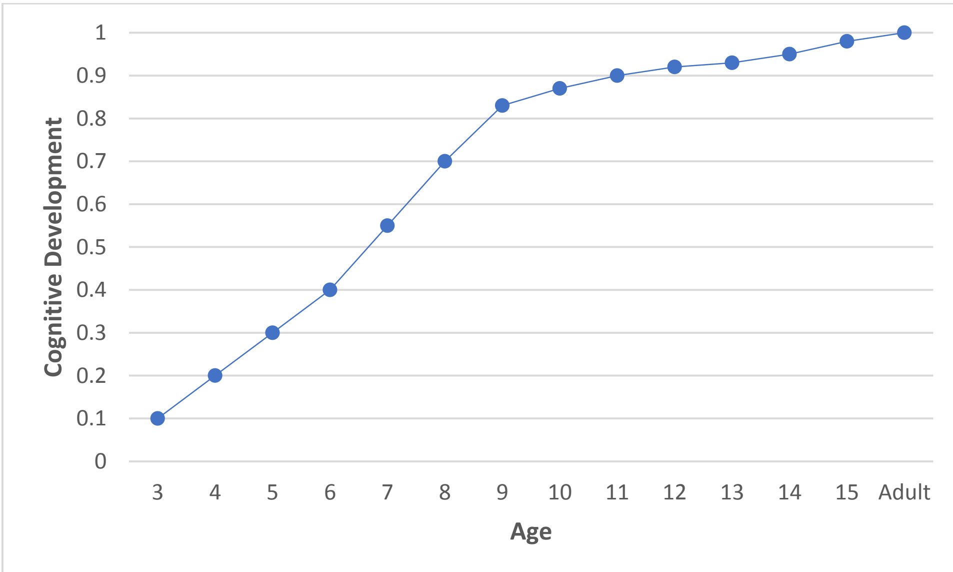
Skills and abilities in executive functions, and therefore cognitive flexibility, are manifested in different ways throughout development. Since executive functioning is a broad term, different components of this large construct demonstrate different development trajectories. Generally, executive functioning skills develop rapidly through childhood but then at a slower rate, even to a plateau, towards adolescence and young adulthood. This suggests that progression of executive functioning abilities is not necessarily linear but may occur in spurts (Anderson, 2002). Executive functions are the last neurocognitive functions to reach maturity due to the delayed maturation of the prefrontal cortex. From an individual's mid-20s until his or her mid-30s there is a continued and steady increase in myelination in the prefrontal cortex, which explains the longer time for maturation of the manifestations of executive functioning cognitively and behaviorally (De Luca & Leventer, 2008).

When it comes to attentional control, the precursor to cognitive flexibility according to Anderson's (2002) model, infants younger than 9 months old have difficulty inhibiting previously learned responses but are able to inhibit certain behaviors and shift to a new response set by the age of 1 year. At 3 years of age, children are able to inhibit instinctive behaviors but make occasional perseverative errors. Improvements in speed and accuracy on tasks of impulse control are then seen at the age of 6 years. Romine and Reynolds (2005) conducted a meta-analysis in individuals between the ages of 5 and 22 years, finding that the greatest advancements in inhibition of prepotent responses were from age 5 to 8 years. However, perseveration errors from the WCST was the only variable to measure inhibition ability. Children at 9 years and older are typically able to monitor and regulate their actions but an increase in impulsivity can be seen for a short period of time around 11 years of age (Anderson, 2002).

In regard to cognitive flexibility, perseverative behavior is common for infants, declines during early and middle childhood, and is rare in adolescence (Anderson, 2002). Infants within the first year of life are able to exhibit fundamental forms of executive functioning as shown by Holmboe et al. (2008), finding evidence that 9-month-old infants learned to inhibit looking towards distractors on multiple tasks and conditions based on their eye movements. The core components of executive functioning that Miyake et al. (2000) postulated in working memory, inhibition, and flexibility begin to rapidly develop during the preschool years (Buttelmann & Karbach, 2017). Espy (1997) examined age-related changes on a task of inhibition and switching in preschoolers, finding that inhibition efficiency varied significantly between the ages of 3 and 4 years and switching efficiency significantly improved between the ages of 4 and 5 years. Anderson et al. (2000) found that 7-year-olds struggle when switching behavior is contingent on multiple dimensions, but their ability to cope with multidimensional switching tasks improves between the ages of 7 and 9. They also found that switching fluency continues to improve throughout middle childhood and into adolescence. When Anderson (2002) later developed his theoretical model of executive functioning, he proposed that cognitive flexibility matured around the age of 12 years but is not fully established until mid-adolescence or early adulthood. Anderson’s projected trajectory of cognitive flexibility is illustrated in Figure 2. Klimkeit et al. (2004) somewhat add to this maturity of cognitive flexibility and other aspects of executive functioning. They found significant improvements occurred in set-shifting, response inhibition, and selective attention in children between the ages of 8 and 10 years but then a plateau in performance was observed in the experimental groups between the ages of 10 and 12 years. Luna et al. (2004) investigated the development of cognitive processes through a wide sample of individuals from late childhood to adulthood. In the 245-participant sample between the ages of 8 and 30 years, they found that adult-level performance began at age 14 for processing speed, age 15 for response inhibition, and age 19 for working memory on oculomotor tasks. They discussed how developmental changes were best represented by an inverse curve, showing that there was a steep change from childhood to adolescence before a plateau of these skills between late adolescence and early adulthood. While these skills relating to cognitive flexibility seem to plateau during this period of development, it is still important to remember that there is a continued and steady increase in myelination in the prefrontal cortex as mentioned by De Luca and Leventer (2008). Rubia et al. (2006) provided strong evidence of trajectory through fMRI data of adolescents and adults. Using a response inhibition task, an interference task, and a set-shifting task, they found that adults demonstrated increased brain activation in frontostriatal networks compared to adolescents. Specific activity within this network was also found to be localized by the type of task, suggesting developmental and neurological differentiation of specific executive functioning tasks. Developmental trajectories of executive functioning and cognitive flexibility have been linked to maturational changes in the prefrontal cortex and associated brain structures such as the parietal regions, which relate to sensory motor functions, and the basal ganglia which serves as a relay station to the frontal lobes (Buttelmann & Karbach, 2017).

Figure 2

Anderson's Projected Developmental Trajectory of Cognitive Flexibility



Note. Adapted from "Assessment and development of executive function during childhood," by P. Anderson, 2002, *Child Neuropsychology*, *8*(2), p. 78. (https://doi.org/10.1076/chin.8.2.71.8724)

Assessment of Cognitive Flexibility in Children

The assessment of executive functioning skills has historically been focused on adult populations. Adult batteries and tasks have subsequently been extended to children and adolescents. Development of children and adolescent batteries has continued throughout the years and has warranted continued research. The focus on executive functioning assessment is increasing in response to the usefulness of this construct in understanding the behavioral and academic profiles that present in clinical and school practice (Baron, 2004). As the awareness and focus continues to increase, so does the opportunity to provide young children with skills to improve early-onset cognitive, academic, social, behavioral, and emotional difficulties. In school settings, tests of intelligence and other basic achievement skills continue to dominate the assessment landscape. Although they are essential for assessing a variety of domains, they often fail to capture what arguably are among the most important cognitive abilities for the developing child, namely the capacity to engage in creative, abstract thinking and therefore the foundation of executive functioning (Delis et al., 2001).

Cognitive flexibility assessment is evaluated in a variety of ways through various types of tasks. However, it is important to be mindful that there are multiple underlying skills and processes that relate to cognitive flexibility during tasks, especially being under the wide spectrum of executive functioning. For example, abilities in simple attentional control are needed to perform cognitive flexibility tasks. Working memory is another skill that aids in effectively tracking requirements during cognitive flexibility or set shifting tasks. Inhibition is also included in many cognitive flexibility measures as the individual is required to overcome an entrenched response and then respond differently.

Broad based batteries of cognitive and behavioral functioning have evaluated some constructs of children and adolescents' executive functioning abilities such as working memory and fluid reasoning. However, neuropsychological batteries look deeper into more specific areas of executive functioning. Unfortunately, neuropsychological batteries that are normed for children and adolescents are scarce in comparison to adult neuropsychological batteries.

First Assessments of Executive Functioning in Children

Two of the first downward extensions of adult neuropsychological batteries were the Halstead-Reitan Neuropsychological Test Battery for Older Children developed for children between the ages of 9 and 14 years and the Reitan-Indiana Neuropsychological Test Battery for children ages 5 to 8 years, each developed in 1974 (Miller & Maricle, 2019). However, psychometric properties of each battery were of concern such as insufficient norms, the inability to differentiate psychiatric and neurological conditions in children, and the inability of the tests to localize dysfunction after a brain injury (Miller & Maricle, 2019).

The CANTAB was originally developed in the 1980s by the University of Cambridge and is now solely a computer-based neuropsychological battery. It is known as the first psychometrically sound standardized neuropsychological battery known to extend to the child population (Bogaczewicz et al., 2015). However, the CANTAB was originally developed to primarily assess neuropsychological abilities in adults but there have been increasing reports in the use of this battery with children (Strauss et al., 2006). The CANTAB has a wide range of norms as practitioners can evaluate individuals between the ages of 4 and 90 years. Tasks include a wide range of neurocognitive domains but are heavily based on nonverbal abilities due to it being computer-based while also being valuable for individuals with limited verbal language skills.

One of the most recognized tests of cognitive flexibility is the WCST. The WCST is considered the gold standard of executive function tests (Delis et al., 2001), particularly in set shifting. It also includes assessment of skills regarding problem-solving, fluid reasoning, and working memory. Subjects are provided feedback during this test and are expected to make changes in their response behavior based on the feedback. Individuals who commit high numbers of perseverative errors demonstrate deficits in cognitive flexibility and the inability to cognitively shift set within the task (Whiting et al., 2017). Another measure, the Test of Everyday Attention for Children (TEA-Ch) is considered primarily an assessment of attention, but it has also been used to assess cognitive switching for the child population. The TEA-Ch was a downward extension of the Test of Everyday Attention (TEA) used to measure attentional processes in adults between the ages of 18 and 80 years. The first edition of the TEA-Ch was developed in 1998 and the second edition (TEA-Ch2) came about in 2016, to assess children between the ages of 5 and 15 years (Strauss et al., 2006). The Reds and Blues, Bags and Shoes subtest on the TEA-Ch2 provides a switching component unlike the other subtests of attention. It is a test of mental flexibility involving switching between two relatively simple tasks. Examinees are asked to sort four repeating stimuli based on color and whether they can be held in the hand or worn on the foot (Pearson Education, 2017).

The previously mentioned neuropsychological batteries for children are based on modifications and downward extensions of existing adult batteries. In 1998, the first instrument published in English and designed exclusively as a neuropsychological battery for children was the NEPSY (Strauss et al., 2006). The second and latest edition, the NEPSY–II, was developed in 2007 and is frequently used in neuropsychological evaluations for children and adolescents today. The NEPSY-II normative sample was based on a random sample consisting of 1,200 preschoolers, children, and adolescents between the ages of 3 and 16 years. One hundred children in each of the 12 age groups were included consisting of 50 males and 50 females (Brooks et al., 2010). The NEPSY–II assesses six functional domains that include 32 subtests and four delayed recall tasks: attention and executive functioning, language, memory and learning, sensorimotor, social perception, and visuospatial processing (Korkman et al., 2007).

Subtests on the NEPSY-II that pertain to cognitive flexibility include Auditory Attention and Response Set, Design Fluency, Inhibition, and Statue. The Auditory Attention and Response Set subtest consists of two tasks. The first portion, Auditory Attention, assesses an individual's selective auditory attention ability while also sustaining it during a 3-minute task. The second part, Response Set, provides the cognitive flexibility facet of the task in which the examinee is required to shift and maintain a new and complex set involving both inhibition of previously learned responses from the first part of the task and also correctly responding to contrasting stimuli. Basically, the Response Set portion requires an individual to track and sustain multiple requirements during a 3-minute task. The Design Fluency subtest incorporates components of psychomotor speed, initiation, and self-monitoring. The child is asked to generate different and unique designs under a time limit by connecting only five dots. The dots are presented in two different conditions, one being in which the dots are structured and the other being in which the dots are randomly placed. The Inhibition subtest is similar to the Stroop Color Word Test. It assesses the examinee's ability to inhibit automatic responses as well as switching between two response types. It can include two or three conditions, based on the child's age. The first condition allows the child to correctly read an array of shapes or direction of arrows. The second condition requires the child to then read the opposite shape or direction, which taps into cognitive flexibility. The third condition requires the most cognitive resources in which the child reads the correct shape or arrow if it is black and to read the opposite shape or arrow if it is white. The Statue subtest is specifically geared to the preschool population as it is given to children between the ages of 3 and 6 years. This task is designed to assess inhibition but also includes the child's ability in motor persistence. The child is asked to close his or her eyes and maintain a body position during sound distracters.

The D-KEFS

The neuropsychological battery of main focus in this study is the D-KEFS. The D-KEFS, developed by Delis et al. (2001), is used to measure a variety of verbal and nonverbal executive functions for children and adults. It consists of nine subtests measuring different executive skills. Research and development of the battery spanned over 10 years. A main objective in the development was to provide a larger and more diverse collection of executive functioning tests than the previous measures mentioned for assessing this complex and multifactorial construct (Delis et al, 2001). Regarding the standardization sample, 1,750 children, adolescents, and adults between the ages of 8 and 89 years were included. Many existing traditional tests of executive functioning provide norms based on relatively small sample sizes unlike common batteries of intelligence and achievement (Delis et al., 2001). This should be taken into account when interpreting the D-KEFS. For example, the Wechsler Intelligence Scale for Children, Fifth Edition (WISC-V), a commonly used battery to measure cognitive functioning had a normative sample that had 2,200 children and 200 children in each of 11 different age groups. This is undoubtedly a broader standardization based than the D-KEFS sample of 1,750 children, adolescents, and adults spanning 81 years. Seventy-five children at each age group between the ages of 8 and 11 years, 100 individuals at each age between the ages of 12 and 15 years, and a total of 175 adolescents between the ages of 16 and 19 years were included in the normative sample of the D-KEFS (Delis et al., 2001). Limitations to the normative data with regard to sample size, particularly of children and adolescents between the ages of 8 and 15 should be considered when comparing to larger and more developed cognitive and achievement batteries. However, the objectives and design of the D-KEFS makes for a great way to evaluate specific aspects of executive functioning that many other neuropsychological batteries do not possess. Many of the D-KEFS subtests draw close similarities with the cognitive flexibility tasks previously described on the NEPSY–II. As frontal lobe damage is associated with difficulties in disengaging attention from salient aspects of the environment, Delis et al. added stimuli to invite more automatic, effortless responding (Strauss et al., 2006). Some of the subtests are designed to determine whether poor performance is due to deficits in fundamental cognitive skills or deficits in higher-level executive functioning.

One subtest on the D-KEFS that measures cognitive flexibility and set-shifting is the Trail Making Test. It is an extension of the adult version, Trail Making Test A and B, and it is a popular neuropsychological instrument in detecting neurological and neuropsychological impairment across processing speed, sequencing, visual-motor skills, and cognitive flexibility (Bowie & Harvey, 2006). However, neither Part A nor Part B has been found to be dependable when trying to localize cerebral dysfunction in adults or children (Baron, 2004). This is due to the variety of neurocognitive domains it assesses for, showing that it is a true measure of the broad area of executive functioning. Instead of only the two standard conditions of number sequencing in Part A and letter-number sequencing in Part B, the D-KEFS Trail Making Test requires completion of 5 separate conditions that measures an individual's flexibility of thinking by having the participant complete multiple visual-motor sequence tasks. Condition 1 is the Visual Scanning task in which the examinee completes a number-cancellation task. The examinee is asked to identify and cross out a specific number on a page amongst other numbers and letters. This task assesses an individual's ability to visually scan for an item as well as an individual's skills in attention. Condition 2 is the Number Sequencing task requiring the examinee to sequence numbers on a visual-motor task. Letters and numbers are presented on a page and the examinee is asked to connect the numbers in order without connecting the letters as distractors. This task allows an examiner to assess an individual's ability to inhibit responses to distracting stimuli. Condition 3 is the Letter Sequencing task, which is similar to Condition 2, as the examinee connects letters in sequence with numbers as distractors. Condition 4 is the premier focus of the Trail Making Test being the cognitive flexibility component, the Number-Letter Switching task. This task measures an examinee's flexibility of thinking by asking them to connect numbers and letters in sequence, but switching from a number to a letter, to a number, and so forth until the end of the task. Performance on this task tells examiners about an individual's ability to multitask, process information simultaneously, and in attention. Examinees with frontal lobe brain dysfunction typically have much difficulty with this condition (Delis et al., 2001). Condition 5 is the Motor Speed task, which provides an isolated and baseline measure of an examinee's motor ability. The examinee is asked to connect a path of dots by way of a dotted line as quickly as they can. Scores are calculated by the number of sequencing, set-loss, omission, commission, and time-discontinue errors. The time in which an examinee completes the task is also factored into the score. Individuals with frontal lobe damage often have often have difficulty with tasks requiring sustained rapid motor responses as well as sequenced, novel motor skills, which can therefore result in perseveration (Schoenberg & Scott, 2011). An examiner must consider a number of possibilities, including whether poor performance is due to slowed information processing, slow psychomotor speed, fine motor impairment, poor visual scanning, or impaired ability to sequence numbers and/or letters (Baron, 2004). The D-KEFS Trail Making Test is appealing in the child clinical setting, particularly when trying to tease out how much of cognitive flexibility difficulties are apparent in comparison to visuomotor or fine motor difficulties.

Another subtest of note is the Color-Word Interference test, which consists of four conditions in which the examinee is asked to read colors and words of colors. This subtest is similar to the Inhibition subtest on the NEPSY–II but adds a cognitive flexibility component that requires more cognitive resources. Condition 1 is the Color Naming task, which asks the examinee to quickly name blocks of colors in rows. This condition provides a baseline for basic naming skills compared to the subsequent conditions. Condition 2 is the Word Reading task requesting the examinee to read rows of colors in a similar fashion as Condition 1, but this time the blocks of colors are replaced with the word of the color. This provides a baseline for reading speed to specifically be compared to Condition 4. Condition 3 is the part of the subtest that usually becomes more challenging for the examinee, the Inhibition task. Stroop (1935) first developed this traditional interference task in which the examinee must inhibit reading the words that are printed in a different colored ink than the actual word. This test has a long history in psychology (Baron, 2004). Research has shown that left-frontal brain damaged individuals had greater difficulty with response inhibition and interference than those who had lesions in other cerebral locations (Perret, 1974). Evidence of orbitofrontal and ventral frontal activation was also found on response inhibition skills on the Stroop test (Bench et al., 1993). The Color-Word Interference subtest is used to measure selective attention and processing speed in addition to cognitive flexibility. Condition 4 is the most challenging, the Inhibition/Switching task. It includes the inhibition element of Condition 3 but adds a cognitive shifting element by asking the examinee to read the word if it is in a box and switch to reading the color of the ink if it is not in a box.

Another cognitive flexibility task from the D-KEFS that incorporates language abilities is the Verbal Fluency test. This subtest is similar to the Word Generation subtest on the NEPSY–II in which one condition asks the examinee to quickly name as many words as they can that begin with a specific letter. The second condition then asks the examinee to quickly name as many words that belong in a specific category. Unlike the Word Generation subtest on the NEPSY–II, the Verbal Fluency test on the D-KEFS includes a third condition, which succinctly measures cognitive flexibility and task switching. During this condition, the examinee is asked to quickly name as many words as they can but are required to switch between two categories. Neurologically, tests of verbal fluency involve a linguistic component, which is manifested through the left cerebral hemisphere, as well as an ideational component, which ties in the frontal lobe function of the task (Baron, 2004). The integration of these components is heightened during this third condition of the test.

The CTMT

The CTMT was developed by Cecil R. Reynolds in 2002. The theory in creating this specific battery goes back to 1938 when the original Trail Making Test was offered a measure of divided attention. It then became part of the U.S. Army Individual Test Battery in 1944, and later became a key component of the Halstead-Reitan Neuropsychological Battery in 1955 (Reynolds, 2002). As one of the most frequently used tests administered by neuropsychologists, the original Trail Making Test was undoubtedly part of the foundation of the CTMT. A theory behind the development of the CTMT was that more sensitive measures of the original TMT could be added with no real loss of the efficiency of the overall trail making measure. It sought to be more reliable with cognitive components being more explicit. The CTMT is comprised of a standardized set of five visual sequencing tasks that are heavily influenced by attention, concentration, resistance to distraction, and cognitive flexibility.

The CTMT is designed for individuals ages 11 and older and was normed on a sample of 1664 individuals in 19 U.S. states. The sample used to prepare these norms was examined in the winter of 1999 and the spring of 2000 while representing the United

States in regards to geographic area, gender, race, ethnicity, family income, parent education, and disability status (Reynolds, 2002).

Trail 1 of the CTMT essentially mimics Trail A of the original Trail Making Test. Trails 2 and 3 are similar to Trails A but introduce distractors. Trail 4 adds an element of cognitive set-shifting while Trail 5 adopts the familiar format of the Trails B of the original Trail Making Test. The raw score is calculated as the number of seconds required for the examinee to complete the trail. The raw score is then converted to a *t*-score. Reynolds (2002) adds that errors should be noted, but they are not converted to any form of standardized or scaled score. Naturally, errors have a negative impact on the examinee's score because all errors are corrected by the examiner during the task, adding to the time needed to complete the trail. This administration procedure is similar to the Trail Making Test on the D-KEFS. In general, the CTMT and D-KEFS use five different trail making tasks to examine more explicit neurocognitive functions.

Perseveration

Perseveration is a key component to examine during tasks of cognitive flexibility. It is referred to as "an abnormal continuation of behavior in the absence of the appropriate stimulus, or the immediate recurrence of a previous response to a later stimulus" (Baron, 2004, p. 188). Basically, it is described as an individual continuing to provide the same responses when they are instructed to provide a variety of responses. It is associated with frontal lobe damage in adults but does occur with damage to other brain regions or when there is frontal system pathway disruption (Kolb & Whishaw, 2015). Individuals who exhibit frequent perseveration typically have difficulty shifting their thinking to another rule or concept within a task or become overly focused in their own problem-solving strategies. For example, individuals providing the same response repeatedly within the same category on the Verbal Fluency test show how individuals demonstrate perseveration in their responses and possibly in their thinking. Perseveration is common on any task that requires an individual with frontal lobe damage to shift response strategies, showing that the frontal lobe is necessary for cognitive and behavioral flexibility (Kolb & Whishaw, 2015). Perseveration errors are not specifically counted in the aforementioned tasks from the D-KEFS and CTMT but perseveration can affect scores and performance.

TBI in Children

TBI affects many individuals in the United States on a yearly basis as it is one of the major causes of death and disabilities in the country. TBI is defined as an injury that is caused by a bump, blow, or jolt to the head that disrupts the normal function of the brain (CDC, 2020). According to the CDC (2020), there were 2.87 million TBI-related emergency department visits, hospitalizations, and deaths in 2014 with 837,000 of those being children and adolescents 17 years old and younger. TBIs are mostly caused by falls, accounting for 48% of all emergency department visits with half of those visits being by children (CDC, 2020). The second largest cause of TBIs is those in which an individual is stuck by or against an object, accounting for 17% of emergency department visits in 2014 (CDC, 2020). For those in the youth population, causes of TBI range from accidental dropping of infants to adolescents who are victims of assaults. Vehicle and bicycle accidents, physical abuse, and sports injuries also fall within this range as causes of TBI in children and adolescents. People who suffer from TBI also go through extreme behavioral and emotional difficulties. Intentional self-harm was the leading cause of TBI-related deaths in 2014, according to the CDC (2020). Boys are more likely to sustain a TBI than girls, although the ratio is lower in infants and young children than during older childhood and adolescence (Faul et al., 2010). Children younger than the age of 5 years are most likely to visit emergency departments to be evaluated for TBI, suggesting that milder injuries may be especially common among young children. In contrast, older adolescents between the ages of 15 and 19 years show the highest rates of hospitalizations and deaths, possibly reflecting the increasing severity of TBI in that age group as a function of transportation-related injuries such as motor vehicle accidents (Faul et al., 2010). Also, children ages 9 years and younger of lower socioeconomic status have substantially higher rates of emergency department visits, hospitalizations, and death in motor related TBIs (CDC, 2020). Although emergency department visits and hospitalization rates are highest among people 75 years of age and older, youth who suffer from a TBI need special attention regarding their functioning and recovery, particularly as they spend much of their time in school.

Even with these overwhelming statistics, it is important to be aware that these are only injuries that are reported. It is likely that many TBIs, particularly those of mild severity, go unreported or unrecognized. Therefore, it is often to referred as the “silent epidemic” or the “invisible disability.” Individuals are often told that they will be normally healthy with no signs of regression or difficulties. However, there are many instances in which the effects of the TBI are delayed and the individual demonstrates cognitive deficits at a different point in their development or recovery. This is especially true of children and adolescents as cognitive abilities are constantly in a period of development during youth. Unfortunately, when TBIs get misdiagnosed sometimes individuals are diagnosed with a psychiatric condition and referred for psychiatric care when their symptoms are neurological and due to the TBI.

Traumatic brain injuries occur on a broad continuum of severity, typically measured using the GCS, and ranging from mild to severe. The GCS uses three components of arousal to assess for severity of the injury such as how individuals respond to opening their eyes, their best motor response upon arousal or stimulus, and their best motor response (Iverson & Lange, 2011b). A mild head injury consists of a brief change in mental status or loss of consciousness, typically 30 minutes or less, and corresponds with a GCS of 13 to 15. A moderate head injury is of longer duration of unconsciousness and mental status change ranging from 30 minutes to 24 hours, with a GCS of 9 to 12. Noticeable physical and cognitive impairments are exhibited, which may or may not resolve with the appropriate treatment. Cognitive rehabilitation is often used as an intervention for individuals suffering from a moderate TBI. A severe head injury results in mental status change or unconsciousness for longer than 24 hours, which is classified as a GCS between 3 and 8. There are rare cases in which a TBI causes great damage to an individual that gets a GCS below a 3. This is referred to as a vegetative state. Individuals in a vegetative state experience sleep-wake cycles and arousal but do not have any interaction with the environment and do not have a localized response to pain (Iverson & Lange, 2011b). A detailed description of GCS classification is shown in Table 1.

TBIs can be considered either as open or closed. The most common type for children and adolescents is the closed type injury in which the initial compression of the head against an object in conjunction with acceleration and deceleration movement of the brain inside the skull (Yeates & Brooks, 2018). The anterior portion of the brain is the most likely to be affected by TBI, which corresponds to the frontal lobe as well as temporal regions. When there is a skull fracture and these areas of the brain are affected, a variety of injuries can occur such as contusions, hemorrhage, hematoma, edema, ventricular dilation, and damage to axons (Iverson & Lange, 2011b).

Mild TBI

Mild TBIs are the most common, comprising 80% of the 1.4 million people who sustain a TBI in the United States each year (Iverson & Lange, 2011a). Sports-related concussions are considered mild TBIs and are included in this statistic. The brain is surrounded by fluid and protective membranes, which usually cushion the brain. During an impact, the brain is pushed against the inside of the skull and can be bruised. Many people who sustain mild TBIs seek no medical attention due to being unaware of the signs and severity or being aware but not appropriately taking the injury seriously. Much of the public are also not aware of the impact cumulative injuries can have on developmental brain functioning. As a result, people may have difficulty connecting current difficulties with past mild TBIs or minor brain insults.

Table 1

Glasgow Coma Scale Classification

Response	Points	Index of Wakefulness
Eye Opening (E)		
None	1	Not attributable to ocular swelling
To pain	2	Pain stimulus is applied to chest or limbs
To speech	3	Nonspecific response to speech or shout; does not imply that the patient obeys command to open eyes
Spontaneous	4	Eyes are open; does not imply intact awareness
Motor Response (M)		
No response	1	Flaccid
Extension	2	"Decerebrate," adduction, internal rotation of shoulder, and pronation of the forearm
Abnormal flexion	3	"Decerebrate," abnormal flexion, adduction of the shoulder
Withdrawal	4	Normal flexor response; withdraws from pain stimulus with abduction of the shoulder
Localizes pain	5	Pain stimulus applied to supraocular region or fingertip causes limb to move to attempt to avoid it
Obeys commands	6	Follows simple commands
Verbal Response (V)		
No response	1	(Self-explanatory)
Incomprehensible	2	Moaning and groaning, but no recognizable words
Inappropriate	3	Intelligible speech (e.g., shouting or swearing), but no sustained or coherent conversation
Confused	4	Patient responds to questions in a conversational manner, but the responses indicate varying degrees of disorientation and confusion
Oriented	5	Normal orientation to time, place, and person

Note. Reprinted [adapted] from *Fundamentals of human neuropsychology*, by B. Kolb, & I. Q Whishaw, 2015, p. 740, Worth Publishers, Copyright 2015 by Worth Publishers.

As mild brain injuries often go unnoticed, it is important to understand possible symptoms. Symptoms usually occur immediately but can show up hours or days after an injury, highlighting the importance of follow-up and monitoring by parents, caregivers, teachers, and coaches. In the initial days post-injury, symptoms of a mild TBI include headaches, fatigue, drowsiness, dizziness, and difficulty concentrating (Iverson & Lange, 2011a). These symptoms are comorbid and have similar characteristics with mental disorders such as depression, ADHD, OCD, and anxiety so it is extremely important to get information regarding recent history of any falls, head collisions, or events during sports competitions. Depression is fairly common following a mild TBI (Iverson & Lange, 2011a). Childhood TBI is associated with an increased risk of formal psychiatric disorder (Yeates & Brooks, 2018) and other neurological and neuropsychiatric problems such as problems with balance, cranial nerve impairments, sleep disturbance, movement and motor disorders, personality changes, and visual impairments (Iverson & Lange, 2011a). A comprehensive review of individuals with TBI by Hesdorffer et al. (2009) found that these psychiatric effects can occur at least 6 months after a head injury.

Moderate to Severe TBI

Out of all TBIs, those of moderate severity account for 10% and those in the severe category account for another 10% (Iverson & Lange, 2011b). The mortality rate is highest among children with severe TBIs in stark contrast with those with mild and moderate TBIs (Yeates, 2010). Moderate to severe TBIs can have much more damaging neurological, neuropsychological, and life functioning effects than mild TBIs. Following a moderate to severe TBI, the brain oscillates within the skull upon strong traumatic impact. Neuronal pathways are therefore affected and may stretch or even sever within the brain, causing a variety of cognitive and behavioral sequelae to occur (Catroppa et al., 2009). Long-term outcomes of pediatric TBI are an active area of research but further research is still needed and warranted. The vast majority of recovery for individuals with a moderate to severe TBI occurs within the first year of the brain injury (Iverson & Lange, 2011b). With much of the research focused on the adult population, recommendations for interventions are effectively more evidence-based than the child and adolescent population. However, what is widely known is that physical, cognitive, and psychological problems can occur in children and adolescents.

For school-age youth, moderate and severe TBIs increases the risk for a wide range of emotional and behavioral problems. Schwartz et al. (2003) reported that 36% of severe TBI children and 22% of moderate TBI children had significant behavioral problems 4 years post-injury. Behaviors such as aggression and impulsivity tended to increase over time, especially in those with severe TBI. Concurrent correlations with these behavioral difficulties included deficits in working memory and poor school competence. Brain injuries during childhood are likely to result in generalized brain pathology which can negatively affect a child's developmental trajectory. Neurobehavioral consequences of pediatric moderate and severe TBI include fluctuations in arousal, disorientation, confusion, and memory loss (Yeates, 2010). These changes occur during the period of posttraumatic amnesia, which ranges from 1 to 24 hours for moderate TBIs and 1 to 7 days for severe TBIs (Lezak et al., 2012).

Language and communication skills are also significantly affected by TBIs of moderate and severe category. However, Catroppa and Anderson (2004) report that language deficits typically improve over time with the most improvement seen in severe pediatric TBI patients. Biggest improvements in intellectual functioning have also been associated with severe pediatric TBI patients. Across the TBI population, IQ scores tend to increase over time following the injury, with the largest increases occurring among children with more severe injuries. However, these increases occur the most rapidly immediately after the injury and IQ scores tend to plateau after 1 to 2 years (Yeates, 2010). Substantial improvements for moderate to severe TBI patients after 2 years are typically not expected but improved functioning can occur as the result of accommodations and interventions (Iverson & Lange, 2011b).

Overall, school-age youth who sustain a moderate or severe TBI experience a variety of neuropsychological deficits. These deficits affect the areas of attention, overall intellectual functioning, language and communication, nonverbal skills, memory, social functioning, academic performance, motor skills, adaptive functioning, and behavioral adjustment (Yeates, 2010). Executive functions also frequently occur in children with moderate and severe TBIs, as the frontal lobe is usually affected by the injury. Lagging abilities in specific executive functions such as working memory, inhibitory control, and planning have been shown in this particular population. However, research explicitly examining cognitive flexibility is extremely scarce in the moderate to severe TBI pediatric population.

Academic and Social Functional Outcomes

As expected, the neurocognitive effects of a TBI have a direct relationship with other areas of life functioning for children. Research has shown that childhood TBI is frequently associated with declines in school classroom performance (Taylor et al., 2002). When examining formal achievement testing for children, deficits are more likely for children who sustained a head injury at a young age (Ewing-Cobbs et al., 2006), suggesting lasting effects and sequelae of the TBI. Teacher ratings of postinjury behavioral adjustment has been found to be a predictive factor of decreased classroom performance and increased likelihood of educational intervention for children with moderate to severe TBI between the ages of 6 and 12 years (Yeates & Taylor, 2006).

It is important to be aware of how children with TBI receive special education services in public schools across the country. TBI became a disability condition in 1990 through the Individuals with Disabilities Education Act (IDEA), now known as the Individuals with Disabilities Education Improvement Act (IDEIA) of 2004 (Vaughn, 2014). IDEIA's classification of TBI only encapsulates those resulting from an external force or injury and does not include acquired brain injuries resulting from any type of infection, anoxia, tumors, or effects of toxic substances. The acquired brain injuries of this nature are typically classified under the Other Health Impairment or Specific Learning Disability category. Unfortunately, schools sometimes provide services based under the category a student falls under as opposed to the unique needs of the student. Therefore, a child who is eligible for special education services under TBI may receive different attention than individuals who fall under Other Health Impairment. IDEIA defines TBI as an "acquired injury to the brain caused by an external physical force, resulting in total or partial functional disability or psychosocial impairment, or both, that adversely affects a child's educational performance" (Vaughn, 2014, p. 2). The term applies to open or closed head injuries but does not apply to brain injuries that are congenital or degenerative, or induced by birth trauma.

A TBI can impede and interrupt development of executive functioning and cognitive flexibility, naturally through how the trauma physically impacts the brain. As young children develop, their cognitive skills are not as consolidated as older children. Therefore, an injury during childhood development can increase the risk of neurocognitive deficiencies after a TBI because they may lose previously acquired skills as well as possibly failing to develop new abilities (Fulton et al., 2012). This highlights the importance of monitoring and assessing children's neurocognitive abilities over time after a TBI. Their vulnerability to deficits may extend beyond deficits that are seen during the time of the injury, resulting in a child growing into their neurocognitive deficits over time.

Often school-aged youth with TBI suffer through lagging neurocognitive skills for an extended period of time, particularly with moderate and severe TBIs. Therefore, it is important to understand how these cognitive skills affect academic achievement and school performance over longer periods of time. Fulton et al. (2012) assessed a group of TBI children compared with a group with children who suffered an orthopedic injury. They found that memory and executive functioning were significant predictors of academic achievement one month after the TBI as well as one year after the TBI. They separated the TBI group into a moderate and a severe group by way of the GCS and found that children with a severe TBI had significantly lower performance on math problem solving than the orthopedic injury group. For all children, math problem solving involves executive functioning, particularly cognitive flexibility, in that multiple methods and solutions are often considered before having to select the best course of action. Blair and Razza (2007) found that kindergarteners' performance on a task of inhibitory control had a prominent correlation with early math ability, suggesting that inhibitory control can be seen as one of the central features of executive functioning. As mentioned before, inhibitory and interference control pertain to abilities in cognitive flexibility. Children who have suffered a TBI, particularly in the frontal lobe, have great difficulties in cognitive flexibility and as a result, difficulties in math problem solving. It is also important to consider how difficulties in cognitive flexibility also affect an individual's ability to self-monitor or self-correct which not only can have an effect on math problem solving but also math calculation. Ewing-Cobbs, Barnes et al. (2004) examined academic achievement of 77 school-aged children at the baseline, 6 month, 1 year, 2 years, 3 years, 4 years, and 5 or more years post-TBI. Children with severe TBI demonstrated persistent deficits across all measures of achievement and more deficits when compared to children with mild-moderate TBI. However, they also found that concurrent neurocognitive skills related to academic outcomes such as nonverbal memory and visual constructional skills being associated with mathematics and word generation as well as rapid naming skills being associated with reading and spelling outcomes. Overall, the findings suggested that specific neurocognitive skills may contribute in unique ways to different types of academic skills, similar to the theoretical basis behind the Core-Selective Evaluation Process (C-SEP) model to identify specific learning disabilities. However, the C-SEP model does not typically use neuropsychological batteries as it is often used with the

Woodcock-Johnson, Weschler, and Kaufman cognitive, achievement, and oral language batteries (Schultz & Stephens-Pisecco, 2018). Unfortunately, some schools shy away from using neuropsychological batteries in evaluations for special education services but neurocognitive skills within executive functioning, such as cognitive flexibility, are at the forefront of what we expect and ask of our children to do in school.

TBIs can also affect social functioning. Research has shown that children display deficits in theory of mind following in a TBI (Dennis et al., 2013), which relates to the ability to attribute mental states, emotions, and perspectives to others. Having difficulty understanding the perspectives of others can effectively result in problems in social interactions with peers for children. Therefore, it is often seen that children who suffer from a TBI cognitively and socially have difficulty in peer interactions. It is also important to consider that these social difficulties, particularly with theory of mind, are similar to symptoms of autism spectrum disorder. Therefore, getting a clear history of prior brain injuries can be the difference in diagnosing a child with autism or a traumatic brain injury. Misdiagnosis of a TBI in this fashion could also affect a child’s eligibility for special education services and subsequently what kinds of interventions the child may be considered for and use. In conjunction with executive functioning deficits, lack of social problem solving and information processing are linked to poor social outcomes after a TBI (Yeates et al., 2004). Results from this particular study investigating cognitive flexibility could be a precursor into expanding on social functioning of those who suffer a TBI. Adaptive behavior and daily living skills are also negatively affected by TBI, particularly those that are classified as moderate or severe (Yeates & Brooks, 2018). An individual sustaining a TBI also affects his or her family system, as caregivers and other family members can play a role in their buy-in and the recovery process. Taylor et al. (2002) found that the family environment moderates academic performance, as more supportive and functional homes lessen the impact of traumatic brain injuries. Long-term positive outcomes for children with TBI are also associated with a good family psychosocial support base (Yeates & Brooks, 2018).

Cognitive Rehabilitation

Rehabilitation is often assumed to be synonymous with improving physical disabilities. However, a rehabilitative process in this fashion is just as important psychologically. Cognitive rehabilitation aims to enhance cognitive functioning for those who have suffered from brain damage as a result of a TBI. A variety of strategies through the use of therapists and technology are used to improve cognitive skills and lessen the impairments people cope with. Cognitive training has been found to positively affect overall cognition, verbal memory, executive functioning, and instrumental activities of daily living (i.e., managing finances, cooking, housework, handling transportation) in adults with brain injuries as long as 14 years post-injury (Hallock et al., 2016).

The history of cognitive rehabilitation goes back to the mid-19th century. In 1865, Paul Broca introduced the idea that with training, patients with aphasia could regain aspects of their compromised oral and written language ability. In the 1940s, Alexander R. Luria, a member of the Russian National Volunteer Corps at the time, organized a hospital dedicated to providing pharmacological and rehabilitative interventions for motor and cognitive disorders in recovering soldiers. Cognitive rehabilitation therapy, particularly for TBI patients, started to become a standard part of care in rehabilitation hospitals throughout the United States and Europe. Since the 1980s, hundreds of outcome studies in cognitive rehabilitation therapy have helped the field mature into a multidisciplinary field grounded in the science of the neuroplasticity of the brain along with the creativity of clinical rehabilitation (Prigatano, 2018). In 1992, the Brain Injury-Interdisciplinary Special Interest Group of the American Congress of Rehabilitation Medicine published guidelines for practice in the area of rehabilitation for TBI, therefore including guidelines for cognitive rehabilitation training programs and protocols. Today, the National Institutes of Health and several professional organizations in Europe and the United States have become more involved in providing evidence-based practice guidelines to clinicians (Rohling et al., 2009).

The art and creativity of cognitive rehabilitation are seen though the variety of rehearsal techniques that have had increased empirical evidence. Stringer (2003) classified two types of general techniques that are used in cognitive rehabilitation therapy, remediation and compensatory techniques. Remediation techniques treat the brain as a muscle that can be strengthened through the exercise of weakened cognitive abilities. This is more of a mental exercise approach to rehabilitation. Compensatory techniques are utilized to improve functioning using any method that allows a patient to circumvent their cognitive limitations. These techniques can be internal, such as teaching a mnemonic strategy to aid in recall of information, or they can be external, such as writing in a notebook to store information. The goal of compensatory techniques is to help individuals become proficient in the use of a strategy as opposed to restoring a cognitive ability. A survey by Stringer (2003) found that compensatory techniques were utilized slightly more than remediation techniques in rehabilitation hospitals and programs across the United States, Puerto Rico, and Canada. Patients with TBI and stroke were the most common in this study and the therapy team consisted of speech therapists, occupational therapists, and neuropsychologists. However, the survey found that neuropsychologists provided the least services in the interdisciplinary team and few programs incorporated neuropsychological testing. This study plans to add to the cognitive rehabilitation research in the scope of neuropsychological practice.

Common types of interventions in cognitive rehabilitation programs include art-based activities, problem-solving activities, clinician-led info sessions, behavioral and cognitive interventions, family or social support interventions, online interventions, and multi-component interventions (Lindsay et al., 2015). Research has demonstrated different specific protocols and approaches that have been effective in cognitive rehabilitation therapy. Levine et al. (2000) implemented goal management training, which is a structured and standardized manual-based rehabilitation protocol that aims to train individuals to periodically stop what they are doing, attend to task goals, evaluate their performance, and monitor their performance. They found that goal management training improved performance of TBI patients on paper-and-pencil measures intended to simulate everyday activities. They also found that participants devoted more time to task completion on a proofreading task from pre-training to post-treatment, interpreting this as an improvement because participants worked more carefully and made significantly less errors. Attention process training (APT), another popular intervention in cognitive rehabilitation that consists of organized tasks that exercise different components of attention, was investigated by Sohlberg et al. (2000) in 14 patients with an acquired brain injury coupled with attention and working memory deficits. After 10 weeks of APT, they found that patients made more improvements on cognitive flexibility tasks, such as the Trail Making Test and the Stroop Color Word Test, than patients who received brain injury education. The low number of subjects in this study should reiterate that APT should not be considered a better intervention than psychoeducation but can be beneficial when these interventions are provided in conjunction with each other.

Time pressure management is another rehabilitation training that is designed to help individuals learn to prevent the pressure of time and therefore compensate for their lagging skills in mental speed (Winkens et al., 2009). The effectiveness of time pressure management on severe TBI patients was analyzed by Fasotti et al. (2000), showing that participants who used this protocol showed significantly greater use of self-management strategies and higher improvement on attention and memory functioning than those who did not receive the 3-week time pressure management treatment.

While there is a lot of evidence and research that supports the use of cognitive rehabilitation for individuals with TBI, research on the effectiveness of techniques with pediatric clients remains scarce (Limond & Leeke, 2005). Research in this population directly affects the provision of services in the school system as an evidence-based intervention for students with a TBI. McCoy et al. (1997) discussed how schools are often ill-equipped to handle the unique physical, cognitive, and behavioral challenges of this population. Therefore, school personnel often do not understand or are inadequately trained to treat the TBI population. Clinical to school reintegration is crucial in this process. Lindsay et al. (2015) reviewed the readiness of school-aged youth to return to normal activities at school, suggesting that school reintegration interventions for youth with moderate or severe brain injury have the potential to improve knowledge of injury, cognitive functioning, behavior, problem solving, social skills, and coping. One important social and emotional aspect that was mentioned is that youth with brain injuries are three times more likely to attempt suicide at school and twice as likely to be bullied at school or online. Effective clinic-to-school reintegration can mitigate these risks but standardized practices in the TBI pediatric population are currently lacking (Lindsay et al., 2015). This holistic approach to rehabilitation advocates for including parental and teacher involvement. For practitioners and professionals, an appropriate philosophy to this approach is that it needs to be interdisciplinary rather than multi-disciplinary. An interdisciplinary approach is more collaborative while a multidisciplinary approach is more parallel. Cognitive rehabilitation is also not limited to the clinical or school setting as it can also be delivered in the home setting. Lindsay et al. (2015) reviewed 17 studies between 1989 and 2014 and reported that interventions that improved cognitive functioning commonly took place in the home and were delivered one-to-one in person or online ranging from seven weeks to one year. Homework components were also found to be beneficial.

Suzman et al. (1997) investigated abilities in five children between the ages of 6 and 11 years who sustained moderate to severe head injuries between 3 and 9 months post-injury. A multi-component rehabilitation package incorporated self-instruction training, self-regulation training, metacognitive training, attribution training and reinforcement. Improvements were found on the Rey-Osterrieth Complex Figure Test and a word fluency task. A decrease in errors on a computerized problem-solving task was another result of the multi-modal cognitive rehabilitation program. The WCST was also an outcome measure but no significant differences were found. As previously mentioned, the WCST has components of cognitive flexibility, but much of the task has to do with problem solving, fluid reasoning, and working memory (Whiting et al., 2017).

Cognitive rehabilitation is a commonly utilized treatment in medical and outpatient settings but is either scarcely incorporated or is naturally overlapped with over services in the school environment (D'Angelo, 2019). For example, a speech-language pathologist may include planning and sequencing activities, but the focus is largely on improving language and pragmatics. Common accommodations for TBI students include homebound instruction, a quiet and simplified classroom, predictable classroom routines, a shortened school day, multiple rest periods, and preferential seating while examples of cognitive interventions include self-monitoring, individual or group cognitive therapy, using scripts, anxiety management strategies, and structured didactic activities that focus on social skills (Aldrich & Obrzut, 2012). More knowledge and research in cognitive rehabilitation can possibly add to the importance it could have if implemented in schools, especially with importance cognitive flexibility has in many areas of life functioning.

Summary

The concurrence of the effects of TBI with deficits in executive functioning has been shown throughout history as well as recent research. However, research in more specific neuropsychological abilities, such as cognitive flexibility, is warranted due to the difficulty of defining executive functioning as it is an extremely broad construct. Neuropsychological batteries used to assess executive functioning and cognitive flexibility have historically been downward extensions of adult populations, but instruments tailored for the children and adolescent population have improved and are continuing to be studied and utilized. Assessment batteries of note that focused on the child and adolescent population include the NEPSY/NEPSY–II, which then led to the development of the D-KEFS, a commonly used battery to measure executive functioning. The CTMT has also been used to measure a variety of executive functioning skills in school-age youth, with specific tasks pertaining to cognitive flexibility.

Executive functioning is linked to the prefrontal cortex, which is composed of the dorsolateral, orbitofrontal, and medial frontal areas of the brain. These neurological areas relate to high levels of cognitive and human behavior. Damage in these brain areas, specifically the dorsolateral prefrontal cortex, is also linked with impairments in cognitive flexibility. Theoretical models were reviewed, beginning with executive functioning before narrowing down to the study of cognitive flexibility as a more solid factor and construct within executive functioning. Child developmental aspects of executive functioning were also discussed through multiple research studies while part of the focus was through Anderson's (2002) projected trajectory of cognitive flexibility. This skill develops at a rapid rate from age 3 to 9 years, when it continues to develop but at a slower rate throughout pre-adolescence. Adolescents and young adults are able to closely approach and achieve adult levels of executive functioning and cognitive flexibility. A child or adolescent's development and trajectory of these skills is often significantly affected if they sustain a TBI.

A significant number of children and adolescents sustain TBIs on a daily, monthly, and yearly basis. Therefore, interventions to improve functioning after sustaining a TBI are needed in practice as well as the need for empirical data in the child and adolescent population. This undoubtedly affects children in the public school system, as federal legislation since the 1990s has identified TBI as a condition that can significantly affect educational progress and therefore is an eligibility category for children to receive special education services. Cognitive rehabilitation has been shown to have positive effects on various cognitive skills, but the effectiveness of this intervention has not been examined in the TBI child and adolescent population in regard to cognitive flexibility. Since standardized practice of cognitive rehabilitation is scarce in the school setting, the importance of brainstorming clinical-to-school integration needs to be addressed and discussed.

CHAPTER III

METHODS AND PROCEDURES

The participants for the current study consisted of 137 children and adolescents who sustained a TBI and were participants in a hospital pediatric day rehabilitation treatment program. The TBI sample was selected from a total of 272 children and adolescents who either participated in the pediatric day rehabilitation program or did not participate. The TBI sample was then divided into two groups: one group was defined as those who participated in the program and the other group was designated as those who did not participate in the program. Outside of the TBI sample, the patients' injuries and experiences include seizures, arteriovenous malformation, stroke, tumor, meningitis, and anoxia. The data for the TBI clinical sample was collected from records at Children's Health Specialty Center, a pediatric clinic located in Plano, Texas.

Day Treatment Program

The clinical data was acquired from a pediatric day cognitive rehabilitation program based out of Our Children's House at Baylor from 2007 to 2015. The program was designed to specialize in rehabilitation care of children who have an acquired brain injury and are in an acute phase of recovery. The goal of this intervention was to provide an intensive, multidisciplinary therapy program to help with patients' recovery. This cognitive-based program was planned to optimize patients' rehabilitation potential. Children between the ages of 5 and 18 years were eligible to receive treatment. Other eligibility requirements included being in an acute phase of recovery and the ability to tolerate intensive therapy. The 4-week program was structured for 6 hours a day from 9:00 am to 3:00 pm, 5 days a week from Monday to Friday. The program accepted a variety of commercial and managed medical insurance plans along with Medicaid. Families who wanted to pay privately were also accepted. All patient personal health information was protected by the neuropsychologist and names were given specific codes for the clinical data set.

Patients received a variety of therapies based on their individual needs. Goals and treatment schedules were based on post-admission assessments. All patients who participated in the program were referred for a neuropsychological evaluation. Patients completed initial neuropsychological testing upon admission and then completed testing at discharge. After initial testing, all of the information collected such as the clinical interview, testing, diagnostic considerations, and recommendations were included in a written report and provided to the patient’s family. The report also included cognitive strengths and weaknesses, help with educational planning, and a plan to help the child through support from the family and teachers. Since patients were missing school from their regular school setting, it was important that the program had a school in order to provide an academic learning environment. Recommendations from the initial evaluation were applied to the needs of the child when they participated in the day treatment program. Throughout the program, treatments were provided based on an individual basis or given in a small group setting. Treatment and therapy in the program were cognitive-based while including speech therapy, occupational therapy, physical therapy, aquatic therapy, and school. All patients received at least 1 hour of cognitive training from a neuropsychologist per day, mainly in compensatory strategies. Patients also received 1 hour of speech therapy which consisted of instruction in pragmatics and comprehension while focusing on some forms of cognitive training. Physical therapy used multitasking activities such as exercises while simultaneously doing a cognitive task. Occupational therapy consisted of cognitive training centered around daily living skills.

This database, which began in 2007, was developed over the course of 8 years in order to allow for research to examine the efficacy of intensive therapy following a traumatic brain injury. It was also designed to later compare the progress of children who have participated in this type of program with children who have not. Research looking at this specific comparison is scarce. Research in the improvement of neurocognitive skills after the course of a day cognitive rehabilitation treatment program is also scarce along with the tracking of these skills longitudinally.

Measures of Cognitive Flexibility

As previously mentioned, cognitive flexibility is measured in a variety of ways through different types of tasks. However, it is important to be cognizant of the fact that other executive functioning skills are naturally included when performing cognitive flexibility tasks. The D-KEFS and the CTMT were used for the current study and analysis. The D-KEFS provides a variety of standalone subtests that measure different aspects of cognitive flexibility. The Trail Making subtest is a test of visual cognitive flexibility with five conditions that incorporate visual scanning, sequencing, and psychomotor fluency. The Verbal Fluency subtest provides three conditions that includes skills in verbal cognitive flexibility as well as word and semantic fluency. The third condition of this subtest provides a switching component integrated with retrieval fluency. The Color-Word Interference subtest is another measure of verbal cognitive flexibility using four conditions integrating skills in response inhibition and naming fluency. The CTMT is similar to the D-KEFS Trail Making subtest, using five conditions to assess different areas of executive functioning. The last two conditions incorporate response inhibition and visual cognitive flexibility.

Standardization of the D-KEFS and CTMT

The D-KEFS was standardized on 1,750 non-clinical individuals between the ages of 8 and 89 years. Seventy-five children in each age between ages 8 and 11 years, 100 individuals in each age group between the ages of 12 and 15 years, and a total 175 adolescents between the ages of 16 and 19 years were included in the normative sample of the D-KEFS (Delis et al., 2001). The sample was based on the 2000 United States Census with consideration of age, sex, ethnicity, years of education, and geographic region. More than 150 sites across the United States were used in the standardization of the D-KEFS and the sample was stratified by geographic regions (Homack et al., 2005). The CTMT is based on a standardized sample of 1,664 individuals between the ages of 11 and 74 years. Of these 1,664 individuals, 748 were of school-age youth between the ages of 11 and 19 years (Reynolds, 2002). The sample was based on the 1990 United States Census with regard to geographic area, gender, race, ethnicity, family income, parent education, and disability status. The sample used to prepare the CTMT norms were collected from 19 U.S. states and tested during the winter of 1999 and the spring of 2000.

Reliability

The reliability of an assessment battery and its respective subtests pertains to the degree to which scores are free of measurement error. A measure has high reliability if it produces similar results under consistent conditions. Price (2017) explained that consistency and stability are the two key aspects of reliability having to do with the degree of similarity of multiple scores on a set of test items as well as this degree over time.

Internal consistency is measured and reported through the Cronbach's alpha statistic, ranging from 0 to 1.00 with values close to 1.00 indicating the measure has high consistency. The number of test items, item interrelatedness, and dimensionality affect the value of Cronbach's alpha. Acceptable values of Cronbach's alpha range from 0.70 to 0.95 (Tavakol & Dennick, 2011). Strauss et al. (2006) provide a more detailed classification to interpret these values, describing that values 0.90 and greater as very high, between 0.80 and 0.89 as high, between 0.70 and 0.79 as adequate, between 0.60 and 0.69 as marginal, and values 0.59 and less as low. High reliability coefficients are preferred for standardized tests because they are administered once and the individual's performance is used to draw conclusions about the individual's level on the specific skill of interest.

Stability, or test-retest reliability, is measured through Pearson correlation coefficient, also known as *r*. Pearson's *r* statistic also ranges from 0 to 1.00 with values close to 1.00 indicating that the measure has high stability. Values from 0.90 and higher are considered excellent, 0.80 to 0.89 is considered good, 0.70 to 0.79 is acceptable, and

0.60 to 0.69 is considered questionable (Glen, 2020). Strong stability demonstrates that a specific measure is reliable to give multiple times over time.

Reliability of the D-KEFS

Internal consistency for the D-KEFS was evaluated for primary measures in the normative sample. On the Trail Making Test, the combined Number Sequencing and Letter Sequencing composite is described to have adequate internal consistency, ranging from 0.57 to 0.79 between the ages of 8 and 19 (Delis et al., 2001; Shunk et al., 2006). On the Verbal Fluency test, internal consistency for the Category Switching condition ranges from 0.37 to 0.62 between the ages of 8 and 19 years. The Color-Word Interference test contains marginal to adequate internal consistency, pertaining to the combined Color Naming and Word Reading composite, with coefficients from 0.62 to 0.75 between ages 8 and 19 (Delis et al., 2001).

Stability, or test-retest reliability, is obtained by administering the same test twice over a period of time to a group of individuals. The scores from the different time periods are then correlated in order to evaluate the test for stability over time. Strauss et al. (2006) report that a 101-case sample distributed across all of the age groups was used to measure stability on the D-KEFS. The time between administrations ranged from 9 to 74 days, with an average of 25 days. On the Number-Letter Sequencing condition of the Trail Making Test, the coefficient for stability was 0.20 between the ages of 8 and 19 years, which is very low. On the Verbal Fluency subtest, the coefficient for correct switches was 0.65 and 0.53 for switching accuracy between the ages of 8 and 19 years. Coefficients for the time to complete the Inhibition and Inhibition/Switching conditions were much higher, with coefficients of 0.90 and 0.80, respectively (Delis et al., 2001). Overall, the D-KEFS tests address a complex spectrum of cognitive processes of executive functioning and therefore variability of reliability between measures is expected (Shunk et al., 2006).

Reliability of the CTMT

The CTMT manual indicates internal consistency among 646 individuals between the ages of 11 and 17 years. For Trail 5 of the test, the internal consistency coefficient is 0.70. Stability was used by testing 30 adults between the ages of 20 and 57 years twice with a 1-week period between testing. The Trail 5 coefficient was 0.75. However, stability of school-age youth were not conducted during the standardization of the CTMT. Scorer reliability for Trail 5 was strong with the coefficient being 0.96. Overall, the manual states that there are small amounts of error and that users can have confidence in the CTMT results (Reynolds, 2002).

Validity

While reliability is extremely important to examine, it alone is not sufficient. Therefore, the examination of a measure's validity is vital. Price (2017) defined validity as a judgement or estimate of how well a test measures what it is intended to measure. Validity can be measured in a variety of ways. Construct validity is the overarching umbrella term for all validity and relates to the extent a test measures what researchers want to know. Construct validity is measured through convergent validity, testing constructs that are expected to be related, and discriminant validity, testing constructs that are not expected to have a relationship. Content validity has to do with whether the test has the necessary content within the test to measure the construct. Criterion validity uses a test measure outside of the main test of analysis in order to examine how it they compare.

Validity of the D-KEFS

It is important to remember that the tests on the D-KEFS are relatively new or modifications of long-standing clinical or experimental tests that have over 60 years of neuropsychological experience (Swanson, 2005). Some of the modifications include the Stroop procedure, Trail Making Test, and a variety of verbal fluency tasks. Overall, the D-KEFS has demonstrably good construct validity. Multiple validity studies have also indicated that the D-KEFS measures have reasonable sensitivity in distinguishing many types of clinical groups from normal controls (Henry & Bettenay, 2010). Convergent validity across the nine subtests of the D-KEFS were all positive, showing that better performance on one measure is associated with better performance on another (Swanson, 2005). Discriminant validity was examined with the California Verbal Learning Test, Second Edition, a verbal memory battery, as correlations were largely non-significant in a 292-subject sample (Henry & Bettenay, 2010). Further validity research examining comparisons between the CTMT and the D-KEFS, particularly in cognitive flexibility, is warranted.

Validity of the CTMT

Reynolds (2002) stated that trail making tasks are highly vulnerable to the effects of brain injury. The various tasks on the CTMT are consistent with the components of Luria’s model of executive function such as anticipation, planning, execution, and self-monitoring (Garcia-Madruga et al., 2016). The tasks on the CTMT are very similar to the concepts of the original Trail Making Test, but with some added variables that are more sensitive to brain dysfunction and can highlight specific areas of deficit. Validity of the CTMT was also assessed by 10 licensed clinical neuropsychologists who had achieved diplomate status in neuropsychology from the American Board of Professional Psychology and/or the American Board of Professional Neuropsychology. They reviewed the five CTMT tasks and assessed the coherence, content, task demands, and ability to evaluate neuropsychological integrity of the brain. All 10 reviewers agreed that the CTMT tasks assessed attention, executive control, visual search, and sequencing. Specifically on Trail 5, they all agreed that the task required response inhibition and the majority agreed that it assessed set-shifting.

Exploratory factor analysis was also conducted across the five trails on the CTMT. Two factors were created with Trails 1, 2, and 3 being one and the other being Trails 4 and 5. The second factor was described to incorporate set-shifting of two varieties. In this study, Trail 5 is being used as a parallel to Condition 4 of the D-KEFS Trail Making because these two tasks are conceptually very similar.

Johnson et al. (2010) explored the utilization of the CTMT with focus on school-age youth. They compared a clinical TBI group with a control group with no known history of head trauma between the ages of 11 and 19 years. The control group was drawn from the normative sample of the CTMT. Principal component analysis of the TBI sample created a single-factor solution being the best while analysis of the control group created two factors, describing Trail 5 as “Complex Sequencing” (Johnson et al., 2010, p.

602) and referring to set-shifting. They concluded that the CTMT demonstrates strong sensitivity and good overall utility for use with a child and adolescent TBI population.

Procedures

Assessment batteries included seven conditions from three subtests in the D-KEFS and one condition from the CTMT. The order of the measures was dependent on the needs of the patient and the judgement of the respective examiner. Standard administration will be explained, the scores for analysis will be described, and the research design will be clarified.

D-KEFS

Trail Making

On the D-KEFS Trail Making Test, examinees on each condition are given an opportunity to learn the task by use of a practice item, allowing the examiner to correct the examinee if needed. During the actual ask, the examinee performs on an unfolded 11x17 inch page with stimuli. On all conditions except for Visual Scanning, the examiner is to correct the examinee if he or she makes a sequencing or set-loss error. Sequencing errors are when the examinee fails to correctly draw a line in the specified sequential order for the task. Set-loss errors are also known as rule violations as the examinee gets off track from the task-specific rule. For example, if the examinee is asked to connect numbers a set-loss error would occur if the examinee connected a letter instead. The primary score of interest is the time it takes for the examinee to complete the task. When the examiner needs to correct the examinee, the examiner does not stop the timer and the time continues to run, therefore affecting their primary score.

Subjects were first assessed on the Visual Scanning condition, where examiners recorded the time it takes an examinee to mark out a specific number on a page amongst other numbers and letters. They then completed the Number Sequencing condition in which examiners recorded the time it takes an examinee to sequentially connect numbers with surrounding letters as distractors. The Letter Sequencing condition was next, as the time an examinee takes to sequentially connect letters amongst number distractors was recorded by the examiner. This was followed by the Number-Letter Sequencing condition with examinees being asked to sequentially switch between numbers and letters (i.e., 1 to A, A to 2, 2 to B, B to 3, etc.). This condition is the main focus of the Trail Making Test, as it measures cognitive flexibility and was the primary condition of focus in this study. The last condition is Motor Speed, where examiners record the time it takes for examinees to connect a path of dots on the page.

Verbal Fluency

In addition to cognitive flexibility skills, the D-KEFS Verbal Fluency test relates to skills in word and retrieval fluency. The instructions are thoroughly explained by the examiner but no practice items are included. Examinees are asked to state as many words as they can within a minute and are asked to respond in a specific way in each condition. Repetition errors and set-loss errors are usually recorded by the examiner.

Subjects are first administered the Letter Fluency condition in which the examiner records the number of words an examinee can quickly say that begin with a specific letter in the span of 1 minute. Examinees are asked to refrain from using names of people, names of places, and numbers during this task. The examinee completes this task for three different letters. The next condition is Category Fluency, where the examiner records the number of words an examinee verbally produces within a specific category in the span of one minute. The examinee completes this task for two different categories. The last condition is Category Switching, which is the cognitive flexibility hallmark of this subtest. During this task, the examinee is asked to quickly name as many words as they can but are required to switch between two different categories within the 1-minute task. The examiner records the total number of correct responses along with the number of correct switches.

Color-Word Interference

During the Color-Word Interference test, examinees are asked to quickly read stimuli based on a specific rule or instruction on a variety of similar tasks. In each condition, examinees are given a practice trial in which they read 10 stimuli, which also gives the examiner the opportunity to correct the examinee if needed. During the actual task, examinees are asked to quickly read 50 stimuli aloud that are placed in five rows with 10 stimuli per row. In addition to the time it takes the examinee to read 50 stimuli, the examiner records the number of errors the examinee makes. Uncorrected errors are errors in which the examinee fails to self-monitor and correct their mistake and self-corrected errors are errors the examinee is able to successfully self-monitor and correct. Sometimes, the number of errors an examinee makes affects his or her primary score of completion time as the examiner’s timer continues to run when the examinee self-corrects their response. However, uncorrected errors do not affect the completion time but can be observed in the analysis of errors. For example, fast competition times coupled with many errors speak to the errors likely being uncorrected errors and can be a symptom of impulsivity in the examinee.

Examinees first complete the Color Naming condition, where the examiner records the time the examinee takes to name blocks of colors (i.e., red, blue, or green). The next condition is Word Reading in which the stimuli are replaced with the words of the colors. Examiners again record the time it takes for the examinee to read the words. Following this task is the Inhibition condition, similar to the traditional Stroop task, where examiners record the time it takes for examinees to read the colors of words that are printed in a different colored ink. The examiner also records the number of errors the examinees makes. The Inhibition condition was of focus in this study because of its cognitive flexibility element in response inhibition. The last condition is Inhibition/Switching, where the examinee is instructed to read the color of the word if it is not in a box and to read the actual word if it is in a box. Five non-boxed and five boxed words are included on each row. Examiners record the time it takes to complete the task as well as the number of errors the examinee commits. Inhibition/Switching was also of focus, as it presents a deeper and more complex cognitive flexibility element than the Inhibition condition.

CTMT

Similar to the D-KEFS Trail Making subtest, the CTMT consists of five conditions that measure different areas of executive functioning while having specific tasks in cognitive flexibility. Trail 1 is similar to the Number Sequencing condition on the D-KEFS in which the examiner records the time it takes for the examinee to draw and connect numbers in order from 1 to 25. Trail 2 mimics Trail 1, but empty distractor circles appear on the same page. Trail 3 also mimics Trail 1, but empty distractor circles along with distractor circles containing irrelevant line drawing appear on the same page. During Trail 4, an element of response inhibition is added. The examinee is asked to connect numbers in order from 1 to 20 where 11 of the numbers are presented as numerals and the remaining 9 are spelled out in English language form. Trail 5 is the condition that is focused on in this study and is very similar to the Number-Letter Sequencing condition on the D-KEFS. The examinee is asked to connect numbers and letters in alternating sequence with empty distractor circles present on the same page. If the examinee commits an error, the examiner is to correct the examinee during the task. This administration procedure mimics the corrective feedback procedure on the D-KEFS Trail Making subtest. However, examiners are not instructed to count errors for scoring purposes but it is recommended for qualitative information (Reynolds, 2002).

Recording Scores and Performance

Raw scores are converted to scaled scores on the D-KEFS and converted to *t*-scores on the CTMT in order to interpret how individuals perform in comparison to their same-age peers. For the purpose of this study, scaled scores from the D-KEFS and *t*-scores from the CTMT were converted to *z*-scores in order to create one variable as both measures were used to assess trail making performance of the clinical sample. Scaled scores were used for the other six cognitive flexibility measures across the Verbal Fluency and Color-Word Interference subtests.

Research Design

Subjects for each experimental group were drawn from the TBI clinical sample based on which tests were administered to them. Data was collected on subjects' performance prior to the start of the program (Initial), at the end of the program (Discharge), and a final time point between 6 and 13 months after the injury (Post-Injury). Due to the nature of within-subjects design and repeated measures ANOVA, subjects were excluded from a specific analysis if they did not complete testing at any time point. For example, if the Post-Injury testing was not completed by the participant their Initial and Discharge performance was not included in the analysis to examine differences across the three time points. Therefore, independent variables consisted of the time point (Initial, Discharge, Post-Injury). At the Post-Injury time point, groups were separated by whether they were receiving any therapy services (speech, occupational, physical). At the Post-Injury time point, independent variables consisted of program participation (P, NP) and exposure to therapy (T, NT). Dependent variables consisted of performance on seven cognitive flexibility assessment measures from three conditions on the D-KEFS and one condition on the CTMT. Independent and dependent variables are listed and illustrated in Table 2.

Table 2

List of Assessment Measures and Experimental Groups for Analysis

Assessment Measures	Time Point	Post-Injury Group
1) Trail Making	1) Initial	1) NPNT
2) Category Switching Correct	2) Discharge	2) NPT
3) Category Switching Accuracy	3) Post-Injury	3) PNT
4) Inhibition		4) PT
5) Inhibition Errors		1) P
6) Inhibiton/Switching		2) NP
7) Inhibition/Switching Errors		1) T
		2) NT

Data Analysis

One main goal of this study was to observe cognitive flexibility skills over time with the exposure to a cognitive rehabilitation program. Subjects' performance was analyzed if they completed a task at three different points: 1) before the start of the program, 2) at discharge from the program, 3) one time period after discharge for follow-up testing. The other main goal was to examine whether exposure to the program had long lasting effects over time when compared to TBI patients who did not participate in the program and whether they were receiving speech, occupational, and/or physical therapy.

The data was analyzed using IBM SPSS Statistics 25. For the purpose of this analysis, a within-subjects design was utilized because the subjects were exposed to each cognitive flexibility task. Therefore, a repeated-measures analysis of variance (ANOVA) was used to compare all TBI subjects' performance before the start of the program (Initial), at the end of the program (Discharge), and at a later time point after discharge

(Post-Injury). Pairwise comparisons were then analyzed to observe where possible differences existed between the three time points. In order to further analyze performance and increase sample size at the time points, a repeated-measures ANOVA was conducted to compare performance between Initial and Discharge only and then again conducted to compare Initial and Post-Injury performance only. An ANOVA is a statistical test that compares multiple group means of a sample in order to determine individual effects of each variable. It can also determine interaction effects of a variable with the sample. The ANOVA is one of the most used procedures to compare group means (Meyers et al., 2006).

In order to compare performance between the four Post-Injury groups, multiple one-way ANOVAs were used to do so. This is different from the repeated measures ANOVA because the four groups are independent of one other. This analysis was completed only at the Post-Injury time point for each measure for the purpose of focusing and examining the longitudinal effectiveness of the cognitive rehabilitation program among the two levels of participation and the two levels of therapy services. In addition, multiple one-way ANOVAs were conducted at Post-Injury to compare performance between those who completed the program (P) and those who did not (NP). The same analysis was also conducted to compare those who received therapy (T) and those who did not (NT).

The use of the repeated measures ANOVA is based on multiple assumptions. One of the major assumptions is sphericity which is the condition where the variances of the differences between all combinations of related groups are equal. This is evaluated through Mauchly's Test of Sphericity. If Mauchly's test is not significant, it indicates that the differences among related groups are equal and the examiner can proceed with the analysis. If this assumption of sphericity is violated, the Greenhouse-Geisser method is used to overcome the effects of this violation in a within-subjects design (Meyers et al., 2006).

Regarding the analysis at Post-Injury, statistical analysis using one-way ANOVA is based on a variety of assumptions. One assumption is that the dependent variable should be measured at the continuous level. The dependent variables in this study were each specific measure of cognitive flexibility. Other assumptions include each sample being drawn independently of each other and that there is no relationship between the observations in each group. In this study, the NPNT, NPT, PNT, and PT groups were independently observed and assessed at Post-Injury. The P and NP groups were also independently observed as well as the T and NT groups at Post-Injury. There should be no significant outliers and the dependent variable should be approximately normally distributed. There also needs to be homogeneity of variance for each combination of the groups of two independent variables (Meyers et al., 2006)

Summary

The purpose of this study was to examine whether a cognitive rehabilitation program had an effect on executive functioning skills on TBI-affected children and adolescents, particularly in cognitive flexibility. The D-KEFS and CTMT, two of the most widely used batteries to assess cognitive flexibility and other neuropsychological skills, were used to measure TBI patient performance. In addition to cognitive flexibility, the tests on these two batteries address skills such as processing speed, cognitive efficiency, attention, working memory, motor functions, visual-spatial processing, and language (Miller & Maricle, 2019). Research questions were formulated to address the progression of cognitive flexibility skills and performance during the program and whether significant changes in skills are observed months after the completion of the program. Performance was analyzed through a repeated measures ANOVA, comparing performance on the D-KEFS and CTMT subtests prior to the program, at discharge, and at a future time point between 6 and 13 months post-TBI. Post-Injury performance on each cognitive flexibility task was compared between four groups: TBI patients who participated in the program and were receiving therapy (PT), TBI patients who participated in the program and were not receiving therapy (PNT), TBI patients who did not participate in the program and were receiving therapy (NPT), and TBI patients who did not participate in the program and were not receiving therapy (NPNT). Post-Injury performance on each cognitive flexibility task was also compared between patients who participated in the program (P) and patients who did not participate in the program (NP). Lastly, Post-Injury performance was compared between patients who were receiving therapy (T) and patients were not receiving therapy (NT). The program was conducted through Children's Health Specialty Center in Plano, Texas between 2007 and 2015. No previous research has examined or investigated any aspects of this 272-patient sample of children and adolescents who experienced seizures, arteriovenous malformation, stroke, tumor, meningitis, and anoxia in addition to TBI. This study aimed to add to the scarce research in this area. Potential findings are in the hopes of providing insight into intervention techniques and strategies for children and adolescents with TBI and how positive effects on cognitive flexibility can improve life functioning.

Hypotheses

Seven measures of cognitive flexibility were used in the study. The following hypotheses were proposed:

1. Comparisons between performance at Initial, Discharge, and Post-Injury.
    a. It was hypothesized that there would be a statistically significant difference between the three time points for each cognitive flexibility measure.
    b. Pairwise comparisons were hypothesized to demonstrate that performance at Discharge and Post-Injury would each be significantly improved compared to the Initial testing for each cognitive flexibility measure.
    c. Pairwise comparisons were hypothesized to demonstrate that there would not be a significant difference between Discharge and Post-Injury performance for each cognitive flexibility measure.
2. Comparisons at Post-Injury between different levels of program participation and exposure to therapy.
    a. It was hypothesized that there would be a statistically significant difference within the four groups for each cognitive flexibility measure.
        i. It was hypothesized that the PT group would have statistically significant higher performance than the NPNT group.

ii. It was hypothesized that the PT group would have statistically significant higher performance than the PNT group.

iii. It was hypothesized that the PNT group would have statistically higher significant performance than the NPT and NPNT groups.

b. It was hypothesized that the P group would have statistically significant higher performance than the NP group.

c. It was hypothesized that the T group would have statistically significant higher performance than the NT group.

CHAPTER IV

RESULTS

Descriptive Information

This chapter includes the results of the statistical analyses conducted for the current study. The participants consisted of 137 children and adolescents who sustained a TBI. Of the 137 participants, 71 participated in the hospital pediatric day cognitive rehabilitation treatment program and 66 did not participate in the program. Average age of the sample was 172.68 months with a standard deviation of 32.93. Table 3 displays the demographics of the TBI sample in this study in regards to gender, ethnicity, and TBI severity as measured by the GCS.

Table 3

Demographics of Study Sample Compared with Program Participation

		Program Participation	
Variable	*n* = 137	Program	No Program
Gender			
Male	78	43	35
Female	59	28	31
Ethnicity			
Caucasian	85	44	41
Hispanic-American	32	15	17
African-American	15	7	8
Asian-American	3	3	0
Other	2	2	0
TBI Severity			
Mild	13	8	5
Moderate	12	6	6
Severe	80	46	34
Missing	32		

Hypothesis One

The first analysis examined cognitive flexibility performance between the Initial, Discharge, and Post-Injury time points. Seven different measures of cognitive flexibility were used to measure performance and are therefore the dependent variables. These were compared by using a repeated measures ANOVA to determine whether significant differences were present between the three time points for each cognitive flexibility measure. An alpha of .05 was selected as the level of significance. Mauchly's test of sphericity was used to test assumptions and the Greenhouse-Geisser statistic was used to correct the assumption if needed. The results of the analyses are illustrated in Table 4.

Table 4

Repeated Measures ANOVA Results of Each Cognitive Flexibility Measure

CF Measure	*n*	*F*	*p*	Partial Eta Squared
Trail Making	25	4.55	$\leq .05$	0.159
Category Switching Correct	23	7.92	$\leq .01$	0.265
Category Switching Accuracy	24	7.26	$\leq .01$	0.240
Inhibition	22	4.31	$\leq .05$	0.170
Inhibition Errors	17	2.84	0.10	0.151
Inhibition/Switching	22	2.76	0.10	0.116
Inhibition/Swtiching Errors	17	5.07	$\leq .05$	0.241

Note. CF = Cognitive Flexibility

A repeated measures ANOVA determined that mean performance differed significantly between time points on Trail Making ($F(2, 48) = 4.548$, $p < .05$). Post-hoc Bonferroni tests revealed that Discharge performance ($M = -1.09$, $SD = 1.30$) was significantly higher than Initial performance ($M = -1.59$, $SD = 1.19$). The findings of the ANOVA are represented in Table 5.

Table 5

Means, SDs, and the Significance Matrix on Trail Making for Each Time Point

				Significance Matrix		
	M	*SD*		Initial	Discharge	Post-Injury
Initial	-1.59	1.19	Initial	—	.028*	.095
Discharge	-1.09	1.30	Discharge	—	—	1.000
Post-Injury	-1.16	1.16	Post-Injury	—	—	—

Note. *$p < .05$

A repeated measures ANOVA with a Greenhouse-Geisser correction determined that mean performance differed significantly between time points on Category Switching Correct ($F(1.36, 29.82) = 7.921$, $p < .01$). Post-hoc Bonferroni tests revealed that Discharge performance ($M = 8.17$, $SD = 2.89$) was significantly higher than Initial performance ($M = 6.04$, $SD = 2.87$). The findings of the ANOVA are represented in Table 6.

Table 6

Means, SDs, and the Significance Matrix on Category Switching Correct for Each Time Point

				Significance Matrix		
	M	*SD*		Initial	Discharge	Post-Injury
Initial	6.04	2.87	Initial	—	.008*	.117
Discharge	8.17	2.89	Discharge	—	—	.070
Post-Injury	7.43	2.84	Post-Injury	—	—	—

Note. *$p < .05$

A repeated measures ANOVA with a Greenhouse-Geisser correction determined that mean performance differed significantly between time points on Category Switching Accuracy ($F(1.57, 36.03) = 7.257$, $p < .01$). Post-hoc Bonferroni tests revealed that Discharge performance ($M = 9.54$, $SD = 3.02$) was significantly higher than Initial performance (*M* = 7.13, *SD* = 3.22). The findings of the ANOVA are represented in Table 7.

Table 7

Means, SDs, and the Significance Matrix on Category Switching Accuracy for Each Time Point

				Significance Matrix		
	M	*SD*		Initial	Discharge	Post-Injury
Initial	7.13	3.22	Initial	—	.006*	.271
Discharge	9.54	3.02	Discharge	—	—	.053
Post-Injury	8.42	3.27	Post-Injury	—	—	—

Note. *$p < .05$

A repeated measures ANOVA with a Greenhouse-Geisser correction determined that there was an overall significant difference between time points on Inhibition ($F(1.67, 35.06) = 4.311$, $p < .05$). However, post-hoc Bonferroni tests did not indicate significant differences comparing each of the time points. The findings of the ANOVA are represented in Table 8.

Table 8

Means, SDs, and the Significance Matrix on Inhibition for Each Time Point

				Significance Matrix		
	M	*SD*		Initial	Discharge	Post-Injury
Initial	6.36	3.63	Initial	—	.109	.081
Discharge	7.55	3.04	Discharge	—	—	1.000
Post-Injury	8.05	3.37	Post-Injury	—	—	—

Note. *$p < .05$

As it pertains to Inhibition Errors, a repeated measures ANOVA with a Greenhouse-Geisser correction determined that mean performance did not differ significantly between the three time points ($F(1.40, 22.46) = 2.837$, $p = .095$). A repeated measures ANOVA with a Greenhouse-Geisser correction was also performed for

Inhibition/Switching. No overall significant difference was found between the time points ($F(1.36, 28.47) = 2.756$, $p = .098$). The findings of the ANOVA are represented in Tables 9 and 10.

Table 9

Means, SDs, and the Significance Matrix on Inhibition Errors for Each Time Point

				Significance Matrix		
	M	*SD*		Initial	Discharge	Post-Injury
Initial	7.47	4.69	Initial	—	.032	.811
Discharge	10.12	2.47	Discharge	—	—	.891
Post-Injury	9.12	4.66	Post-Injury	—	—	—

Note. Post-hoc comparisons were not interpreted due to repeated measures ANOVA results not having an overall significant difference between groups.

Table 10

Means, SDs, and the Significance Matrix on Inhibition/Switching for Each Time Point

				Significance Matrix		
	M	*SD*		Initial	Discharge	Post-Injury
Initial	5.95	4.82	Initial	—	1.000	.282
Discharge	5.86	3.31	Discharge	—	—	.004
Post-Injury	7.73	3.18	Post-Injury	—	—	—

Note. Post-hoc comparisons were not interpreted due to repeated measures ANOVA results not having an overall significant difference between groups.

A repeated measures ANOVA determined that mean performance differed significantly between time points on Inhibition/Switching Errors ($F(2, 32) = 5.074$, $p < .05$). Post-hoc Bonferroni tests revealed that Post-Injury performance ($M = 10.35$, $SD = 3.41$) was significantly higher than Initial performance ($M = 7.94$, $SD = 3.77$). The findings of the ANOVA are represented in Table 11.

Table 11

Means, SDs, and the Significance Matrix on Inhibition/Switching Errors for Each Time Point

				Significance Matrix		
	M	*SD*		Initial	Discharge	Post-Injury
Initial	7.94	3.77	Initial	—	.835	.003*
Discharge	8.94	3.88	Discharge	—	—	.243
Post-Injury	10.35	3.41	Post-Injury	—	—	—

Note. *$p < .05$

When comparing Initial to Discharge performance without the Post-Injury time point, a repeated measures ANOVA was used to analyze mean differences for each of the seven cognitive flexibility measures. Results revealed that Discharge performance (*M* = -1.01, *SD* = 1.33) was significantly higher than Initial performance (*M* = -1.65, *SD* = 1.20) on Trail Making. On Category Switching Correct, Discharge performance (*M* = 8.27, *SD* = 2.58) was significantly higher than Initial performance (*M* = 6.00, *SD* = 2.71). Similar results were observed on Category Switching Accuracy as Discharge performance (*M* = 9.46, *SD* = 2.71) was also significantly higher than Initial performance (*M* = 7.05, *SD* = 2.99). Regarding Inhibition, Discharge performance (*M* = 7.39, *SD* = 3.21) was significantly higher than Initial performance (*M* = 6.39, *SD* = 3.61) and a similar result was observed on Inhibition Errors with Discharge (*M* = 10.09, *SD* = 2.26) being significantly higher than Initial (*M* = 8.04, *SD* = 4.24). In regards to Inhibition/Switching and Inhibition/Switching Errors, no significant difference was found between Initial and Discharge. The findings of the ANOVA are represented in Table 12.

Table 12

Repeated Measures ANOVA Results Between Initial and Discharge

Cognitive Flexibility Measure	*n*	Initial *M*	Discharge *M*	*p*	Partial Eta Squared
Trail Making	37	-1.65	-1.01	.000*	0.333
Category Switching Correct	37	6.00	8.27	.000*	0.461
Category Switching Accuracy	37	7.05	9.46	.000*	0.405
Inhibition	33	6.39	7.39	.024*	0.149
Inhibition Errors	23	8.04	10.09	.009*	0.272
Inhibition/Switching	33	6.06	6.15	.902	0.000
Inhibition/Swtiching Errors	23	7.74	8.78	.143	0.095

Note. $*p < .05$

When comparing Initial to Post-Injury performance without the Discharge time point, a repeated measures ANOVA was used to analyze mean differences for each of the seven cognitive flexibility measures. Results revealed that Post-Injury performance (*M* = -0.85, *SD* = 1.22) was significantly higher than Initial performance (*M* = -1.13, *SD* = 1.27) on Trail Making. Post-Injury performance (*M* = 8.49, *SD* = 3.26) on Category Switching Correct was significantly higher than Initial (*M* = 6.73, *SD* = 2.92). On Category Switching Accuracy, Post-Injury performance (*M* = 9.10, *SD* = 3.39) was also significantly higher than Initial performance (*M* = 7.54, *SD* = 3.33). Post-Injury performance (*M* = 8.84, *SD* = 3.20) was significantly higher than Initial performance (*M* = 7.78, *SD* = 3.72) on Inhibition. Regarding Inhibition/Switching, Post-Injury performance (*M* = 9.05, *SD* = 3.53) was significantly higher than Initial performance (*M* = 7.32, *SD* = 4.55). Similar results were observed on Inhibition/Switching Errors as Post-Injury (*M* = 10.96, *SD* = 2.81) was significantly higher than Initial (*M* = 8.79, *SD* = 3.36). In regards to Inhibition Errors, no significant difference was found between Initial and Discharge. The findings of the ANOVA are represented in Table 13.

Table 13

Repeated Measures ANOVA Results Between Initial and Post-Injury

Cognitive Flexibility Measure	*n*	Initial *M*	Post-Injury *M*	*p*	Partial Eta Squared
Trail Making	40	-1.13	-0.85	.041*	0.103
Category Switching Correct	37	6.73	8.49	.002*	0.247
Category Switching Accuracy	39	7.54	9.10	.009*	0.167
Inhibition	37	7.78	8.84	.028*	0.126
Inhibition Errors	28	8.36	9.93	.098	0.098
Inhibition/Switching	37	7.32	9.05	.009*	0.175
Inhibition/Swtiching Errors	28	8.79	10.96	.000*	0.457

Note. *$p < .05$

It was hypothesized that Discharge and Post-Injury performance would each be significantly improved to Initial performance for each of the seven cognitive flexibility measures. Significant improvements in performance were found at Discharge compared to Initial in five of the seven cognitive flexibility measures: Trail Making, Category Switching Correct, and Category Switching Accuracy, Inhibition, and Inhibition Errors. A significant improvement was found at Post-Injury compared to Initial on six of the seven cognitive flexibility measures: Trail Making, Category Switching Correct, Category Switching Accuracy, Inhibition, Inhibition/Switching, and Inhibition/Switching Errors. It was also hypothesized that no significant differences would be found between Discharge and Post-Injury performance for each of the seven cognitive flexibility measures. This hypothesis was accurate.

Hypothesis Two

The second analysis examined cognitive flexibility performance at the Post-Injury time point only. Four groups were created to represent two levels of previous program participation and two levels of current exposure to therapy. The four groups are: 1)

NPNT, 2) NPT, 3) PNT, and 4) PT. Performance between the four groups across the seven cognitive flexibility measures was compared by using separate one-way ANOVAs to determine whether a significant difference was present between the four groups. In addition, two-group comparisons were also analyzed by use of one-way ANOVA. The two-group comparisons were based on program participation: 1) P and 2) NP. Another two-group comparison was based on therapy exposure: 1) T and 2) NT. The separate one-way ANOVAs was used to determine whether a significant difference existed between the two groups. An alpha of .05 was selected as the level of significance. Bonferroni tests were used to compare differences between each group. The homogeneity of variances for the ANOVA was tested using Levene's test, which tests the assumption that each group of independent variables has the same variance. If the assumption was violated, it was corrected by use of the Welch test and then the Games-Howell comparisons between the four groups.

It was hypothesized that there would be a statistically significant difference present within the four groups for each of the seven cognitive flexibility measures. Separate one-way ANOVAs revealed that there was at least one significant difference between the four groups on Trail Making ($F(3, 95) = 5.565$, $p < .01$), Category Switching Correct ($F(3, 93) = 5.506$, $p < .01$), Category Switching Accuracy ($F(3, 97) = 6.053$, $p < .01$), Inhibition Errors ($F(3, 82) = 4.118$, $p < .01$), and Inhibition/Switching Errors ($F(3, 81) = 6.124$, $p < .01$). Significant differences were indicated in five of the seven cognitive flexibility measures. The results of the analyses are illustrated in Table 14.

Table 14

One-way ANOVA Results at Post-Injury

Cognitive Flexibility Measure	*F*	*p*	Observed Power
Trail Making	5.57	$\leq$ .01	0.934
Category Switching Correct	5.51	$\leq$ .01	0.932
Category Switching Accuracy	6.05	$\leq$ .01	0.953
Inhibition	0.45	0.72	0.137
Inhibition Errors	4.12	$\leq$ .01	0.833
Inhibition/Switching	1.36	0.26	0.351
Inhibition/Swtiching Errors	6.14	$\leq$ .01	0.954

It was hypothesized that the PT group would have statistically significant higher performance than the PNT and NPNT groups. Bonferroni post-hoc comparisons revealed that PT group performance was not significantly higher than the PNT group for any of the cognitive flexibility measures nor was it significantly higher than the NPNT group for any of the seven measures. However, PNT group performance (*M* = -0.33, *SD* = 1.00) was significantly higher than PT group performance (*M* = -1.45, *SD* = 1.08) on Trail Making.

It was also hypothesized that the PNT group would have statistically significant higher performance than the NPT and NPNT groups. Bonferroni post-hoc comparisons revealed that PNT group performance was significantly higher than NPT group performance across all five cognitive flexibility measures that demonstrated a significant main effect. On Trail Making, PNT performance (*M* = -0.33, *SD* = 1.00) was significantly higher than NPT group performance (*M* = -1.45, *SD* =1.10). Category Switching Correct results showed that PNT group performance (*M* = 9.53, *SD* = 3.73) was significantly higher than NPT performance (*M* = 6.32, *SD* = 2.93). Category Switching Accuracy results showed that PNT group performance (*M* = 9.94, *SD* = 3.84) was significantly higher than NPT group performance (*M* = 6.44, *SD* = 3.19). Results from Inhibition Errors showed that PNT group performance (*M* = 10.47, *SD* = 3.20) was significantly higher than NPT performance (*M* = 6.75, *SD* = 3.88). Results from Inhibition/Switching Errors revealed that PNT performance (*M* = 11.00, *SD* = 2.67) was significantly higher than NPT performance (*M* = 6.16, *SD* = 4.13).

It was hypothesized that the P group would have statistically significant higher performance than the NP group for each of the seven cognitive flexibility measures. Results revealed that P group performance was significantly higher than NP group performance on two of the seven cognitive flexibility measures. Inhibition Errors results showed that P group performance (*M* = 10.14, *SD* = 3.76) was significantly higher than NP group performance (*M* = 7.41, *SD* = 3.70). Similarly, Inhibition/Switching Errors results demonstrated that P group performance (*M* = 10.29, *SD* = 3.30) was significantly higher than NP group performance (*M* = 7.72, *SD* = 3.84).

It was hypothesized that the T group would have statistically significant higher performance than the NT group for each of the seven cognitive flexibility measures. Results revealed that T group performance was not significantly higher than NT group performance on all of the seven cognitive flexibility measures. Unexpectedly, NT group performance was significantly higher than T group performance in four of the seven cognitive flexibility measures. The results of each analysis regarding the comparisons between all groups at the Post-Injury time point are illustrated in Tables 15 to 35.

Table 15

Sample sizes, means, SDs, and the Significance Matrix on Trail Making for Each Exposure Group

					Significance Matrix			
	n	*M*	*SD*		NPNT	NPT	PNT	PT
NPNT	36	-0.63	1.27	NPNT	—	.046*	1.000	.064
NPT	24	-1.45	1.10	NPT	—	—	.013*	1.000
PNT	18	-0.33	1.00	PNT	—	—	—	.018*
PT	21	-1.45	1.08	PT	—	—	—	—

Note. *$p < .05$

Table 16

Group Comparision Between Program Participation on Trail Making at Post-Injury

	n	*M*	*SD*	*p*
P	39	-0.93	1.17	.916
NP	60	-0.96	1.26	

Note. *$p < .05$

Table 17

Group Comparision Between Therapy Exposure on Trail Making at Post-Injury

	n	*M*	*SD*	*p*
T	45	-1.45	1.08	.000*
NT	54	-0.53	1.19	

Note. *$p < .05$

Table 18

Sample Sizes, Means, SDs, and the Significance Matrix on Category Switching Correct for Each Exposure Group

					Significance Matrix			
	n	*M*	*SD*		NPNT	NPT	PNT	PT
NPNT	36	9.03	3.04	NPNT	—	.006*	1.000	.398
NPT	25	6.32	2.93	NPT	—	—	.007*	1.000
PNT	17	9.53	3.73	PNT	—	—	—	.247
PT	19	7.42	2.52	PT	—	—	—	—

Note. *$p < .05$

Table 19

Group Comparision Between Program Participation on Category Switching Correct at Post-Injury

	n	*M*	*SD*	*p*
P	36	8.42	3.28	.469
NP	61	7.92	3.26	

Note. *p < .05

Table 20

Group Comparision Between Therapy Exposure on Category Switching Correct Making at Post-Injury

	n	*M*	*SD*	*p*
T	44	6.80	2.78	.000*
NT	53	9.19	3.25	

Note. *p < .05

Table 21

Sample Sizes, Means, SDs, and the Significance Matrix on Category Switching Accuracy for Each Exposure Group

					Significance Matrix			
	n	*M*	*SD*		NPNT	NPT	PNT	PT
NPNT	38	9.53	3.06	NPNT	—	.002*	1.000	.814
NPT	25	6.44	3.19	NPT	—	—	.004*	.414
PNT	18	9.94	3.84	PNT	—	—	—	.574
PT	20	8.20	2.78	PT	—	—	—	—

Note. *p < .05

Table 22

Group Comparision Between Program Participation on Category Switching Accuracy at Post-Injury

	n	*M*	*SD*	*p*
P	38	9.03	3.40	.305
NP	63	8.30	3.44	

Note. *p < .05

Table 23

Group Comparision Between Therapy Exposure on Category Switching Accuracy at Post-Injury

	n	*M*	*SD*	*p*
T	45	7.22	3.11	.000*
NT	56	9.66	3.30	

Note. *$p < .05$

Table 24

Sample Sizes, Means, SDs, and the Significance Matrix on Inhibition for Each Exposure Group

					Significance Matrix			
	n	*M*	*SD*		NPNT	NPT	PNT	PT
NPNT	37	8.30	3.81	NPNT	—	1.000	1.000	1.000
NPT	22	8.41	3.47	NPT	—	—	1.000	1.000
PNT	18	9.39	2.45	PNT	—	—	—	1.000
PT	20	8.35	3.63	PT	—	—	—	—

Note. *$p < .05$

Table 25

Group Comparision Between Program Participation on Inhibition at Post-Injury

	n	*M*	*SD*	*p*
P	38	8.84	3.13	.486
NP	59	83.4	3.66	

Note. *$p < .05$

Table 26

Group Comparision Between Therapy Exposure on Inhibition at Post-Injury

	n	*M*	*SD*	*p*
T	42	8.65	3.44	.701
NT	55	8.38	3.51	

Note. *$p < .05$

Table 27

Sample Sizes, Means, SDs, and the Significance Matrix on Inhibition Errors for Each Exposure Group

					Significance Matrix			
	n	*M*	*SD*		NPNT	NPT	PNT	PT
NPNT	31	7.84	3.58	NPNT	—	1.000	.133	.453
NPT	20	6.75	3.88	NPT	—	—	.020*	.078
PNT	17	10.47	3.20	PNT	—	—	—	1.000
PT	18	9.83	4.29	PT	—	—	—	—

Note. **p* < .05

Table 28

Group Comparision Between Program Participation on Inhibition Errors at Post-Injury

	n	*M*	*SD*	*p*
P	35	10.14	3.76	.001*
NP	51	7.41	3.70	

Note. **p* < .05

Table 29

Group Comparision Between Therapy Exposure on Inhibition Errors at Post-Injury

	n	*M*	*SD*	*p*
T	38	8.21	4.31	.516
NT	48	8.77	3.65	

Note. **p* < .05

Table 30

Sample Sizes, Means, SDs, and the Significance Matrix on Inhibition/Switching for Each Exposure Group

					Significance Matrix			
	n	*M*	*SD*		NPNT	NPT	PNT	PT
NPNT	37	8.22	3.97	NPNT	—	1.000	.868	1.000
NPT	21	7.57	3.52	NPT	—	—	.397	1.000
PNT	18	9.78	3.14	PNT	—	—	—	.617
PT	20	7.80	3.81	PT	—	—	—	—

Note. **p* < .05

Table 31

Group Comparision Between Program Participation on Inhibition/Swithing at Post-Injury

	n	*M*	*SD*	*p*
P	38	8.74	3.60	.333
NP	58	7.98	3.79	

Note. *$p < .05$

Table 32

Group Comparision Between Therapy Exposure on Inhibition/Swithing at Post-Injury

	n	*M*	*SD*	*p*
T	41	7.68	3.62	.174
NT	55	8.73	3.76	

Note. *$p < .05$

Table 33

Sample Sizes, Means, SDs, and the Significance Matrix on Inhibition/Switching Errors for Each Exposure Group

					Significance Matrix			
	n	*M*	*SD*		NPNT	NPT	PNT	PT
NPNT	31	8.68	3.37	NPNT	—	.133	.057	.820
NPT	19	6.16	4.13	NPT	—	—	.001*	.054
PNT	17	11.00	2.67	PNT	—	—	—	.591
PT	18	9.61	3.76	PT	—	—	—	—

Note. *$p < .05$

Table 34

Group Comparision Between Program Participation on Inhibition/Swithing Errors at Post-Injury

	n	*M*	*SD*	*p*
P	35	10.29	3.30	.002*
NP	50	7.72	3.84	

Note. *$p < .05$

Table 35

Group Comparision Between Therapy Exposure on Inhibition/Swithing Errors at Post-Injury

	n	*M*	*SD*	*p*
T	37	7.84	4.27	.046*
NT	48	9.50	3.31	

Note. *$p < .05$

A repeated-measures ANOVA was conducted to test the hypothesis that performance at Discharge and Post-Injury would be significantly improved compared to performance at Initial. It was also hypothesized that there would be no significant difference between Discharge and Post-Injury performance. Bonferroni comparisons were used to compare differences within the three time points. To investigate the second hypothesis, one-way ANOVA was used. The second hypothesis pertained to the comparisons in performance at Post-Injury between program participation and exposure to therapy. It was hypothesized that the PT group would significantly have the highest performance, followed by the PNT group, and then the NPT group. Since the emphasis of the current study was centered around performance in response to the cognitive rehabilitation program, comparisons between the NPT group and NPNT group were not of focus. It was also hypothesized that P group performance would be significantly higher than NP performance and T group performance would be significantly higher than NT group performance. Given the results, it is important to delve into the interpretation, implication, and application of the findings along with considering this study’s limitations and potential for future investigations.

CHAPTER V

DISCUSSION

TBI has been shown to potentially affect the functioning and development of many children and adolescents as it is one of the leading public health concerns in the United States. Many TBIs occur in the prefrontal cortex, which is the center of cognitive flexibility (Schoenberg & Scott, 2011). This study investigated the cognitive flexibility performance of a pediatric TBI sample over time in relation to their participation in a daily cognitive rehabilitation program. Deficits in cognitive flexibility relate to various academic, social, emotional, behavioral, and adaptive skills. Therefore, it is logical to understand that this skill is essential for many areas of life functioning. As examples to highlight its importance, Zelazo (2020) considers cognitive flexibility as one of the three main executive functions and Buttelmann and Karbach (2017) describe cognitive flexibility as a core dimension of executive functions. The lack of cognitive flexibility can lead to difficulties in impulsiveness, multi-tasking, problem-solving, empathy, socially appropriate behaviors, emotional regulation, and various areas of academic achievement. For children and adolescents who have suffered a TBI, cognitive rehabilitation has historically been a treatment intervention used for this population. However, research in cognitive rehabilitation in the pediatric TBI population as it specifically pertains to cognitive flexibility is scarce.

The assessment of executive functioning and cognitive flexibility has developed throughout the years and has now extended to the pediatric population over the past 50 years. The D-KEFS, created in 2001, is one of the most commonly used batteries to assess executive functioning and skills of cognitive flexibility. The CTMT, published in 2002 is another standardized battery that is similar to the hallmark Trail Making Test, which was originally created in 1944 (Reynolds, 2002). In order to assess cognitive flexibility performance, the D-KEFS and CTMT were used for analysis in this study. Both batteries have been shown to be sensitive to identifying deficits in the TBI population (Anderson et al., 2016; Armstrong et al., 2008).

The seven cognitive flexibility measures examined in this study assessed different skills within the umbrella of cognitive flexibility. Each subtest used in this investigation measures verbal and visual forms of cognitive flexibility in their own unique way. Historically, the assessment of cognitive flexibility has evolved through updated versions of hallmark and gold standard tasks of executive functioning. The subtests used in this study from the D-KEFS and CTMT are a product of those manifestations of the growth of cognitive flexibility assessment.

Hypothesis One

The first hypothesis in this study addressed the comparison in cognitive flexibility performance through three time points in relation to the cognitive rehabilitation program as an intervention. When comparing the means between the three time points, Discharge performance was significantly better than Initial performance in three of the seven cognitive flexibility measures: Trail Making, Category Switching Correct, and Category Switching Accuracy. When removing the Post-Injury time point and solely analyzing Initial compared to Discharge, similar results were observed along with the addition of significantly improved performance on Inhibition and Inhibition Errors. These results highlight improved performance on visuomotor, verbal, and simultaneous processing of visual and verbal cognitive flexibility. Although the Inhibition/Switching condition also requires simultaneous visual and verbal cognitive flexibility, this task requires more cognitive resources than the Inhibition condition. No significant differences were found between Initial and Discharge performance on Inhibition/Switching and Inhibition/Switching Errors.

When comparing the means between the three time points, Post-Injury performance was significantly higher than Initial on one of the cognitive flexibility tasks: Inhibition/Switching Errors. However, different results were observed when analyzing performance for the patients who did not participate in the program but completed Initial and Post-Injury testing. Significant improvements at Post-Injury compared to Initial were found in six of the seven cognitive flexibility measures: Trail Making, Category Switching Correct, Category Switching Accuracy, Inhibition, Inhibition/Switching, and Inhibition/Switching Errors. Multiple cognitive flexibility skills were shown to improve 6 to 13 months after a TBI.

An important facet to consider and conceptualize is whether improved cognitive flexibility performance was due to the cognitive rehabilitation program or if it was attributed to natural healing and recovery of the TBI in general. Research has shown that the vast majority of recovery after a TBI takes place within the 2 years after injury (Fleminger & Ponsford, 2005). Cognitive and motor skills have also been shown to significantly improve within the first three months after a TBI (Zarshenas et al., 2019).

Sigurdardottir et al. (2009) found that 64% of TBI patients make good cognitive recovery after 12 months. While cognitive flexibility performance was improved immediately after the cognitive rehabilitation program, fully attributing the program to overall effects would not be reasonable. This is due to similar results being observed longitudinally for those who did not participate in the program as well as the aforementioned research showing that natural recovery occurs after a TBI.

The Number-Letter Sequencing condition on the D-KEFS along with Trail 5 of the CTMT measure visual cognitive flexibility mixed with fine motor speed and psychomotor fluency components. An examinee's ability to visually scan for information is a key component during this task. The Trail Making task also measures an individual's essential ability to multitask and process information simultaneously along with maintaining and keeping track of directions, the ability to sequence information, and abilities in divided attention (Delis et al., 2001). Results in this study show that patient performance significantly improved on these abilities over time. This highlights previous research that demonstrated left-side dorsolateral and medial frontal activity during cognitive switching of the Trail Making measure (Zakzanis et al, 2005).

The Category Switching condition on the Verbal Fluency subtest of the D-KEFS measures verbal cognitive flexibility. In addition to the ability to shift sets, this condition pertains to an individual's semantic knowledge and retrieval, productivity in fluency, and lexical organization. This subtest on the D-KEFS assesses an individual's ability to name correct responses within each semantic category (Switching Correct) as well as how accurately the examinee can switch back and forth between categories (Switching

Accuracy). Results show that patient performance significantly improved on both of these verbal cognitive flexibility measures over time. Bifrontal brain damage has been described to correlate to deficits in maintaining cognitive set and inhibiting irrelevant associations on the Category Switching condition of the D-KEFS Verbal Fluency (Delis et al., 2001). A conclusion can be made that these skills were improved as the response proficiency increased along with the patients' ability to accurately switch back and forth between categories. It appears that significant improvement was observed after completion of the program as well as 6 to 13 months after a TBI.

The Inhibition and Inhibition/Switching conditions on the Color-Word Interference subtest on the D-KEFS combine components of verbal and visual cognitive flexibility. Other abilities that these tasks pertain to include rapid naming, processing speed, and reading ability. However, the primary ability assessed during these Stroop-like tasks is the ability to inhibit automatic responses. Errors committed during these tasks can reflect impulsivity as well. Significant improvements from Initial to Discharge were observed as well as a separate analysis showing significant Post-Injury improvement compared to Initial. These results were consistent with the hypothesis. The Color-Word Interference subtest from the D-KEFS resembles the classic Stroop task that originated in 1935. Activation of the anterior cingulate cortex, dorsolateral prefrontal cortex, insula, and inferior frontal regions were likely to be improved similarly to previous research on the Stroop test (Grandjean et al., 2012; Leung et al., 2000). On the more cognitively demanding Inhibition/Switching condition, patients who did not participate in the program had significantly higher performance at Post-Injury than Initial performance.

However, this was not observed for those who participated in the program but did not complete testing at Post-Injury.

When observing performance of patients who completed testing at all three time points, the majority of results did not consist of significant improvements in the seven cognitive flexibility measures. In three of the seven measures, mean Discharge performance was significantly higher than Initial performance. Patients who only completed testing at the first two time points demonstrated significantly improved Discharge performance than Initial in five of the seven cognitive flexibility measures. One purpose of the current investigation was to examine cognitive flexibility skills longitudinally. This is where the Post-Injury time point is vital to this question and analysis. Post-Injury performance was significantly improved from Initial performance of patients who did not participate in the cognitive rehabilitation program in six of the seven measures. In comparing performance between Discharge and Post-Injury performance, no significant regression of cognitive flexibility performance was observed based on the results. This can be concluded because no statistically significant difference was found in all seven cognitive flexibility measures. Given these results, further research could consider investigating a longer time period after the TBI than the 6 to 13 months criterion used in this study. These results demonstrate that the cognitive rehabilitation program in conjunction with immanent TBI recovery contributed to improved cognitive flexibility performance.

Hypothesis Two

When further examining cognitive flexibility performance over time, the second hypothesis attempted to address this question. Four groups were compared across the seven cognitive flexibility measures based on the level of treatment and intervention patients received. The purpose of the NPNT group was to serve as a control group when looking at cognitive flexibility at the Post-Injury time point and therefore compare performance at a longitudinal time-point. The PT group was considered to be the highest level of treatment and intervention, as the patients in this group received exposure to the cognitive rehabilitation program as well as current exposure to therapy at the Post-Injury time point. The two intermediate groups of intervention between the NPNT and PT groups were the NPT and PNT groups. In addition to the four-group comparison, two-group comparisons were conducted based on program participation (P, NP) and also exposure to therapy (T, NT).

It was hypothesized that there would be a statistically significant difference within the four groups for each of the seven cognitive flexibility measures. This hypothesis was accurate for five of the measures but not all seven. Amongst the five cognitive flexibility measures, no significant differences were found comparing PT and NPNT group performance. This was not expected, according to the hypothesis.

In analyzing larger sample sizes, it was hypothesized that P group performance would be significantly better than NP performance for each of the seven cognitive flexibility measures. This hypothesis was accurate for two of the seven measures: Inhibition Errors and Inhibition/Switching Errors. At the Post-Injury time point, the cognitive rehabilitation program did not have a substantial effect on cognitive flexibility performance. However, mean performance in both groups on each of the seven measures fell in the average scaled score range between 7 and 13.

Larger sample sizes also pertained to group comparisons based on exposure to therapy. It was hypothesized that T group performance would be significantly better than NT performance for each of the seven cognitive flexibility measures. Unexpectedly, this hypothesis was not accurate as none of the seven cognitive flexibility measures consisted of significantly better T group performance than NT performance. In contrast, NT group performance was significantly better than T group performance in four of the seven measures. These results do not necessarily mean that exposure to therapy is detrimental to cognitive flexibility skills. A multitude of research supports speech, occupational, and physical therapy being a beneficial treatment intervention of individuals who have suffered a TBI. It is logical to postulate that the difference in T and NT group results are likely erratic as opposed to suggesting that therapy exposure is detrimental.

It was also hypothesized that the PNT group would have significantly better performance than the NPT group. This hypothesis was accurate for all five of the measures that contained a statistically significant result: Trail Making, Category Switching Correct, Category Switching Accuracy, Inhibition Errors, and Inhibition/Switching Errors. A deeper analysis between these two groups is examining comparison between the P and NP groups as well as the T and NT groups. PNT group performance generally being better than NPT performance is consistent with P-NP and T-NT comparisons. The P group showed significantly higher performance than the NP group on two cognitive flexibility measures and NT performance was higher than T group performance in four cognitive flexibility measures. Therefore, it is not surprising that PNT was higher than NPT in five of the seven measures. Although the analysis between PNT and NPT performance isolates each intervention, program participation and therapy exposure, these results should be interpreted with caution. Small sample sizes and erratic group results could have contributed to this. Also, the hierarchy of expected group performance according to the hypothesis was not consistent due to the results in this study. The NPNT group was designed as a control group with no intervention and hypothesized to have the lowest cognitive flexibility performance amongst the four groups. However, the results showed that mean NPNT performance was not the lowest in any of the seven measures and was actually significantly higher than NPT performance in three of the cognitive flexibility measures. Again, it is important to be cognizant of the low sample sizes of the four Post-Injury groups. It is also important to keep in mind of the aforementioned research highlighting that the majority of natural TBI recovery does occur within the first two years after the injury (Fleminger & Ponsford, 2005).

It was hypothesized that PT group performance would be significantly better than PNT group performance. However, this was not the case. There was a significant difference between the two groups on Trail Making, but the PNT group performance was significantly better than PT group performance. Another result to keep in mind is that the mean PNT group performance was consistently higher than PT group performance across the seven cognitive flexibility measures, although only one of the seven measures indicated a statistically significant difference. These results pertain to the larger sample size results between the T and NT groups, with NT group performance generally being higher than T group performance. It was expected that the highest level of invention, the PT group, would have better performance than the PNT group. However, the PT-PNT comparison consisted of smaller sample sizes than the T-NT group comparison. The T and NT group comparison provides deeper analysis as to why results showed that PNT performance was generally higher than PT group performance. It would not be reasonable to use the PT and PNT comparisons to make conclusions about the effectiveness of the cognitive rehabilitation program compared to exposure to therapy. However, the results from group comparisons at Post-Injury as well as the progression of cognitive flexibility skills over the three time points presents considerations about interventions for the pediatric TBI population.

Implications for Intervention

When an individual suffers a TBI, particularly of moderate and severe classification, executive functioning deficits are expected to occur. With the frontal lobe making about one-third of the cerebrum (Schoenberg & Scott, 2011), it is very possible that an injury to the brain can directly impact this area of the brain. Cognitive flexibility falls into the wide umbrella of executive functioning, meaning that a TBI can likely affect this particular neuropsychological skill.

Cognitive rehabilitation programs and interventions such as the one described in this study are intensive ways to improve functioning of individuals who suffer brain injuries. These services are often provided in clinical, hospital, and private practice settings. Inpatient settings typically provide longer duration of intervention than outpatient settings, but they often last weeks and months as well as multiple hours for each session. Questions about accessibility are also warranted in these settings due to whether patients have insurance. Another question is the duration and how much an insurance provider will provide for an intensive cognitive rehabilitation program.

When specifically discussing school services, students who qualify for special education services under the category of TBI have access to receive speech, occupational, and physical therapy. However, students typically do not have access to an intensive cognitive rehabilitation program that is similar to the one described in this study. A question to consider is how this type of program can be duplicated or modeled in the public school system. Can cognitive rehabilitation be specifically stated as a related service in a student's IEP similar to speech, occupational, or physical therapy? Could schools demonstrate the ability to set, track, and monitor IEP goals centered around cognitive rehabilitation and, specifically, cognitive flexibility?

Cognitive flexibility relates to so many different skills, functions, and expectations in school. Academic manifestations of cognitive flexibility occur in a variety of ways across reading, math, and writing. These manifestations can consist of having difficulty with cuing strategies for reading and recalling info in connected text, generating different options and strategies for solving math problems, and resisting to accept topics for writing suggested by an outside source (McCloskey & Perkins, 2013). Socially, lagging social problem-solving skills are linked to poor social outcomes after a TBI (Yeates et al., 2004) and children have been shown to display deficits in theory of mind following a TBI (Dennis et al., 2013). These social skills not only fall under the umbrella of executive functioning but also relate to cognitive flexibility skills. The results from this study could provide evidence as to improving the overall functioning of the pediatric TBI population in the public school setting.

A movement towards cognitive therapy as a related service in special education would undoubtedly require more resources and funding in the school setting. According to the National Center for Education Statistics (2021), less than 1% of individuals between the ages of 3 and 21 years who received services under IDEA in the 2019-2020 school year fell under the category of TBI. This number is in contrast to other eligibilities such as Specific Learning Disability (33%), Speech Language Impairment (19%), and Other Health Impairment (15%). Therefore, much of the attention and funding goes towards these students in higher numbers. However, cognitive-based therapy can be helpful towards students who meet criteria under categories besides TBI. For example, many individuals who meet criteria under Other Health Impairment have been diagnosed with ADHD. Cognitive rehabilitation and cognitive-based interventions have been shown to improve the functioning of individuals who have been diagnosed with ADHD. Specifically, Klingberg et al. (2005) recruited ADHD children ages 7 to 12 years and found improvements in response inhibition, working memory, complex reasoning, and behavioral symptoms after a computerized cognitive-training program for a minimum of 20 days. Johnstone et al. (2012) focused on inhibitory control training in ADHD children by using a 25-session intervention over a 4 to 5-week period. They found improvements in ignoring distracting stimuli and sustaining attention. Cognitive-based intervention could also benefit students who meet criteria under Specific Learning Disability, particularly if they were determined to be eligible by way of a Pattern of Strengths and Weaknesses model. Conceptualizing cognitive-based therapy and intervention into a specific service in Individual Education Programs may cause school districts to consider reallocating their funds and resources, which could effectively allow students who have suffered TBIs to receive more intensive services in the school setting.

Limitations

The current study has its limitations. Some of the limitations pertain to the sample sizes, which can also relate to limitations of using archival data. When a researcher uses archival data, they lose more control of the sample sizes that they would choose to use because the data has already been collected. Researchers are able to recruit and control more of the participant size when they are collecting their own data based on their initial research plan.

When analyzing performance of the TBI patients who completed testing at Initial, Discharge, and Post-Injury, small sample sizes were detected. Small sample sizes lead to larger margin of errors while large sample sizes increase statistical power. In statistics, the usual and acceptable power value is 0.80 (Bartlett, 2019; Hunt, n.d.). The repeated measures ANOVA conducted at Initial, Discharge, and Post-Injury yielded lower sample sizes than the subsequent repeated measures ANOVA conducted at Initial and Discharge and then at Initial and Post-Injury. Therefore, the statistical power was increased. Accordingly, the repeated measures ANOVA of the three time points should be interpreted with caution compared to the same analysis conducted at two time points because the sample sizes were larger.

Statistical power is also important to consider when analyzing the cognitive flexibility performance between groups at Post-Injury. When comparing four groups by use of one-way ANOVA, larger sample sizes are required for appropriate statistical power compared to differentiating two groups. This was the reason that the analysis comparing P and NP performance along with T and NT performance was included in addition to the PT, PNT, NPT, and NPNT analysis. Comparing two groups at Post-Injury was a more acceptable analysis based on the increase in statistical power and more acceptable sample sizes between the two groups. Therefore, the comparisons between the four groups at Post-Injury could be seen as a limitation.

Across the multiple analyses, larger sample sizes would have been more beneficial because this would have increased the probability of a true positive when examining the results. However, when using archival data the researcher loses some control over this. The researcher has to consider multiple options. Some of these options include deciding whether to change the nature of their research questions to create larger sample sizes, changing the type of analyses to strengthen original findings, or continuing to have the same research questions but interpret the results with caution. This study attempted to use additional analyses to add more detail and strength to original findings. However, the use of archival data still presents its issues.

Other limitations pertain to the scores that were not included or recorded in the data set. The Number-Letter Sequencing condition on the D-KEFS Trail Making subtest allows the examiner to record three different errors the examinee makes: sequencing errors, set-loss errors, and time-discontinue errors. These errors were not included in the data set. Although the examinee's completion time is effectively influenced by the number of errors they make, the specificity of the type of error can describe the deficit or lagging skill in more detail. Set-loss errors typically relate to an individual's struggle to shift cognitive sets rather than maintaining the set. These errors are likely to reflect problems with cognitive flexibility more than difficulties in sustaining attention (Miller, n.d.). An examinee who commits more sequencing errors than set-loss errors may signal less of a cognitive flexibility deficit. Unlike the D-KEFS, the CTMT is not designed to record specific errors during the task.

The Category Switching condition of the D-KEFS Verbal Fluency subtest also allows the examiner to record and score the number of errors the examinee makes. Set-loss errors along with repetition errors are the two types that are recorded. Data on the number of set-loss errors the subjects committed could have also provided more information about cognitive flexibility performance in this study.

The Inhibition and Inhibition/Switching conditions of the D-KEFS Color-Word Interference mirrors the response inhibition and cognitive flexibility aspects of the original Stroop test. However, this subtest does rely on the examinee's ability to read. For a patient who has significant deficits in reading, poor performance on these tasks may not necessarily equate to a deficit in cognitive flexibility. Possibly, a more effective measure of visual and verbal cognitive flexibility could have been the Inhibition subtest from the NEPSY–II. This measure asks the examinee to identify shapes (i.e., circle or square) or directions of arrows (i.e., up or down) instead of reading words.

What is unknown, but possibly inconsistent, is the length of time each neuropsychological evaluation was for each patient. The patients who completed the cognitive flexibility tasks in the current study performed this as part of a larger neuropsychological battery. It is also unknown whether the cognitive flexibility tasks were given at the beginning, in the middle, or towards the end of each evaluation. Research shows individuals who have sustained a TBI often suffer from increased physical, psychological, and mental fatigue (Bell, 2009). It is unknown how often and how long patients received breaks during their respective evaluations.

When discussing the realm of cognitive flexibility assessment, studies and investigations have rested on objective measures. This is in the midst of questions that have been raised about the ecological validity of these measures' ability to predict functioning outside of the testing environment. Performance in testing fails to take into account the broader context of behavioral, social, and emotional aspects of cognitive flexibility. Generally, the best practice for psychologists is to not solely rely on performance and scores in the testing environment for diagnosis, eligibility, or treatment considerations. Testing is only a piece of the puzzle and this study should be also looked at as such.

As previously mentioned, different skills within cognitive flexibility were measured through the subtests and tasks in this study. However, a composite for cognitive flexibility could not statistically be created with fidelity because there was a combination of scaled scores and *z*-scores in this study. In school psychology and neuropsychology, practitioners often use composites to convey overall abilities in a particular area or skill. However, this study did not have an overall composite for cognitive flexibility amongst the seven measures. However, there is benefit in observing the specific skills within this umbrella as this study attempts to convey. Practitioners also communicate and describe results of performance within a specific area or skill. The presence of a cognitive flexibility composite could have provided a more global measure of performance from the pediatric TBI sample in this study. That being said, this may not be considered a significant limitation. The D-KEFS was created as eight standalone subtests and not intended to factor into one or multiple executive functioning composites.

It is also important to keep in mind that this study is not generalizable to all TBIs. As mentioned before, 80% of TBIs fall in the mild category while moderate and severe each comprise of about 10% (Iverson & Lange, 2011a; Iverson & Lange, 2011b). The patient sample in this study does not reflect general statistics of TBI as most of the subjects had suffered a severe TBI. However, this study still provides valuable evidence and insight into the cognitive flexibility performance and treatment of children and adolescents who are affected by a TBI.

Future Investigations

Given the wide umbrella of executive functioning, it is evident that more research is needed in this neuropsychological construct for children and adolescents who have sustained a TBI. Therefore, more research is warranted delving into cognitive flexibility in the pediatric TBI population. Given the continued advancements in electronics and technology, similar studies to this one could investigate cognitive flexibility performance in response to cognitive-based computer training. A study of this nature could potentially look at this type of intervention inside and outside of the school setting and its effects on cognitive flexibility skills. Programs such as Lumosity and Neuropsychonline are examples of brain training software that target cognitive flexibility, but CogMed is a much more widely known program that targets working memory and attention. Ko et al. (2020) conducted a randomized controlled trial of a tablet computer-based cognitive program for children with cognitive impairment between the ages of 18 and 36 months. After 12 weeks of intervention, they found significant improvements in attention, shifting, self-care, and social function regardless of the severity of the cognitive delay. More evidence as to how this mode of cognitive rehabilitation can benefit the pediatric TBI population could add to the overall toolbox of intervention. Computer-based cognitive training also could allow for more mobilization and access to many children and adolescents. It may be more feasible to incorporate these types of computer software in schools rather than having a student attend a 4-week program for 6 hours a day like the cognitive rehabilitation program described in this study.

Conclusion

Cognitive flexibility is a vital executive function that pertains to many areas of life functioning. A TBI to the frontal lobe is very likely to influence an individual’s mental ability to switch between thinking about two different concepts or their ability to think about multiple concepts simultaneously. Cognitive flexibility deficits after a pediatric TBI can impact the child or adolescent’s academic, social, emotional, behavioral, and adaptive functioning. In order to alleviate and treat negative effects of a TBI, cognitive rehabilitation has been shown to be an intervention for this population.

One thing to consider is that the pediatric TBI sample in this study is not reflective of general statistics regarding the severity of the TBI. Most TBIs are of mild severity. However, most of the patients in this study suffered a moderate to severe TBI while a smaller portion of the sample suffered a mild TBI. The results of the current study added to the scarce amount of research that specifically examines cognitive flexibility skills in the pediatric TBI population in response to a cognitive rehabilitation program at multiple time-intervals.

Results showed that there were significant improvements in cognitive flexibility performance on visuomotor tasks (Trail Making), verbal tasks (Verbal Fluency), and simultaneous visual and verbal tasks (Color-Word Interference) after a 4-week cognitive rehabilitation program. However, these improvements cannot be fully attributed to the program because similar performance was observed for individuals who did not complete the program but demonstrated significant improvement at a longitudinal post-TBI time point. It might be suggested that the cognitive rehabilitation program in conjunction with general TBI improvement over time led to better performance on cognitive flexibility tasks. Amongst the subjects who completed testing at all three time points, overall significant improvements were not observed based on their performance at Post-Injury. However, no significant regression in cognitive flexibility performance was observed as well. In order to further analyze longitudinal effects of the program, multiple groups were created at different levels of exposure to program as well as exposure to current therapy at that longitudinal time point.

When observing the four group differences regarding the level of exposure to therapy and the program at Post-Injury, most of the significant differences were found in which the PNT group performed better than the NPT group. However, performance from the PT and NPNT groups does not create strong evidence that the program had more of an effect on cognitive flexibility skills than exposure to therapy. In addition, when comparing group differences between two groups at Post-Injury, some significant differences were observed but not enough to make an overall conclusion about the complete effectiveness of the cognitive rehabilitation program as well as exposure to therapy.

Improvements in cognitive flexibility performance across multiple tasks and measures were observed in this study. Therefore, it is logical to consider intervention implications for the pediatric TBI population. Schools can still consider cognitive-focused interventions to include as a service for school-age youth who receive special education services under IDEA under the category of TBI as well as other eligibilities. Cognitive flexibility is a key executive function, which relates to many areas of overall functioning in the pediatric TBI population.

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