WISC-IV PROFILES AMONG CHILDREN AND ADOLESCENTS WITH TRAUMATIC BRAIN INJURY AND NON-TRAUMATIC ACQUIRED BRAIN INJURY: IMPLICATIONS FOR SERVICE DELIVERY IN SCHOOLS

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ABSTRACT

WISC-IV PROFILES AMONG CHILDREN AND ADOLESCENTS WITH TRAUMATIC BRAIN INJURY AND NON-TRAUMATIC ACQUIRED BRAIN INJURY: IMPLICATIONS FOR SERVICE DELIVERY IN SCHOOLS

Catherine M. O'Sullivan

In the fields of school psychology and neuropsychology, there is poor evidence of empirically based methods that can be used as best practice with brain injured children. As such, given that the WISC-IV is the most commonly used assessment in the country, there seems to be a disconnect between the literature and the psychometric value of the WISC-IV, as prior research indicates that the WISC-IV has poor sensitivity in this population when relying upon the inherent four factor structure. The primary purpose of the present study was to determine the fit of the CHC theory structure of the WISC-IV's core subtests in brain injured children. The CHC theory model was found to provide appropriate fit within the brain injured pediatric population. In addition, this model has been found to be preferable to the inherent structure of the WISC-IV. The current study provides evidence for the use of CHC theory with brain injured populations, as the constructs have been demonstrated to be measured the same way across groups. The present study is the first to demonstrate the utility of an empirically based assessment method, the CHC theory model, with children who have sustained a brain injury. In addition, the effects of age, time since injury, and nature of injury have been discussed. The present results have significant implications for test selection, interpretation, and intervention regarding children who have sustained brain injuries.

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Table of Contents

List of Tables

List of Figures

WISC-IV Profiles Among Children and Adolescents with Traumatic Brain Injury and Non-Traumatic Acquired Brain Injury: Implications for Service Delivery in Schools

Chapter 1

Statement of the Problem

Traumatic and acquired brain injury, or TBI and ABI, undeniably affect numerous children and adolescents in their ability to learn and function in their daily activities despite being relatively infrequent. According to the Centers for Disease Control (CDC), the prevalence of TBI from 0 to 14 years old was over 500,000 children affected annually, accounting for 92.7% of emergency room visits between the years 2002 and 2006 with an increase of 14.4% seen across these four years (Faul, Xu, Wald, & Coronado, 2010). The prevalence of ABI is not well documented. The Brain Injury Network has asserted that TBI was a form of ABI, urging NINDS to change their classification accordingly (Brain Injury Network, 2006-2012). In order to fully identify the lasting effects of the injuries and how they will impact the child's ability to perform in school, comprehensive neuropsychological assessments are often indicated which include but are not limited to cognitive assessments. Although the most commonly used cognitive assessment in the United States is the Wechsler Intelligence Scale for Children, Fourth Edition (WISC-IV), the four factor model inherent to this assessment is not empirically supported for typically developing children, but rather, a more comprehensive five factor model based on the CHC Theory is indicated (Hebben & Milberg, 2009; Keith et al., 2006). However, limited research is available regarding the appropriateness of this model in children with traumatic and acquired brain injury.

The present study primarily aims to determine whether the five factor CHC based model of the WISC-IV is empirically supported. Although school districts are not often involved in the initial assessment of brain injured children, many children with a history of head injury do not demonstrate noticeable academic or behavioral difficulties until material becomes more challenging as they progress through school (Miller, 2007). As the field of school neuropsychology emerges, school psychologists must be aware of cognitive factors associated with these children (Miller, 2007). This is especially pertinent considering the recently implemented Concussion Management and Awareness Act in New York state in 2012 (NYSED, 2012). By investigating cognitive skills associated with TBIs and ABIs using the most commonly administered battery, school districts assessing children can be informed of patterns of cognitive functions in brain-injured populations.

In the following sections, forms of brain injury will be discussed collectively, as most research discussing children with brain injury do not distinguish between TBI and ABI. Thus, the nature of pediatric brain injuries, theoretically based cognitive assessment and application to brain injured populations, and the demographic variables contributing to assessment validity will be reviewed.

Chapter 2

Literature Review:

Traumatic and Acquired Brain Injury Sustained During Childhood

Prior to reviewing assessment techniques, it is imperative to understand the nature of TBI and ABI, as well as structural changes and their functional consequences. Within the first five years after brain injury, parents reported that over 43% of children between five and sixteen years old had decreased quality of life on a daily basis, as suggested by increased cognitive, emotional, and behavioral challenges (Limond, Dorris, McMillan, 2009). An estimated 50% with brain injury, 90% of whom had mild TBI and 29% that were younger than 16, continued to require treatment one year after their injury (Rickels, Von Wild, & Wenzlaff, 2010). Some TBI cases remain unidentified, over 60% of which sustain continued symptoms of memory problems, headaches, depression, and attention challenges, while many require assistance for vocational rehabilitation, domestic abuse, homelessness, or mental health issues thereafter (Hux, Schneider, & Bennett, 2009). Other cognitive symptoms post-TBI include sleep disturbances, fatigue, and less commonly, suboptimal effort on assessment measures (Lundin, DeBoussard, Edman, & Borg, 2006; Kirkwood & Kirk, 2010). For children, identification, assessment, and treatment of these symptoms are crucial to obtaining optimal prognoses. Thus, one must first gain an understanding of the nature of the injury prior to conducting assessments for transition to school.

The Nature of Brain Injuries

The nature of brain injuries in children and adolescents differs for those who have suffered TBI versus those with ABI. Traumatic brain injuries are typically described as being open or closed head injuries, such that the term 'open head injuries' infers that an the skull is cracked or fractured, exposing the brain causing direct insults to the affected brain region (Carter, Aldridge, Page, & Parker, 2009). 'Closed head injuries' include those in which the skull is intact, but indirect insults can occur, including coutrecoup injuries, where the opposite side of the brain is injured as well, as inflicted by the impact of the brain striking the skull during movement related accidents (Lezak, Howieson, & Loring, 2004; Carter, Aldridge, Page, & Parker, 2009). Brain hemorrhages occur in TBI and ABI cases. TBI related brain hemorrhages are induced by a traumatic event, resulting in ruptured blood vessels, and the blood may form blood clots called hematomas (Carter, Aldridge, Page, & Parker, 2009). A common form of TBI related hemorrhage is a subdural hemorrhage, occurring between the two outer meninges around the brain, causing pressure on brain tissue in the affected area, possibly yielding one-sided paralysis, confusion, drowsiness, or seizures (Carter, Aldridge, Page, & Parker, 2009).

Common acquired brain injuries include damage from seizure activity, encephalitis, meningitis, ischemic attacks, stroke, subarachnoid hemorrhage, and brain tumors. Seizure disorders, such as epilepsy, are caused by abnormal neuronal firing, which interrupts brain functioning. Factors leading to decreased seizure thresholds are stress, lack of sleep, flashing lights, and stimulants (Carter, Aldridge, Page, & Parker, 2009). Encephalitis occurs when brain tissue becomes inflamed due to a virus or autoimmune reaction, sometimes leading to swelling and brain damage, causing altered speech, memory, behavior, confusion, seizures, coma, and sometimes death (Carter, Aldridge, Page, & Parker, 2009). Meningitis is an inflammation of membranes covering the brain and spinal cord called meninges, resulting from a viral or bacterial infection, sometimes leading to paralysis, language dysfunction, visual impairment, seizures, and coma (Carter, Aldridge, Page, & Parker, 2009). Transient ischemic attacks are caused by blood clots momentarily blocking arteries that bring blood to the brain, resulting in unilateral vision loss, speaking or comprehension challenges, unilateral weakness or paralysis, coordination difficulties, dizziness, and loss of consciousness (Carter, Aldridge, Page, & Parker, 2009). Strokes can include ischemic attacks that last over 24 hours, ruptured arteries that bleed into the brain, a ruptured blood vessel in the brain that bleeds, or a subarachnoid hemorrhage. Subarachnoid hemorrhages are bleeding between the two outer membranes enveloping the brain, likely caused by a ruptured berry aneurysm or an arteriovenous malformation (AVM), which is an abnormally formed collection of blood vessels on the surface of the brain that is present from birth (Carter, Aldridge, Page, & Parker, 2009). Longitudinal evidence suggests that between 3.9% and 4.3% of those with AVMs experience hemorrhages each year (Stapf et al., 2001).

Brain tumors are growths occurring in or around the brain and spinal cord, compressing areas surrounding the tumor, often requiring surgical resection, chemotherapy, and/or radiation. According to researchers at Johns Hopkins (2012), the most common forms of childhood brain tumors include medulloblastomas and gliomas, which include astrocytomas, brain stem gliomas, ependymomas, and optic nerve gliomas. Medulloblastomas are the most common malignant brain tumors in children, accounting for 15% of brain tumors, typically forming in the cerebellum, affecting more males than females (Johns Hopkins, 2012). Astrocytomas develop from astrocytes in the cerebrum or the cerebellum. Ependymomas are glial cell tumors developing in the ventricles' lining or spinal cord, occurring near the cerebellum and blocking flow of cerebral spinal fluid (Johns Hopkins, 2012). Gliomas can coincide with neurofibromatosis, a condition in which multiple nervous system tumors grow in cells of nerves and myelin, with 30 to 50% of new cases occurring due to gene mutation (Johns Hopkins, 2012; NINDS, 2012).

Severity

A number of studies have demonstrated the predictive validity of the severity rating obtained following brain injury on later outcome measures (DiStefano, Bachevalier, Levin, Song, Scheibel, & Fletcher, 2000; Shum, Harris, & O'Gorman, 2000; Anderson, Catroppa, Morse, Haritou, & Rosenfeld, 2005; Catroppa & Anderson, 2005; Hessen, Nestvold & Anderson, 2007; Dykeman, 2009; Gerrard-Morris et al., 2009; Fuentes, McKay, & Hay, 2010). Likewise, the symptom loading on the first day of injury is correlated with symptoms remaining three months later (Lundin, DeBoussard, Edman, & Borg, 2006). Children with more severe injuries have demonstrated specific and generalized cognitive and functional effects as compared to those with mild to moderate injuries (Fuentes, McKay, & Hay, 2010; Shum, Harris, & O'Gorman, 2000; Catroppa & Anderson, 2005; Gerrard-Morris et al., 2009). Likewise, severity has been highly documented in the literature as a factor related to long-term neuropsychological and behavioral outcomes (Anderson, Catroppa, Morse, Haritou, & Rosenfeld, 2005; Hessen, Nestvold & Anderson, 2007). These outcomes will be discussed more in depth in later sections.

The primary scale used to quantify brain injury severity is the Glascow Coma Scale (GCS), the most widely cited scale used to measure severity of injury. The GCS, first published by Teasdale & Jennett in 1974, is primarily based on the visual, verbal, and motor responses of the patient, with cumulative scores in these areas rating severity on a scale from 1 to 15 (Cummings & Trimble, 2002). On this scale, associated degrees of posttraumatic amnesia are taken into consideration when determining severity. Posttraumatic amnesia is the amount of time memories are lost following a trauma (Cummings & Trimble, 2002). On the GCS, scores from 1 to 4 are very severe and associated with greater than 1 week of posttraumatic amnesia and scores from 5 to 8 are severe and related to between 24 hours and one week of posttraumatic amnesia (Cummings & Trimble, 2002). Likewise, scores from 9 to 12 are identified as moderate with between 1 hour and 24 hours of posttraumatic amnesia, and a score from 13 to 15 is labeled mild, as associated with less than 1 hour of posttraumatic amnesia (Cummings & Trimble, 2002).

Long Term Effects

Functional consequences are evident both immediately after the child's injury and up to decades later. Children with moderate to severe TBI have been found to exhibit significant cortical thinning from diffuse atrophy at 3 months post-injury in the areas of the bilateral anterior prefrontal region, bilateral temporal lobes, parahippocampal gyri, bilateral posterior cingulate, and bilateral parietal and precuneus regions (McCauley et al., 2010). These children exhibit poor prospective memory for events (McCauley et al., 2010). Memory weaknesses continue to cause distress for children as they age, as ten years following the injury, individuals who suffered brain injury at an average of ten years old were found to have poorer performances in intellectual skills, verbal measures, verbal learning, memory, visuo-constructive skills, and executive functions (Horneman & Emanuelson, 2009). For individuals who experienced severe injury, substantial recovery of some skills was noted, but poor visuo-constructive and executive functioning skills persisted (Horneman & Emanuelson, 2009). Additionally, during childhood, the corpus callosum, a tissue connecting the two hemispheres of the brain that facilitates communication, continues to develop in children with mild to moderate closed head injuries (Levin, Benavidez, Verger-Maestre, Perachio, Song, Mendelsohn, & Fletcher, 2000). However, in those with severe head injury, the development of this layer is halted and even tends to decrease in size between three and thirty-six months post-TBI (Levin et al., 2000).

Further, several studies have documented changes beyond one decade after sustaining a brain injury. Over fourteen years following TBI for children who were injured at a mean age of fourteen, individuals demonstrated a gradual decline in verbal intelligence scores, with poor performance noted on attention and working memory tasks, and the most significant weaknesses noted in verbal learning (Aaro Jonsson, Horneman, & Emanuelson, 2004). The functional impact of these injuries for just under half of this sample included not adjusting well to adult lifestyles and retiring early rather than joining the workforce (Aaro Jonsson, Horneman, & Emanuelson, 2004). Twenty-three years following mild TBI in a sample of individuals who were injured as children and adults, predictors of poor outcome included length of post-traumatic amnesia and EEG patterns within the first 24 hours after injury (Hessen, Nestvold, & Anderson, 2007). However, only for those injured as children, head injury severity was associated with current neuropsychological functioning, suggesting that child victims of TBI may be more prone to chronic neuropsychological dysfunction than adults (Hessen, Nestvold, & Anderson, 2007).

Finally, nearly forty years post-TBIs from motor vehicle accidents during preschool, vocational and social outcomes were largely associated with intellectual capacity and verbal memory (Nybo, Sainio, & Muller, 2005). Nearly one-third of the sample maintained a full-time job and had a marital relationship (Nybo, Sainio, & Muller, 2005). Of the remaining two-thirds, nearly one-tenth had part-time work, while the rest were not employed (Nybo, Sainio, & Muller, 2005). Literature warns that outcome cannot be declared until adulthood, as skills may continue to decline (Aaro Jonsson, Horneman, & Emanuelson, 2004; Horneman & Emanuelson, 2009).

Behavioral Effects

Significant behavioral symptoms are observed in children who have sustained a TBI, varying by age. In infants and young children between three and twenty-three months of age, symptoms evident at a month and a half post-injury may include reduced initiation and response to social interaction, poor compliance with activities, and a lack of expressed positive affect (Landry, Swank, Stuebing, Prasad, & Ewing-Cobbs, 2004). In preschool aged children, common challenges include hyperactivity, distractibility, impulsivity, and emotional dysregulation as expressed through temper tantrums, while older children and adolescents may exhibit problems with inhibition, impatience, irritability, agitation, and an increase in preexisting challenging behaviors (Mayfield & Homack, 2005). Some problems are indirectly caused by the injury, for example, children with problems with poor inhibition may impulsively insult other children, causing them to become isolated. Therefore, it is necessary to address and evaluate cognitive, physical, psychosocial, emotional, and behavioral weaknesses while assessing potential environmental stressors, which often influence the child's daily life (Noggle & Pierson, 2010).

Transition to School

Through assessment, progress monitoring, and intervention, the role of psychologists remains vital as children with brain injury transition to school. Initially during transition, external stressors can confound progress, such as pre-morbid familial problems, including marital distress between parents, low socio-economic status, and parental emotional difficulties (Semrud-Clikeman, 2010). These factors can conflict with the family's ability to adjust to the functional impacts of the child's injury, preventing them from attending to the child's needs. Other factors impacting transition include age at the time of injury, the amount of time since injury, and the child's, educator's, and families' expectations for continued recovery (Stavinoha, 2005; Mayfield & Homack, 2005; Semrud-Clikeman, 2010). Age at the time of injury has been associated with prognosis, as individuals injured in late childhood had the most positive cognitive outcomes, followed by infant and preschool groups, with those in middle childhood performing the worst across all domains of Intelligence Quotient (Crowe, Catroopa, Babl, Rosenfeld, & Anderson, 2012). The amount of time since injury is also significant, as when a child progresses through school, the demands of higher order cognitive functions increase, and children with brain injury will likely have more difficulty while professionals are less likely to consider this as a contributing factor as time passes (Stavinoha, 2005; Semrud-Clikeman, 2010).

During the first six months, initial, fluent gains in functional skills are observed in early stages of recovery, and families, children, and professionals unfamiliar with typical

TBI progress may assume that rate of progress will be continuous, however, it tends to stabilize around two years post-injury (Dykeman, 2009). Psychoeducation about prognosis and recovery trajectory must be provided to ensure that all individuals involved in the care and education of the child create appropriate expectations. Challenges likely to increase over time include labile mood, aggression, and social isolation (Semrud-Clikeman, 2010). Further, although the location of injury is significant, the interdependence of neural systems often yields diffuse functional impacts that cannot be accounted for by relying on location alone (Stavinoha, 2005). Common factors that can impede successful transition include overstimulation and cognitive fatigue, as children with brain injury often have difficulty managing overstimulating environments and fatigue sooner than peers (Mayfield & Homack, 2005). In such a situation, the child may overreact, act out, or have exacerbated physical symptoms due to overstimulation and cognitive demand (Mayfield & Homack, 2005). These factors are exacerbated when right hemisphere injury occurs, as poor insight into their limitations may ensue (Mayfield & Homack, 2005).

Assisting in the transition process begins in early stages of brain injury through progress monitoring. A Response to Intervention (RtI) approach is applicable, as each child's recovery rate is unique and behavioral charting provides valuable information regarding the frequency, duration, severity, and intensity of challenging behaviors while taking into account setting events and other factors impacting behavior (Dykeman, 2009). In utilizing an RtI approach, appropriate recommendations can be made, facilitating a smooth transition while reducing potentially stressful situations (Dykeman, 2009). Due to the intensity of needs among brain injured children returning to school, children tend to return with Tier 2 or 3 instructional needs according to the RtI framework (Dykeman, 2009). Specific guidelines have been highlighted for initial and follow up assessments intended to help children as they transition. As with all assessments, the approach should be hypothesis driven, considering the stage of recovery reached at the time of assessment while gathering observational data, parent and teacher reports when available, and gaining an understanding of prior performance (Stavinoha, 2005). Likewise, understanding the child's developmental level, strengths, competencies, and the educational demands placed on them is crucial for interpretation and providing valid recommendations that will enhance positive behaviors in the classroom (Mayfield & Homack, 2005; Stavinoha, 2005). Thus, when brain injured children are referred through the RtI model due to academic, behavioral, or unexplained changes in personality, a school neuropsychological evaluation may be warranted to identify neurocognitive explanations for the child's poor response to intervention and to identify evidence based interventions from evaluation data (Miller, 2007). Therefore, school personnel must have a thorough understanding of cognitive development and evidence based assessment practices.

Assessment of Brain Injured Children

Cognitive Development

Cognitive skills continue to develop through childhood and adolescence, and understanding the developmental processes is necessary to assess the cognitive skills of youths, particularly when a brain injury occurred during development. By three years old, the hippocampus becomes more mature, and memory retention becomes more advanced, with limited memories recalled prior to this age (Carter, Aldridge, Page, &

Parker, 2009). Myelination of axons in the reticular formation of the brainstem is completed by age seven, yielding a heightened attention span (Carter, Aldridge, Page, & Parker, 2009). The processing of body growth between six and thirteen years old affects areas of the parietal cortex, allowing for further progression of linguistic and spatial understanding, while intellectual and social skills continue to develop (Carter, Aldridge, Page, & Parker, 2009). During adolescence, parietal and temporal lobes mature, allowing for more efficiency in spatial, sensory, auditory, and language areas. Adolescents tend to rely on the amygdala for emotion regulation and processing, while the prefrontal cortex, related to thinking and planning, is not yet fully developed (Carter, Aldridge, Page, & Parker, 2009). Brain injuries of childhood and adolescence can disrupt development, leading to potential long-term dysfunction. Therefore, comprehensive assessments must be conducted to determine the extent to which the injury has affected cognitive functioning.

Theory Driven Assessment: CHC Theory

The Cattell- Horn- Carroll (CHC) theory is a taxonomy used to depict the broad and narrow abilities that can guide test selection, organization, and interpretation for intelligence and achievement batteries (Flanagan, Ortiz, & Alfonso, 2007). Integrating the Cattell-Horn and Carroll models, CHC theory is the result of over 60 years of factor analytic, developmental, neurocognitive, and heritability evidence demonstrating a design appropriate for the most comprehensive method of assessment (Flanagan, Ortiz, & Alfonso, 2007). This theory includes ten broad abilities and over seventy narrow abilities. The ten broad abilities include *Fluid Intelligence (Gf)*, *Quantitative Knowledge (Gq)*, *Crystallized Intelligence (Gc)*, *Reading and Writing (Grw)*, *Short Term Memory*

(*Gsm*), *Visual Processing* (*Gv*), *Auditory Processing* (*Ga*), *Long Term Storage & Retrieval* (*Glr*), *Processing Speed* (*Gs*), and *Decision/ Reaction Time/ Speed* (*Gt*) (Flanagan, Ortiz, & Alfonso, 2007). Furthermore, Cross-Battery Assessment methods described by Flanagan, Ortiz, and Alfonso (2007) assert that comprehensive assessment should be theory driven and measure at least two qualitatively different narrow abilities to validly measure each broad ability. Implementing CHC theory within a Cross-Battery Assessment framework ensures that valid universal interpretations can be drawn from evaluations while providing guidelines for crossing batteries without producing excess error.

The WISC-IV and CHC Theory

The most recent version of Wechsler Intelligence Scale for Children, Fourth Edition (WISC-IV; Wechsler, 2003) was designed for children ages 6 to 16. The WISC-IV (Wechsler, 2003) is more aligned with CHC theory than previous versions (Flanagan & Kaufman, 2004). Although the WISC-IV (Wechsler, 2003) is organized into four Indexes, five broad CHC abilities are represented (Flanagan & Kaufman, 2004). According to CHC Theory, the WISC-IV (Wechsler, 2003) adequately represents *Crystallized Intelligence* (*Gc*), *Fluid Reasoning* (*Gf*), *Visual Processing* (*Gv*), *Short-Term Memory* (*Gsm*), and *Processing Speed* (*Gs*) given that the supplemental subtest of *Gv*, *Picture Completion*, is administered (Flanagan & Kaufman, 2004; Flanagan, Ortiz, & Alfonso, 2007). The specific research regarding the performance of children with brain injury on each of the broad abilities represented in the WISC-IV (Wechsler, 2003) will be discussed in the following sections.

Cognitive Assessment and Pediatric Brain Injury

Recent research has identified that, when using the WISC-IV (Wechsler, 2003) with children who have TBI, criterion validity is lacking for all Indexes except for the *Processing Speed Index* (Donders & Janke, 2008). Thus, given the strong research background of the classification scheme delineated by CHC Theory, the tasks of the WISC-IV (Wechsler, 2003) will be interpreted using CHC factors. It is useful to note that a common profile for children with TBI ages 6 to 15 has been identified, suggesting that the WISC-IV (Wechsler, 2003) indexes *Verbal Comprehension*, *Perceptual Reasoning*, and *Working Memory* were decreased as compared to the normative sample, whereas the *Processing Speed Index* was more severely affected (Rackley, Allen, Fuhrman, & Mayfield, 2012). However, these data must be interpreted with caution, as the criterion validity of the *Verbal Comprehension*, *Perceptual Reasoning*, and *Processing Speed Indexes* is poor, indicating that interpretation of the WISC-IV (Wechsler, 2003) indexes may not be highly sensitive to the impact of brain injury in children.

Moreover, research regarding the functional capacity of specific broad abilities in children with TBI or ABI is limited, thus, an overview of the structural and functional data available will follow according to the CHC factors adequately measured by the WISC-IV (Wechsler, 2003).

Crystallized Intelligence

Crystallized Intelligence (*Gc*) is a term used to describe the breadth and depth of acquired cultural knowledge and how this knowledge is applied, including declarative static and procedural dynamic knowledge (Flanagan, Ortiz, & Alfonso, 2007).

Declarative knowledge is stored in long term memory while activated when related information is in working memory, and procedural involves reasoning that intends to transform knowledge (Flanagan, Ortiz, & Alfonso, 2007). Semantic declarative memories are encoded in the temporal lobes and become activated through the frontal lobe, which relies on stored knowledge to guide behavior (Carter, Aldridge, Page, & Parker, 2009). Alternatively, procedural memories facilitate performing automatic motor actions by storing information about learned skills in the putamen and incorporating instinctive, automatic actions, which are stored in the caudate nucleus, and body skills of timing and coordination, which are stored in the cerebellum (Carter, Aldridge, Page, & Parker, 2009).

A declining trend in verbal intelligence over the course of fourteen years post-injury has been identified among people who sustained severe TBI during childhood (Aaro Jonsson, Horneman, & Emanuelson, 2004). On cognitive measures, the *Vocabulary* score of the WISC-IV (Wechsler, 2003) has been found to be significantly correlated with verbal learning and memory, as assessed by the California Verbal Learning Test-Children's version (CVLT-C; Delis, Kramer, Kaplan, & Ober, 1994) (Fuentes, McKay, & Hay, 2010). This relationship between crystallized intelligence, short-term, and long-term verbal memory is fascinating in that it highlights the process by which information becomes crystallized, initially through immediate learning and then becoming consolidated through long-term storage and retrieval. Given the poorly documented performance of children with brain injuries on tasks of *Crystallized Intelligence* in current literature, the present study will provide a unique contribution to existing literature.

Fluid Reasoning

Fluid Reasoning (*Gf*) skills include mental processes performed when presented with a novel task and may include perceiving relationships, identifying concepts and patterns, drawing inferences, understanding implications, problem solving, extrapolation, reorganizing and transforming information (Flanagan, Ortiz, & Alfonso, 2007). Documentation of *Fluid Reasoning* skills, localization of these skills, and performance in brain injured children is extremely sparse, elucidating the value of the current study.

Visual Processing

Visual Processing (*Gv*) involves mental reversal and rotation of objects, interpreting the change in objects moving through space, perception and manipulation of spatial configurations, and maintenance of spatial orientation (Flanagan, Ortiz, & Alfonso, 2007). These processes are interpreted through visual perception, in which light enters the eye, the message travels to the optic nerve, crosses the optic chiasm, and nerve fibers connect with a specialized thalamic area, after which signals are sent to the visual cortex and are processed through the dorsal and ventral routes (Carter, Aldridge, Page, & Parker, 2009). The dorsal pathway determines the position, movement, size, and shape of the target, traveling to the parietal areas, which develop plans of action unconsciously (Carter, Aldridge, Page, & Parker, 2009). The ventral pathway brings information from the primary visual cortex to the temporal lobes, identifying what is seen, assigning a meaning for recognition, and recalling related information from memory (Carter, Aldridge, Page, & Parker, 2009). The dorsal and ventral pathways terminate in the frontal lobes, where the person consciously perceives what is seen (Carter, Aldridge, Page, & Parker, 2009).

Age, severity, and location of focal injuries dictate the functional impacts of brain injury on visual processing. Children who sustained TBI between ages three and six had deficits varying as a result of severity, as severely injured children had generalized impairments and less severe TBI showed weakness in visual memory and executive function (Gerrard-Morris et al., 2009). For mild TBI, deficits of higher order visual tasks exist immediately after injury, lasting up to at least three months post injury (Brosseau-LaChaine, Gagnon, Forget, & Faubert, 2008). Left or right focal stroke in children yielded poor efficiency of visual search for the contralateral side of their injuries (Schatz, Craft, Koby, & DeBaun, 2004). Those with right hemisphere injuries tend to demonstrate deficient global processing and spatial judgment, while those with left hemisphere injuries tend to have intact local versus global processing and spatial judgment (Schatz, Craft, Koby, & DeBaun, 2004). Those with bilateral injury from stroke had combined effects of left and right injuries, such as disrupted visual search across left and right fields, poor global processing, and poor spatial judgment (Schatz, Craft, Koby, & DeBaun, 2004). Thus, impairment of visual processing increases as a function of the injury complexity and severity.

Short Term Memory

Short Term Memory (*Gsm*) is the ability to attain and hold information stored in immediate awareness while using it within a few seconds (Flanagan, Ortiz, & Alfonso, 2007). Short-term memory involves the central executive part of the frontal lobes, which holds the "plan of action" while receiving information from other regions to process through two neural loops, one for visuospatial information and the other for linguistic or auditory information (Carter, Aldridge, Page, & Parker, 2009). The circuits are registered in the sensory cortices and travel to the frontal lobes, where it is consciously noted (Carter, Aldridge, Page, & Parker, 2009). These processes are mediated by prefrontal cortex neurons (Carter, Aldridge, Page, & Parker, 2009).

The nature of head injury dictates the lasting effects on different types of *Short Term Memory* tasks. Language is typically localized in the left hemisphere, and children with left hemisphere, namely left temporal lobe injuries, tend to have poorer performance on short-term verbal memory tasks than those with right-hemisphere injuries, while those with right temporal lobe lesions have poor performance on visual memory tasks (Driscoll, 1994; Ariza, Pueyo, Junque, Mataro, Poca, Mena, & Sahuquillo, 2006). Prefrontal lesions contribute to impairment of verbal learning and memory, while severity and age significantly affect memory performance (DiStefano et al., 2000). Bilateral frontal lesions predict worse performance in children with closed head injuries than more focal lesions, while left hippocampal volume post- TBI correlates with recognition memory and right hippocampal volume does not significantly affect performance (DiStefano et al., 2000). In a study of adult veterans post-penetrating TBI assessed with episodic verbal and visual memory tasks, lesion location was independent of the findings, as all subjects demonstrated deficits in *Short Term Memory* across theses tasks (Schooler, Caplan, Revell, Salazar, & Grafman, 2008). Moreover, severity of injury amplifies memory weaknesses, as individuals with severe TBI tend to demonstrate visual and verbal memory weaknesses, committing more false-positive errors and learning at a slower rate on verbal memory tasks than controls (Shum, Harris, & O'Gorman, 2000). In general, it appears that consideration of sidedness and severity seems to be a useful tool in predicting memory findings in children.

Processing Speed

Processing Speed (*Gs*) is the fluency of cognitive task performance, particularly when required to maintain attention and concentration (Flanagan, Ortiz, & Alfonso, 2007). Speed of information processing is associated with myelination of nerves that make up white matter in the brain, as myelin allows for enhanced conduction of neural information (Miller, 2007). Injuries causing damage to or deterioration of myelin are associated with poor *Processing Speed.* Moreover, tasks measuring visual versus verbal fluency involve the areas that process primarily the visual (right hemisphere) versus verbal (left hemisphere) functions (Lezak, Howieson, & Loring, 2004). These processes were discussed in the *Visual Processing* and *Crystallized Intelligence* section above. On motor speed tasks, children with right hemisphere injury perform worse with the non-dominant left hand than children with left hemisphere injuries, yet no differences were found between groups on tasks requiring the right dominant hand (Driscoll, 1994). In general, impact of injury on performance varies with the nature of the task.

TBI related deficits in *Processing Speed* have been well documented (Catroppa, Anderson, Morse, Haritou, & Rosenfeld, 2007; Beauchamp, Catroppa, Godfrey, Morse, Rosenfeld, & Anderson, 2011; Schiehser, Delis, Filoteo, Delano-Wood, Han, Jak, Drake, & Bondi, 2011; Tonks, Williams, Yates, & Slater, 2011). Children with TBI often have ongoing *Processing Speed* difficulties, with findings extending beyond five and ten years post injury (Catroppa et al., 2007; Beauchamp et al., 2011). Additionally, when children sustain a brain injury between the ages of 2 and 7, development of the executive skills of sustained attention, shifting attention, divided attention, and speed may be hindered (Catroppa et al., 2007). Age is significant in identifying *Processing Speed* weaknesses, as those above age 10 demonstrate more significant executive dysfunction than those below age 10, while *Processing Speed* and executive functioning correlate significantly with socioemotional disturbance (Tonks, Williams, Yates, & Slater, 2011). Further, self-reported depressive symptoms are associated with poor attention and *Processing Speed* in adults with TBI during early stages of recovery, but poor insight into executive and *Processing Speed* weaknesses are evident (Schiehser et al., 2011). Volition and severity also play a role in *Processing Speed* outcomes. In college students with TBI, accuracy did not improve when provided with additional time, but they took longer to respond to each item (Battistone, Woltz, & Clark, 2008). Other research suggests that TBI and healthy subjects have comparable accuracy but significant differences in speed (Fong, Chan, Ng, & Ng, 2009). An indicator of *Processing Speed* recovery is severity, as determined by the GCS score (Fuentes, McKay, & Hay, 2010). Likewise, those with severe injuries tend to have the poorest performance and show the most improvement over time, while attention on timed and complex tasks remain significant weaknesses (Catroppa & Anderson, 2005). Thus, factors that must be considered when assessing *Processing Speed* in children with TBI are age, volition, and severity.

Demographic Factors

Bilingualism

The current research for bilinguals with brain injuries primarily involves case studies. Factors affecting linguistic outcomes include cerebral representation of the second language, method and age of acquisition, premorbid proficiency, and learning style (Marrero, Golden, & Espe-Pfeifer, 2002). Severe left frontotemporal, cortical, and subcortical lesions inflicted during early stages of language development are associated with long-term procedural language acquisition dysfunction, inhibiting first and second language development (Tavano, Galbiati, Recla, Formica, Giordano, Genitori, & Strazzer, 2009). If the first language is more complex than the less proficient second language and left fronto-temporal damage occurs, production of shorter, simpler sentences in the primary language as compared to the second results, likely because acquisition of a second language right hemisphere activation for the second language (Polczynski-Fiszer & Mazaux, 2008). Additionally, when gaining proficiency in a second language, skill improves with memory recovery post-TBI, as patients can consolidate more complex lexical items (Polczynski-Fiszer & Mazaux, 2008). When equally proficient in two languages, selective deficits can occur in both languages, including deficits for nouns, verbs, and irregularly inflected verbs (Miozzo, Costa, Hernandez, & Rapp, 2010). Moreover, bilingual children with TBI demonstrate significantly different brain activation patterns in language areas as compared to those with non-TBI injuries (Karunanayaka et al., 2007). Further, verbal and nonverbal intelligence in bilingual children up to one-year post injury did not differ significantly, yet bilinguals did not show the improvement in verbal comprehension, immediate, or delayed verbal memory as seen in monolinguals over time (Alberty, 2012). Thus, linguistic challenges post-brain injury varies by the nature of the injury, the unique linguistic background, proficiency, and language complexity. Neuropsychological assessments must include evaluation of both languages, as linguistic processes are differentially affected, such that premorbidly preferred languages may be less affected by brain injury (Marrero, Golden, & Espe-Pfeifer, 2002).

Theories of language lateralization posit that the left hemisphere is implicated in early language acquisition and formal language learning, while the right tends to be more involved in informal learning of the second language, especially when acquired later in life (Marrero, Golden, & Espe-Pfeifer, 2002). This theory is difficult to assess, as bilinguals may think in their first language, even after achieving proficiency in another language, therein producing controversial results for brain imaging studies (Marrero, Golden, & Espe-Pfeifer, 2002).

Socioeconomic Status

Socioeconomic status (SES) has been noted as a significant predictor of short and long term outcomes in children with brain injury (Anderson, Morse, Catroppa, Haritou, & Rosenfeld, 2004; Catroppa & Anderson, 2003). In early childhood, between the ages of 2 and 6, neurobehavioral outcome was better predicted by SES, injury severity, and pre-injury adaptive behavior skills, which each accounted for more than the lesion characteristics (Catroppa, Anderson, Morse, Haritou, & Rosenfeld, 2008). In middle childhood, age 8 through 12, recovery of intellectual abilities over 24 months was best predicted by SES (Catroppa & Anderson, 2003). Therefore, SES must be considered when assessing children and determining appropriate services that can promote optimal levels of cognitive and neurobehavioral recovery.

Sex Differences

According to CDC data from 2002 to 2006, nearly fourteen times as many males have emergency department visits, hospitalizations, and deaths due to TBI (Faul, Xu, Wald, & Coronado, 2010). Males between ages 0 and 4 had the most emergency department visits, hospitalizations, and deaths (Faul, Xu, Wald, & Coronado, 2010).

Functional deficits related to sex in TBI patients are not well documented. However, male sex accounts for a modest level of variance in list learning and memory trials, as males showed increased risk for retrieval deficits, likely due to factors of poor *Processing Speed* or efficiency (Donders & Hoffman, 2002). Thus, it is possible that gender differences may exist in the recovery of various cognitive factors.

Chapter 3

The Present Study

The current study was intended to clarify whether the data obtained from brain injured children's cognitive profiles appropriately fit the model provided through the CHC theory based on the data obtained from the clusters that may be formed from the core subtests of the WISC-IV. Nine of the ten core subtests may be used to accurately represent the broad abilities, yielding representation of four clusters, demonstrating at least two qualitatively different narrow abilities for each broad ability. These four clusters include *Crystallized Knowledge* (*Gc*), *Fluid Reasoning* (*Gf*), *Short-Term Memory* (*Gsm*), and *Processing Speed* (*Gs*). CHC clusters of the brain injured children and the non-injured children of the WISC-IV standardization sample were analyzed using Confirmatory Factor Analysis (CFA) to provide a basis for interpretation of assessment results, therein contributing to the growing field of school neuropsychology. This study employs a quasi-experimental design, where the classification (Brain Injured versus Non-Injured) is the independent variable. The dependent variables are the CHC factors attained from the WISC-IV of the current sample based on the core WISC-IV subtests (*Gc*, *Gf*, *Gsm*, *Gs*).

Research Questions

The primary research question in the present study was:

1) Will the data from brain injured children fit the classification taxonomy provided by the CHC theory?

Additional research questions included:

2) Will strong factorial invariance be evident in the Brain Injury group as compared to the data provided in the standardization sample of the WISC-IV?

   If so, will latent mean differences emerge among groups?

3) Will age account for significant variability among the results?

4) Will severity account for significant variability between the groups?

5) Will the point at which a child is tested during their recovery significantly impact the overall results?

6) Will the nature of injury (focal vs. diffuse) significantly dictate the types of weaknesses among the two groups?

Hypotheses

Based on these research questions, the following hypotheses have been generated:

1) The model specified by the CHC theory will fit the data provided in the Brain Injury group.

2) The Brain Injury group will demonstrate strict invariance in model fit as compared to the Non-Injury group. As such:

   a) *Processing Speed* will demonstrate latent mean differences such that the Brain Injury group will demonstrates significantly poorer performance than the Non-Injury group

   b) *Short Term Memory* will demonstrate latent mean differences such that the Brain Injury group will perform significantly worse than the Non-Injury group

3) Age will account for significant variability such that children in middle childhood will demonstrate the poorest results.

4) Initial severity will account for significant outcome variability.

5) Children tested later in recovery will show stronger skills than those tested earlier.

6) Nature of injury will account for significant variability such that diffuse injuries will demonstrate more variance than the focal injury group

Chapter 4

Methods

Participants

A total of 210 subjects were recruited via the database at a rehabilitation hospital for children in Westchester, NY, and the WISC-IV normative and TBI samples. 105 subjects formed each group. These subjects were matched based on age, sex, and ethnicity wherever possible to create the Non-Injury group from the normative sample based on the data obtained from the Brain Injury group, which combined a hospital database and the TBI normative sample of the WISC-IV. See Table 1 for the frequency of demographic factors.

Brain Injury Group: The majority of the participants in the Brain Injury group were former patients of a Brain Injury Unit in a hospital in Westchester, NY. In total, after removing profiles that did not contain the full WISC-IV core battery, 65 patients remained. Additional profiles for this group were obtained from the WISC-IV normative sample of children with Traumatic Brain Injury. 43 profiles existed in this sample, 3 of which were removed due to missing data. Thus, a total of 105 subjects encompassed the Brain Injury group, which was 61.9% male, 38.1% female, 47.6% Caucasian, 24.8% African American, 16.2% Hispanic. 8.6% Asian, and 2.9% Other. The ages ranged from 6.33 to 16.99 (M= 12.6; SD= 2.91, Skewness= -0.42; Kurtosis= -0.93). 65% of the cases from the WISC-IV sample were classified as having traumatic brain injuries without fractures, while 35% had brain injuries that included fractures. The types of brain injuries included in the hospital based sample included acquired brain injuries (43.3%), traumatic brain injuries involving fractures (30%), and traumatic brain injuries not involving fractures (26.7%). Data regarding type of brain injury was unavailable for five subjects. Of the hospital sample, acquired brain injuries included tumors (15.4%), hemorrhages, strokes, or hematomas (13.8%), encephalitis (4.6%), and other acquired injuries (6.2%). Of the ten tumor patients, four had astrocytomas, two suffered posterior fossa tumors, one had a medullablastoma, one had both a medulloblastoma and a posterior fossa tumor, one had a glioma, and one patient had a diagnosis of neurofibromatosis. Of the nine hemorrhage, stroke, and hematoma patients, two suffered infarcts, two were affected with Acute Disseminated Encephalomyelitis (ADEM), two had Arteriovenous Malformations (AVM), one had a Middle Cerebral Artery (MCA) aneurysm, one internal capsule bleed, and one was a hematoma in a patient with Acute Lymphoblastic Leukemia (ALL). Two of the three encephalitis patients had suffered seizures related to their diagnosis. The four patients with other acquired brain injuries included one patient with cerebellar demyelination, one with pansinusitis, one congenital hydrocephalus patient who had suffered seizures and an infarct resulting from shunt malfunction, and one who was found to have an abnormal temporal lobe with mucosal thickening. The TBI injuries from the hospital sample included accidents involving motor vehicles (38.5%), other accidental injuries (13.8%). The group suffering from other accidental injuries included occurrences involving sleds, falls, skateboards, and boat propellers. The exact amounts and percentages of each group's descriptive statistics are presented in Table 1.

When pooling the data obtained from the rehabilitation hospital database and that of the WISC-IV special group study for children with TBI, a discriminant analysis was performed to ensure that the data obtained from each source did not differ significantly.

The results yielded that these groups were fairly homogenous (Cannonical $r(105) = .328$; Wilks' $\lambda = .261$; $p > .05$), therein supporting the notion that pooling the data together would create a homogenous Brain Injury group for the present study.

Non-Injury Group: The Non-Injury group was obtained using age, sex, and ethnicity matched pairs from the normative sample of the WISC-IV based on the identity of the subjects in the Brain Injury group. These individuals were matched within 0.2 years for age. When ethnicity matches were not available, as evident in three cases, an exact age and sex matched pair was extracted. 105 profiles were extracted from the normative sample. This includes 61.9% male, 38.1% female, 49.5% Caucasian, 24.8% African American, 17.1% Hispanic, and 8.6% Asian. The ages ranged from 6.34 to 16.97 (M= 12.6; SD= 2.91; Skewness= -0.42; Kurtosis= -0.93). The total amount and percentages of children in this group according to demographic factors are listed in Table 1.

Table 1

Demographic Characteristics

Characteristic	Brain Injury		Non-Injury	
	N	%	N	%
Sex				
Male	65	61.9	65	61.9
Female	40	38.1	40	38.1
Ethnicity				
Caucasian	50	47.6	52	49.5
African American	26	24.8	26	24.8
Hispanic	17	16.2	18	17.1
Asian	9	8.6	9	8.6
Other	3	2.9	0	0
Injury Type- Hospital Sample:	n= 65			
Motor Vehicle Related	25	38.5		
Hemorrhage, Stroke, Hematoma	9	13.8		
Tumor	10	15.4		
Other Accident	9	13.8		
Encephalitis	3	4.6		
Other Acquired Brain Injury	4	6.2		
Unknown Cause	5	7.7		

Note. Age Range for Each Group = 6.3 to 16.9 (M= 12.6; SD= 2.9)

The types of injuries and affected areas of the brain were documented to the greatest extent possible, in addition to the time since injury, age at which assessment took place, injury severity, and the linguistic background of the child where the information was available. However, specific information regarding the time since injury, injury severity, and linguistic background were unavailable for the subjects obtained from the WISC-IV standardization samples for both the TBI and Normative groups and thus, these factors were unable to be fully investigated. Information available within the WISC-IV datasets regarding the type of injury or location of injury only included whether the child had sustained an open or closed head injury.

Instruments

Wechsler Intelligence Scale for Children, Fourth Edition (WISC-IV)

The WISC-IV is an individual assessment used to assess intelligence of children from 6:0 years old through 16:11 years old (Wechsler, 2003). This tool is divided into composite scores that are intended to represent cognitive functions on four domains, including the Verbal *Comprehension* Index (VCI), Perceptual Reasoning Index (PRI), Working Memory Index (WMI), and *Processing Speed* Index (PSI). This tool also provides a broad measure based on the four Indexes called the Full Scale Intelligence Quotient (FSIQ). This tool includes ten core subtests, with five supplemental subtests offered.

The normative sample excluded specific groups of children with any physical condition or illness that could depress performance, including stroke, epilepsy, brain tumors, traumatic brain injury, brain surgery, encephalitis, and meningitis. 2,200 children, equally divided between male and female, were included in the normative sample across ages 6 through 16 (Wechsler, 2003). The racial backgrounds and geographic location were proportionate to that represented in the March 2000 U.S. Census data. Internal consistency reliability coefficients average range from 0.65 to 0.94 for subtests, from 0.81 to 0.97 for Indices, and from 0.70 to 0.97 overall. Data for 16 special groups yielded reliability coefficients from 0.73 to 0.0.97 for children with open head injuries and from 0.77 to 0.97 for children with closed head injury (Wechsler, 2003). Test-retest reliability was established with 243 children, of whom 74.1% were White, 7.8% were African American, 11.1% were Hispanic, and 7.0% were from other racial backgrounds, yielding correlations from the 0.70s to 0.90s. In terms of validity, intercorrelations for subtests ranged from 0.10 to 0.74. Content validity was established using the prior and current Wechsler batteries (WISC-III, WPPSI-III, WAIS-III, WASI) (Wechsler, 2003). Correlations with other batteries were explored, such as with the GRS-School Form, the BarOn EQ, and the ABAS-II.

The group for Traumatic Brain Injury included 43 children from 6 to 16 years old who had a history of moderate to severe TBI, with few children included who had sustained mild TBI included if CT or MRI abnormalities were demonstrated. Children who had sustained a TBI within 6 months, post-morbid IQ scores <60, premorbid skills <70, a duration of unconsciousness beyond 24 hours, premorbid psychiatric disorders, tumors or medical related injuries were excluded from the sample.

Procedures

First, IRB approval was obtained from St. John's University and from the rehabilitation hospital in Westchester, NY. Test results were then obtained from a database of children and adolescents who sustained non-traumatic acquired brain injury and traumatic brain injury. This data was de-identified and coded accordingly prior to removing data from the facility to ensure anonymity of subjects. Subjects were also attained from the standardization samples of the WISC-IV's normative and Traumatic Brain Injury groups. The data from the WISC-IV TBI sample was then combined with the brain injury data of the dataset obtained from the rehabilitation hospital. This data collectively formed the Brain Injury group. Next, the data obtained from the standardization normative data of the WISC-IV was reviewed and the primary researcher chose comparison profiles that were matched for age, sex, and ethnicity to form the Non-Injury group. The results were organized not by Indexes but rather according to the CHC factors (Flanagan & Kaufman, 2004; Flanagan, Ortiz, & Alfonso, 2007) represented among the subtests, as the five factor model has been identified to be a better fit across ages than the existing WISC-IV structure (Keith et al., 2006). However, because only the core subtest scores were available in the TBI subject database obtained from the rehabilitation hospital, only four factors were formed (*Gc*, *Gf*, *Gsm*, *Gs*) because the *Visual Processing* (*Gv*) cluster cannot be accurately represented using only the core WISC-IV subtests. The data from each group (Brain Injury vs. Non- Injury) was then analyzed.

Analysis of Data

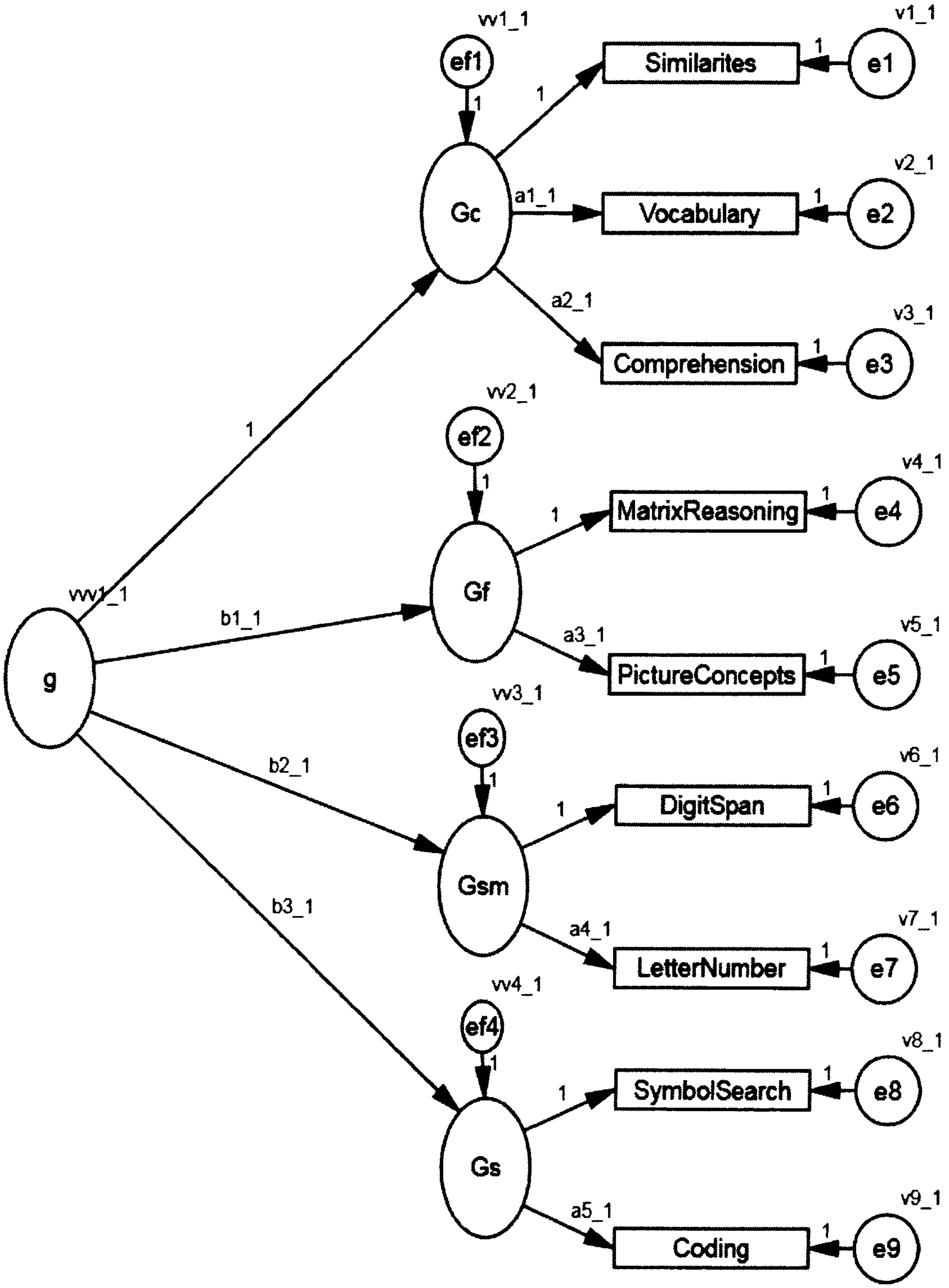
A Confirmatory Factor Analysis (CFA) was performed using Amos 21 to determine whether the brain injured children and adolescents' cognitive profiles based on the WISC-IV data fit the model provided by CHC theory. For comparative purposes, a CFA of the Brain Injury group data was also performed. Next, a Multi-Group CFA was performed, which allows for observation of each individual group's fit (Sun, 2005) to the

CHC theory based model when comparing the Brain Injury and Non-Injury groups to test for measurement invariance across these two groups. If measurement invariance is established, the latent means will be compared across groups. In addition, to evaluate the effect of age, three age groups were identified (6:0-9:9; 10:0-12:9; 13:0-16:9) and a 3 (age group) x 9 (subtest) MANOVA was performed. As a follow up analysis, the effects of ethnicity (Caucasian, African American, Hispanic, Asian, Other), sex (male, female), time since injury (≤6 months, >6 months), and nature of injury (TBI-no fracture, TBI with fracture, ABI) were controlled to review whether a significant finding emerged based on age group. This permitted for a 3 (age group) x 9 (subtest) MANCOVA. Severity could not be evaluated due to inconsistent reporting of GCS values, and thus, severity will not be addressed in the Results section. To assess the effects of time since injury, the data was divided into two groups; those who had been tested within 6 months of their injury and those who were tested after more than 6 months post-injury. A 2 (Time ≤6 months; Time >6 months) x 9 (subtest) MANOVA was performed to determine the effects of time since injury on subtest performance. To address whether the nature of the injury impacted subtest performance in the Brain Injury group, the group was first divided into two separate groups; those who had sustained skull fractures and those without fractures. A 2 (Injury: Fracture vs. Non-Fracture) x 9 (subtest) MANOVA was performed. To further investigate the potential effect of nature of injury, a third group was identified, which included those who had sustained acquired non-traumatic brain injuries. A 3 (Injury: TBI-Fracture, TBI-Non-Fracture, ABI) x 9 (subtest) MANOVA was performed. Finally, a follow- up analysis was performed to view the relationship between children with ABI and those with different types of TBIs.

Determination of Cutoff Values

The primary question to be answered by this research was whether the data from brain injured children fit the classification taxonomy provided by the CHC theory. In order to determine model fit, several fit indices must be considered. Much controversy exists in the literature regarding which fit indices may qualify a model as meeting acceptable fit criterion. Thus, several criterion will be discussed. Confirmatory Factor Analysis (CFA) is therefore used to test the fit of a model that has been identified through theory or research to a given population (Tabachnick & Fidell, 2007). A common understanding exists that the observed variables do not always account for all of the variability evident in the latent (unobserved) variables, and thus, the software used in conducting a CFA accounts for measurement error (Schumacker & Lomax, 2004). In the CHC theory model, latent variables include *Gc*, *Gf*, *Gsm*, and *Gs*, while observed variables include the subtests that are expected to load onto each of the latent variables, as suggested by CHC theory. The basic CFA hypothesized model designed based on CHC theory data and the available subtests (observed variables) for the purposes of the present study can be viewed in Figure 1. Following identification of this model, a CFA was performed, the chi-squared statistic was calculated, and several fit indices were analyzed to determine goodness of fit of the a priori model.

Figure 1: A priori CHC model



In order to thoroughly describe a CFA in light of controversy over what factors determine a strong model fit, specific guidelines have been identified by Schreiber, Nora, Stage, Barlow, & King (2006) regarding the information that should be addressed when conducting CFAs for research purposes. Nontechnical evaluative information that should be considered includes having research questions that dictate the use of CFA, information regarding the conceptual framework of the model, inclusion of descriptive statistics, a graphic display of the hypothesized and final models, and implications that follow from the findings. The majority of these factors have been addressed in previous sections, the graphic presentation of the hypothesized and final models follow, and implications are stated in the Discussion section below. Pre-analysis technical issues include the determination of sample size, which is generally suggested to contain ten subjects per estimated parameter (Schreiber, Nora, Stage, Barlow, & King, 2006). In the current study, 5- 1st order regression weights, 3- 2nd order regression weights, 9- 1st order variances, 5- 2nd order variances, and 9 intercepts, indicating that for a total of 31 parameters, approximately 310 subjects would produce optimal results, whereas the current study included 105 subjects per group and a total sample size of 210 subjects. The estimations gathered by the current study may therefore be limited by a restricted sample size. Additional technical issues which must be addressed according to Schreiber, Nora, Stage, Barlow, & King, 2006, include the handling of missing data, which has been discussed above, and the software program employed, which is the AMOS 21 software program, and the estimation method utilized, which was the Maximum Likelihood method.

Post-analysis factors which should be discussed include the coefficients of hypothesized relationships, analyzing residuals, fit indices, standardized residuals through the residual matrix, and the reliability of the observed variables or subtests as they relate to the latent factors as determined through the squared multiple correlations (Schreiber, Nora, Stage, Barlow, & King, 2006). Of the fit indices, when initially performing a CFA and prior to modifying the model to improve fit, suggested fit indices include the (Non-Normed) Tucker Lewis Index (TLI), the Comparative Fit Index (CFI), and the Root Mean Square Error of Approximation (RMSEA) (Schreiber, Nora, Stage, Barlow, & King, 2006). In addition, many articles cite the Standardized Root Mean Square Residual (SRMR). However, very few articles actually describe the purpose of these fit indices and what they actually indicate regarding the data beyond whether they suggest a 'good' or 'poor' fit. Thus, a brief description of fit indices follows in order to more appropriately interpret the meaning of the data and how it fits the hypothesized model.

Several aspects of fit must be considered when performing a CFA. When considering fit indices, the types that are most often cited include the Absolute Fit and Relative (Incremental) Fit Indexes. There are also Parsimony based and Non-Centrality Fit Indices. Absolute fit Indices (AFI) can also tend to be sensitive to sample size, such that it can over-reject models when the sample size is below 250 subjects. AFI's measure the degree to which the hypothesized model is demonstrated through the sample data compared to the Saturated Model, which is based on the covariance matrix for observed data (Singh, 2009). The Chi-Squared test is an AFI that measures how well a model fits the observed data; however, this measure is not valid when sample sizes are small, as it can tend to be insensitive (Singh, 2009). AFI's also include the Adjusted Goodness of Fit Index (AGFI), which is based on a linear regression equation model, the Goodness of Fit Index (GFI), which views the relative variance and covariance accounted for by the model applied, and Hoetler's measure of sample size, which suggests the appropriate sample size for fit sufficient for the Chi-Squared test (Singh, 2009). Additional measures of AFI that are commonly cited include the residual based fit indices, namely the Root Mean Square Error of Approximation (RMSEA) and the Standardized Root Mean Square Residual (SRMR). Residual analyses review the discrepant aspects that may exist between the reproduced model's correlations and the correlations resulting from the observed data (Singh, 2009). The RMSEA measures the within factor residual covariance, however the power to do so is limited when there are three or fewer factors, and as factor loadings increase, the RMSEA becomes more sensitive to the incorrect amount of latent factors (Savalei, 2012). In sum, when there are more latent factors, the sensitivity to misspecification of RMSEA decreases and sensitivity increases when there are fewer indicators of factors (Savalei, 2012). Finally, the SRMR is essentially the mean of residual values between the input and observed matrices or the mean residual covariance or correlation (Singh, 2009). Thus, the RMSEA is a measure that suggests fit to the population, whereas the SRMR is a sample based fit index (Singh, 2009; Savalei, 2012).

The remaining fit indices that attain strong attention in the current literature include the Relative or Incremental Fit, Parsimony based, and Non-Centrality Fit measures. Three main Comparative Fit Indices (CFI) compose the Relative Fit Index (RFI), which collectively describe the change in the fit of the target model nested within a baseline model (Hu & Bentler, 1999; Singh, 2009), such as after imposing additional constraints. The first, which includes the Normed Fit Index (NFI), makes no assumptions about the distribution, the second, such as the Tucker Lewis Index (TLI) which is also known as the Non-Normed Fit Index (NNFI), assumes a central Chi-Squared distribution, and the third, which includes the Bentler's Fit Index (BFI), utilizes the information from the NFI with that of the expected values of the target, baseline, and non-centrality Chi-Squared distributions (Singh, 2009). The NFI, which is sensitive to sample size, measures the total covariance of the observed variables explained by the target model, the TLI, which is independent of sample size and is used with normality and Maximum Likelihood estimation methods, provides information about the expected values of the target model, and the BFI identifies misspecification by using non-centrality parameters (Singh, 2009).

Finally, parsimonious measures should also be considered to ensure that the model is not too complex. If comparing models with varying amounts of constructs, the Akaike Information Criteria (AIC) can be noted. The researchers must evaluate their studies to determine which fit indices are most appropriate based on their data and the goals of the research.

In the current study, the fit indices chosen include those which were utilized in a similar study which investigated the model fit of the WISC-IV's inherent structure versus proposed by CHC theory (Keith, Goldenring Fine, Taub, Reynolds, & Kranzler, 2006). These indices are the Chi Squared (χ^2), the TLI, the CFI, the RMSEA, and the SRMR. The AIC was used in the previous study and this value will be used in the current study to compare the fit of the CHC theory based model and the WISC-IV inherent model. In addition, the GFI and NFI will be considered. The Chi-Squared probability value should be greater than 0.05 to accept the null hypothesis that there is not a significant difference between the proposed and observed models. Lance, Butts, & Michels (2006) present misinterpretations that have been made of the initially presented cutoff values for several of these indices. For instance, they highlight the fact that NFI and TLI below 0.9 do not necessarily indicate poor fit, but rather, that the model can typically be improved when these values do not fall above 0.9 (Bentler & Bonett, 1980). Further, when using Maximum Likelihood estimation as in the current study, the TLI and CFI values are suggested to be above 0.95 (Hu & Bentler, 1998; Hu & Bentler, 1999; Schreiber et al., 2006). A GFI greater than 0.9 is generally accepted, although it should not be blindly accepted as indicating good fit but rather it should be viewed in the context of other indicators of fit (Lance, Butts, & Michels, 2006). For the RMSEA, values of <0.08 are generally accepted, with smaller values (<0.06) indicative of better fit (Browne & Cudeck, 1990; Hu & Bentler, 1999; Schreiber et al., 2006). Lastly, for the SRMR, values of less than 0.08 are desired (Hu & Bentler, 1999; Schreiber et al., 2006). These values will be considered in order to assess model fit in the present study. In addition, multicollinearity was ruled out through analysis of the correlations between variables within each group to ensure that strong correlations did not exist between different subtests, particularly those which did not load onto a shared factor.

Chapter 5

Results

Normality

Prior to running statistical procedures for production of the CFA and MANOVA designs used in the present study, distribution normality was assessed given that normality is assumed under each of these procedures. Univariate normality was assessed in SPSS 21 by reviewing the 5% Trimmed Mean in comparison to the original mean value across each of the ten subtests when accounting for differences based on age, sex, ethnicity, and group membership. All means were similar to the Trimmed Means, indicating that extreme outliers did not significantly alter the mean of the groups based on group membership or demographic variables. On a univariate level, Muthen & Kaplan (1985) initially identified skewness and kurtosis values of +/-1.0 to have little effect on the variables, whereas when skewness or kurtosis values are larger than +/- 2.0, in conjunction with high correlations among variables, distortions are likely, particularly when Maximum Likelihood SEM estimates or chi-squared statistics would be utilized (Gao, Mokhtarian, & Johnston, 2008). However, a rule of thumb that has been more widely cited in recent years is that suggested by Kline (2005), suggesting that skewness values less than 3 and kurtosis values less than 7 are acceptable. Based on these guidelines, normality appeared to be consistent across groups. Although these guidelines are somewhat broad compared to previous suggestions of the skewness and kurtosis values that would indicate normality, when preparing data for multivariate SEM procedures with Maximum Likelihood estimation methods, ideal normality was "almost never achieved with raw empirical data" and although transformations could sometimes help, they could often "make the model more difficult to interpret and still fail to result in normality" (Gao, Mokhtarian, & Johnston, 2008).

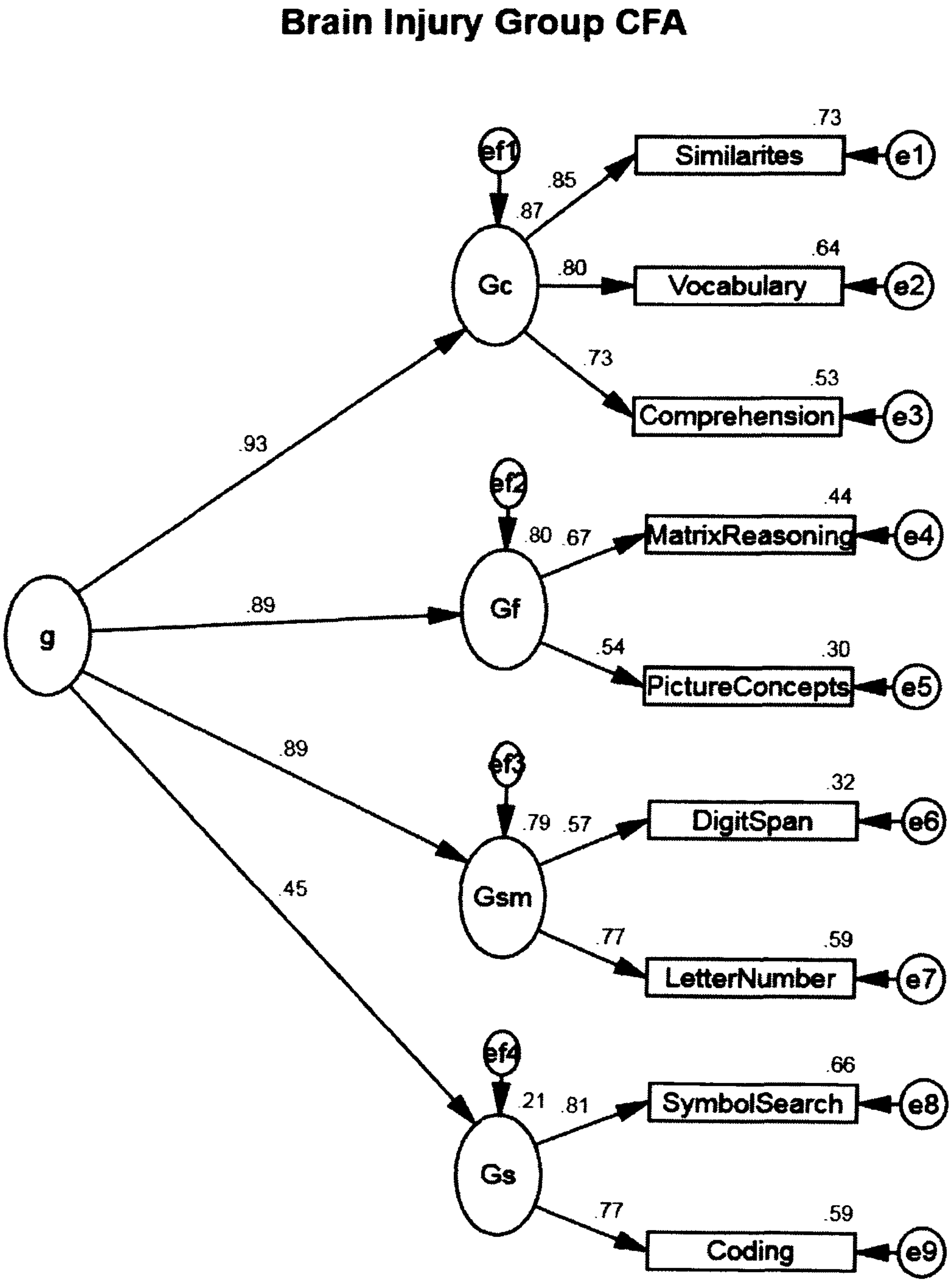
In considering multivariate normality based on the combined sample results, the Mahalanobis distance, which describes the distance of a case from the center (mean) of the other cases, is useful in identifying whether specific outliers may have a significant impact across variables (Tabachnick & Fidell, 2007; Pallant, 2010). This distance is also considered to be the distance between two multivariate populations (Stevens, 1996; Tabachnick & Fidell, 2007). Given that the value based on the current samples does not exceed the critical value specified by Pearson & Hartley (1958) as cited in Tabachnick & Fidell (1996), the sample is said to meet criterion for multivariate normality across the ten core subtests of the WISC-IV (Mahalanobis Distance: Maximum= 21.627; C.V.= 29.59). In addition, by using the Mardia's coefficient for multivariate normality, a normal multivariate distribution assumption was further supported for both groups (Brain Injury: Kurtosis= 1.858; C.R. = 0.676; Non-Injury: Kurtosis= -0.244; C.R. = -0.89). Linearity and heteroscedasticity were assessed by visually inspecting bivariate plots between each pair of t-scores to ensure that scores lacked obvious violations.

Confirmatory Factor Analysis: Brain Injury Group

The initial hypothesis of the present study stated that the data from brain injured children would fit the classification taxonomy provided by CHC theory. To investigate this model fit, a Confirmatory Factor Analysis (CFA) was performed using the data obtained from the Brain Injury group. The four factors of the CHC model that can be attained from the WISC-IV core subtest data fit well within the Brain Injury group (see Table 2) ($\chi^2[23]= 27.959, p = .217$, CFI = .984, RMSEA = .046, GFI= .942, NFI= .920, TLI= .975, SRMR= .0549). Construct validity was established through reviewing the correlations within the model. *Gc*, *Gf*, and *Gsm* correlated with the overall intelligence factor (*g*) strongly (*r* =.93;.89;.89), respectively, while *Gs* correlated moderately with *g* (*r* =.45). All *Gc* subtests (*Comprehension*, *Vocabulary*, *Similarities*) correlated strongly with the *Gc* factor (*r* =.73; .80; .85), respectively, the subtests of the *Gf* factor (*Picture Concepts*, *Matrix Reasoning*) correlated moderately with *Gf* (*r* =.54; .67), respectively, subtests of *Gsm* (*Digit Span*, *Letter-Number*) correlated moderately to strongly with *Gsm* (*r* =.57; .77), respectively, and subtests of *Gs* (*Coding*, *Symbol Search*) correlated strongly with the *Gs* factor (*r* =.77; .81), respectively (See Figure 2). Thus, the data from the Brain Injury group fit the CHC model well, supporting the initial hypothesis regarding the appropriateness of the CHC model for use with brain injured children.

Figure 2

Path Diagram Based on CHC Theory- Standardized Estimates for the Brain Injury Group



Follow-up Analysis: CHC Theory Structure vs. WISC-IV Structure

A follow-up analysis was performed to compare the CHC Theory structure identified above to the inherent structure of the WISC-IV to determine whether one of these models provides an enhanced fit when considering the data from the Brain Injury group. The a posteriori hypothesis herein is that the CHC theory group structure would fit the data for brain injured children better than the WISC-IV inherent model. To investigate the model fit of the WISC-IV inherent model, a Confirmatory Factor Analysis (CFA) was performed using the data obtained from the Brain Injury group (See Figure 3). First, to represent the CHC Theory based structure, the four factor model (*Gc*, *Gf*, *Gsm*, *Gs*) was calculated, yielding acceptable model fit. However, because this does not include the *Block Design* subtest, as *Gv* is not accurately represented by one subtest alone, the subtest *Block Design* was loaded directly onto *g* to create a more appropriate comparison for the WISC-IV inherent structure. This model fit was poor, but when a correlation was added between the residual error variances of *Matrix Reasoning* and *Block Design*, both subtests of which each measure some aspect of *Gv*, the shared covariance represented by *Gv* was then accounted for and the model fit improved significantly. This model was used to compare to the model fit for the inherent four factor (VCI, PRI, WMI, PSI) model of the WISC-IV. Based on the Akaike Information Criterion (AIC), which estimates relative goodness of fit whereby a lower AIC value indicates a preferable model fit, the CHC Theory based model was supported as a superior model, although both models would be considered acceptable. See Table 2 for Fit Indices.

Table 2

Model Fit: CHC Theory Model vs. WISC-IV Model

Model	χ^2	df	p	AIC	TLI	CFI	GFI	NFI	RMSEA	SRMR
CHC	27.96	23	.217	71.959	0.975	0.98	0.94	0.92	0.046	0.055
CHC with *Block Design*	55.35	31	.005*	103.352	0.901	0.93	0.90	0.86	0.087	0.070
CHC, *Block Design* and BD↔MR**	42.26	30	.068	92.256	0.948	0.97	0.92	0.90	0.063	0.068
WISC-IV Model	46.37	31	.037*	94.373	0.937	0.96	0.92	0.88	0.069	0.076

Note. *$p<0.05$. df= degrees of freedom; Normed Chi-Square= X^2/df (Cutoff < 2); TLI= Tucker Lewis Index (Cutoff>0.95); CFI= Comparative Fit Index (Cutoff >0.95); GFI= Goodness of Fit Index (Cutoff >0.9); NFI= Normed Fit Index (Cutoff >0.9); RMSEA= Root Mean Square Error of Approximation (Cutoff <0.06); SRMR= Standardized Root Mean Square Residual (Cutoff <0.08).

**BD↔MR= Covariance between Residuals of *Block Design* and *Matrix Reasoning* Subtests

Figure 3

Path Diagram Based on Structure of WISC-IV- Standardized Estimates- Brain Injury Group

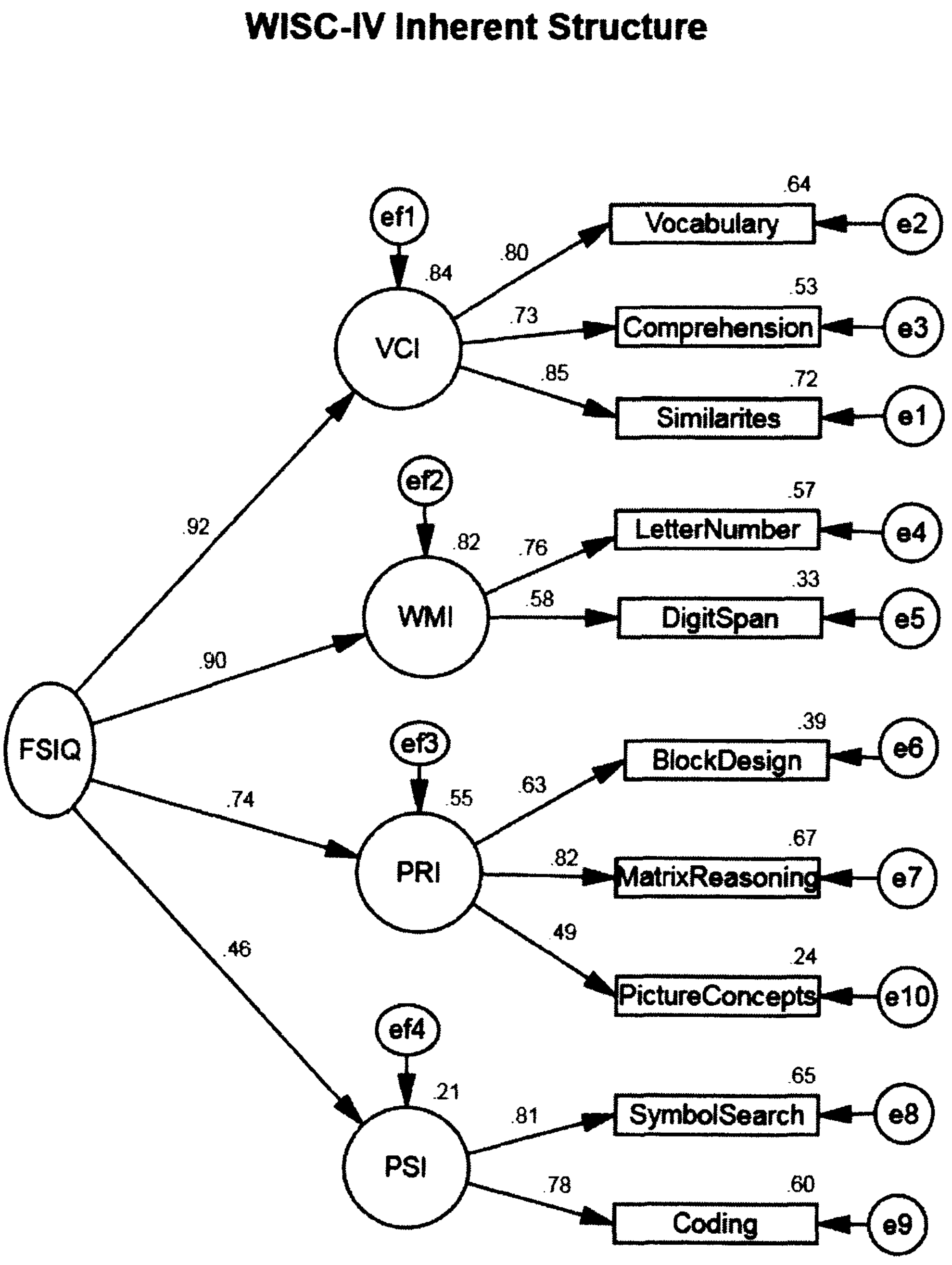
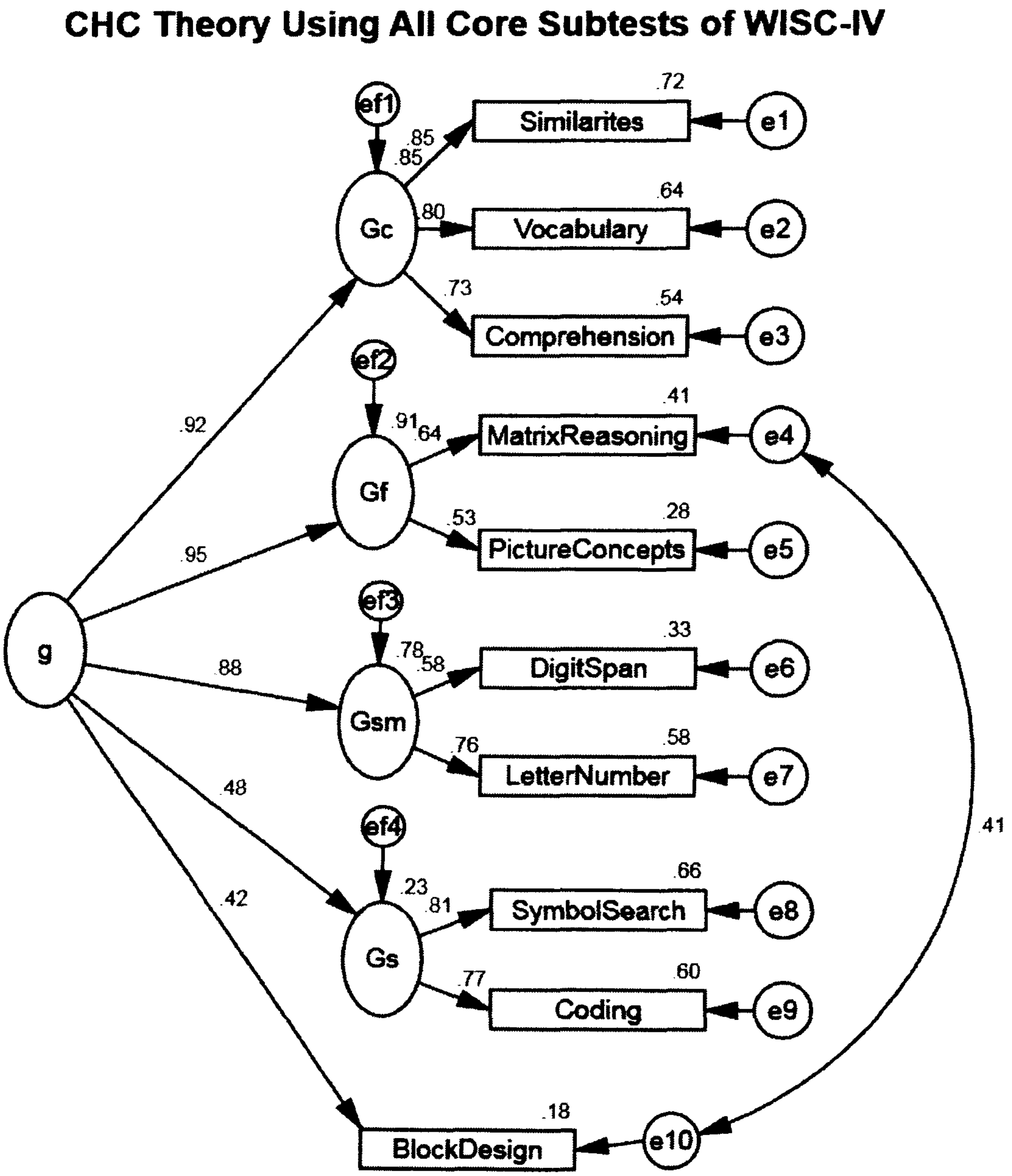


Figure 4

Path Diagram CHC Theory-All Core of WISC-IV- Standardized Estimates- Brain Injury Group



CHC Theory Using All Core Subtests of WISC-IV

Multi-Group Confirmatory Factor Analysis

A multi-group confirmatory factor analysis approach was used to test for measurement invariance of CHC Theory factor structure based on the WISC-IV across the Brain Injury and Non-Injury groups. If measurement invariance was tenable, then valid comparisons related to the latent constructs can be made and if factor loadings were invariant, comparison of the groups based on factor variances can be conducted. Then, if scalar invariance is supported, the comparison of factor means across groups can then be made to test the hypotheses regarding *Gsm* and *Gs*. This procedure required performing a Multi-Group Confirmatory Factor Analysis to first estimate the fit of the CHC Theory model to each of the groups. Then, the relative fit of each group to the specified model when no constraints have been placed is evaluated to establish configural invariance.

Steps to establish higher order factorial invariance in models that contain 2nd order factors have been identified by Dimitrov (2010). Subsequent to establishing configural invariance, invariance of 1st order and 2nd order factor loadings should be evaluated individually to establish metric invariance. Next, invariance of intercepts in the measurement model are evaluated, followed by testing invariance of intercepts in the structural model to determine scalar invariance. A follow-up analysis conducted with the information gathered up to this point was conducted to establish scalar invariance of the latent *g* mean differences, which includes the first order and subtest intercept invariance. When this is successful, it can then be said that the differences in the *g* factor can account for all observed mean differences in the subtests. This was not supported and thus, some of the first order intercepts (*Gsm*, *Gs*) were freed while the remaining were constrained. Therefore, differences in the first order intercepts could not fully be accounted for by the differences in *g*, and their mean differences were evident beyond the influence of *g*. After establishing scalar invariance, invariance of disturbances (uniquenesses) of the 1st order factors are then measured, and finally, invariance of residual variances of the observed variables can be assessed (Dimitrov, 2010). For the purposes of the present study, specific emphasis will be placed on the constraints that relate to configural, metric, and scalar invariance for the measurement portion of the model.

The primary fit indices include the traditional Chi Squared difference test in addition to the change in CFI (ΔCFI), which has been found to be less impacted by model complexity and sample size, and thus a more valid measure of comparative model fit than the Chi Squared difference test (Cheung & Rensvold, 2002). The Chi Squared difference test ($\Delta\chi^2$) supports invariance of the parameters being tested if the $\Delta\chi^2$ is not statistically significant at the $p<.05$ level (Dimitrov, 2010). The unconstrained standardized path diagram for the Brain Injury group can be found on Figure 5 and the standardized path diagram for the Non- Injury group can be found on Figure 6. Superficial review of these two diagrams suggests that the first and 2nd order factor loadings are fairly consistent across groups such that both groups demonstrate moderate 2nd order loadings associated with *Gs* and strong 2nd order factor loadings associated with *Gc*, *Gsm*, and *Gf*.

Figure 5

Path Diagram for Multi-Group CFA- Brain Injury Group- Standardized Estimate-Unconstrained

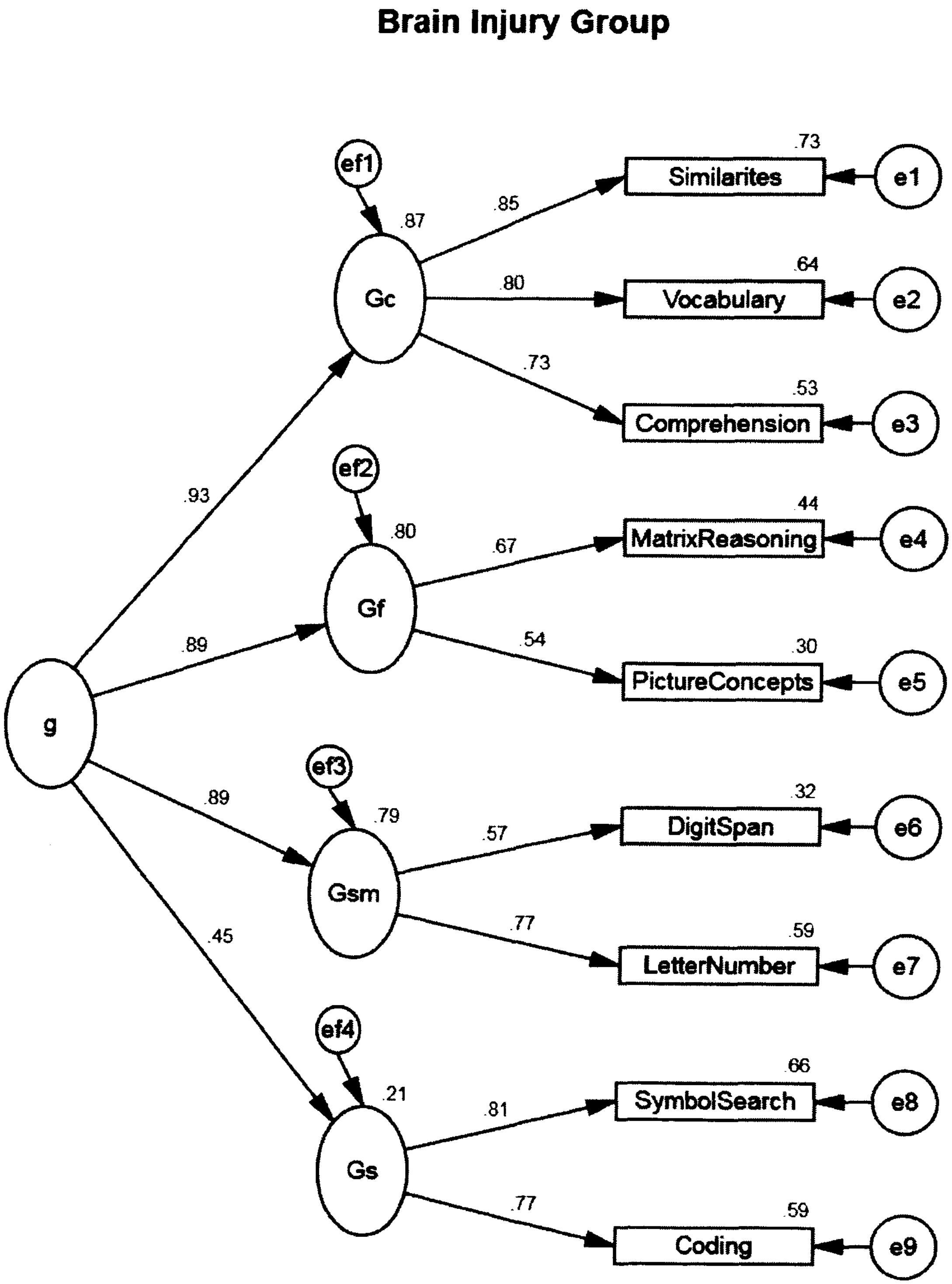
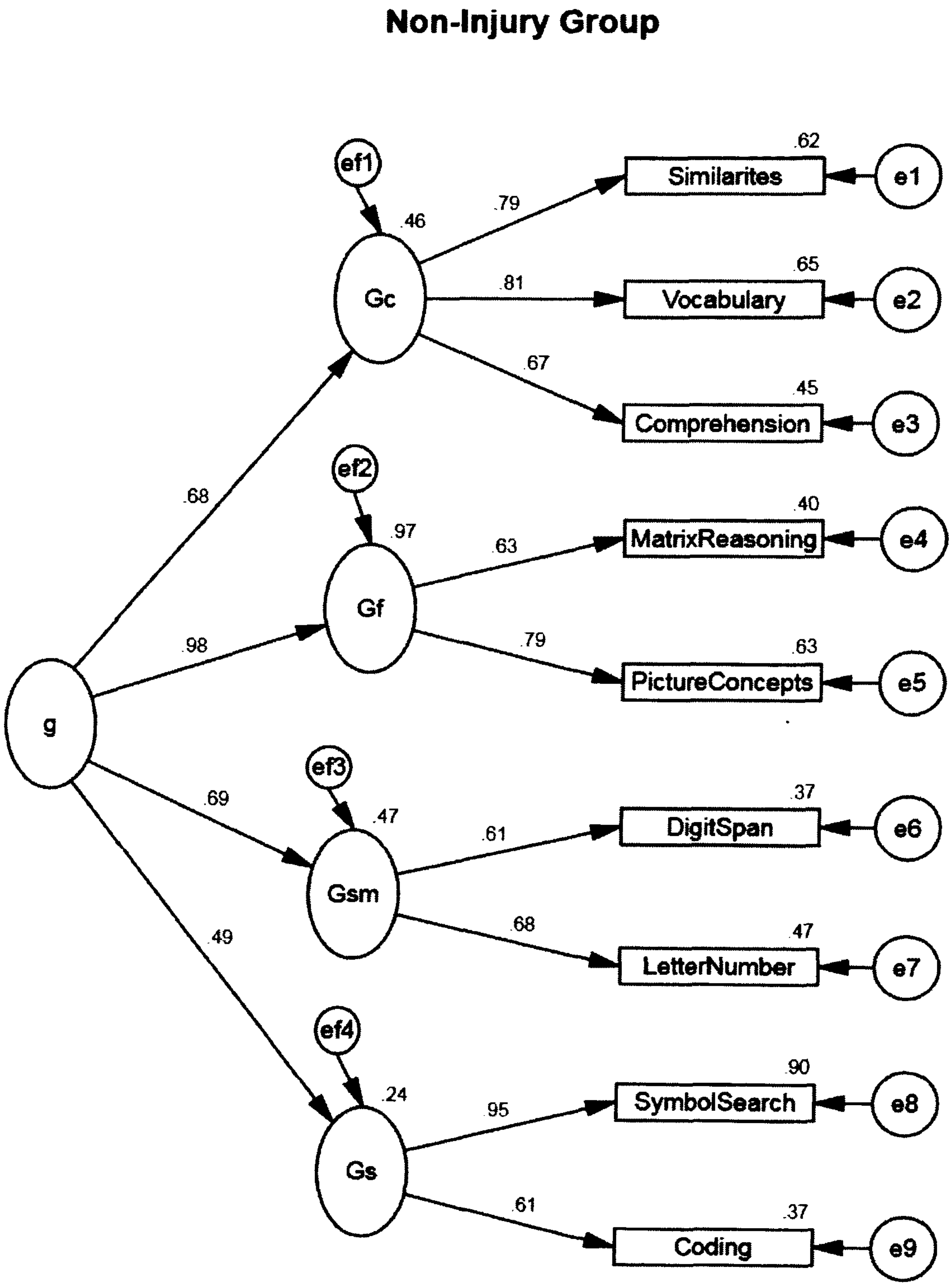


Figure 6

Path Diagram for Multi-Group CFA- Non-Injury Group- Standardized Estimates-Unconstrained



When considering the relationship in how the CHC theory based model fits the data for each of the two groups, configural invariance must be established. The fit statistics confirm that the model is satisfactory across all fit indices (see Table 3) (χ^2 [46] = 62.57, p =.05, CFI = .97, RMSEA = .04, SRMR= .05). Thus, configural invariance is supported.

Metric invariance was established using a forward sequential procedure based on the 1st and 2nd order factor loadings through nested comparisons. When constraints were placed on the 1st order factor loadings, invariance was supported (see Table 3) ($\Delta\chi^2[5]$ = 4.381, $\Delta\chi^2 p$ =.496, ΔCFI = .00). A regression weight of 1 is indicated to be placed on the most invariant factor, *Gf*, prior to conducting invariance testing for the 2nd order factor loadings (Gustafsson, 1984; Bickley, Keith, & Wolfe, 1995; Keith, Goldenring Fine, Taub, Reynolds, & Kranzler, 2006). When constraints were placed on the remaining 2nd order factor loadings, invariance was rejected ($\Delta\chi^2[3]$ = 8.943, $\Delta\chi^2 p$ =.030, ΔCFI = .03). In accordance with the methods defined by research, the constraint on each factor loading was then released one at a time to determine if the misfit could be localized to one loading, therein resulting in the highest degree of model fit when unconstrained. It should be noted that current literature recommends that fewer than 20% of parameters may be freed to establish partial invariance (Byrne, 1989; Levine et al., 2003; Dimitrov, 2010). It was therefore found that releasing the *Gsm* factor yielded the best model fit ($\Delta\chi^2[2]$ = 4.171, $\Delta\chi^2 p$ =.124, ΔCFI = .00), suggesting that *g* is different in the groups when *Gsm* is included. This is because *g* is significantly more strongly related to *Gsm* in the Brain Injury group (r = .90) than in the Non-Injury group (r = .67). Based on the present findings, configural invariance has been supported while full metric invariance could not be established using the strict criteria of relying on the $\Delta\chi^2$, as the ΔCFI was sufficient in the fully constrained model. According to these specifications, partial metric invariance has been demonstrated. In other words, the constructs of *Gc*, *Gf*, *Gs*, and *Gsm* were measured in the same way for each of the groups, but the relationship between *g* and *Gsm* was such that *g* may be measured differently for the Brain Injury group versus the Non-Injury group.

Table 3

Evaluation of Configural and Metric Invariance

Step	Constraint	χ^2	df	p^a	$\Delta\chi^2$		ΔCFI	RMSEA	SRMR	Accept
					$\Delta\chi^2(\Delta df)$	$\Delta\chi^2$ p				
Configural	Baseline	62.57	46	.05	---	---	---	.04	.05	Accept
1st Order Factor Loading	Loadings from Factors to Subtests	66.95	51	.06	4.38 (5)	.496	.00	.04	.06	Accept
2nd Order Factor Loading	Loadings from *g* to *Gc, Gf, Gsm, Gs*	75.89	54	.03*	8.94 (3)	.030*	.01	.04	.06	Reject
	Loadings with *Gc* freed	75.80	53	.02*	8.85 (2)	.012*	.01	.05	.06	Reject
	Loadings with *Gs* freed	75.70	53	.02*	8.75 (2)	.013*	.01	.05	.06	Reject
	Loadings with *Gsm* freed	71.12	53	.05	4.17 (2)	.124	.00	.04	.06	Accept

Note. $p < .05$; CFI Cutoff >.95; RMSEA Cutoff <.06; SRMR Cutoff <.08
*Significant at $p<.05$; $\Delta\chi^2$ used for nested model comparisons. 1st order compared to unconstrained. 2nd order compared to 1st order.
p^a= *p* value for Baseline comparison.

To test for scalar invariance, the subtest intercepts were constrained to be equal and latent mean differences were allowed to be estimated by freeing the control (Non-Injury) group's latent means (technically intercepts). The latent mean estimates for this group, therefore, represent the latent mean difference from the Brain Injury group. More specifically, all of the constraints that were evident in the partial metric invariant model, which included freed loadings on the *Gsm* factor, were maintained, and the additional constraints of the 1st order intercepts of all nine subtests were added. The resulting fit was acceptable ($\Delta\chi^2[5] = 8.88$, $\Delta\chi^2 p = .114$, ΔCFI = .016), indicating that full scalar invariance has been established. However, because the model fit *p* value was weak, the constraint on each intercept was then released systematically to determine whether subtests can be identified that account for unique variance. When the constraint on the subtest *Vocabulary* was released, model fit improved, indicating that some differences may exist in the performance of brain injured and non-injured children on this subtest, however, the fully constrained model's $\Delta\chi^2$ was sufficient and accepted over this model. The resulting subtest mean values may be found on Figure 7.

After scalar invariance has been supported, an estimation of the mean difference values on the first order factors can calculated between groups. Please refer to Figure 7 for the unstandardized path diagram of the Non-Injury group which represents the mean differences between groups. Analysis of mean differences on the latent factors reveals that the *Gs* factor mean, which represents the mean difference in scaled score points between the two groups for *Gs*, is more than one standard deviation (Scaled Score Value=3.4) based on the mean of 10 and standard deviation of 3. Further analysis of the mean differences between groups indicated that the Brain Injury and Non-Injury groups performed significantly different on all factors, which include *Gc* (Mdiff=1.575; SE=.371), *Gf* (Mdiff=1.431; SE=.374), *Gsm* (Mdiff=1.938; SE= .392), and *Gs* (Mdiff=3.447; SE= .422) at the $p<.05$ level. However, this finding is in absence of reviewing the effect of the mean differences of the 2nd order factor after subtest intercepts (scalar) invariance has been established, and thus, further analyses were later performed to fully evaluate whether *g* fully accounts for all of the mean differences evident in subtest scores or whether first-order factors also account for the differences beyond *g*.

Table 4

Evaluation of Scalar Invariance

Step	Constraint	χ^2	df	p^a	$\Delta\chi^2$		CFI	ΔCFI	RMSEA	SRMR	Accept
					$\Delta\chi^2(\Delta df)$	$\Delta\chi^2$ p					
Intercept of Measured Variables	Subtest Load	80.00	58	.03*	8.88 (5)	.114	.95	.016	.04	.06	Accept
	Free *Symbol Search*	79.25	57	.03*	8.13 (4)	.087	.96	.007	.04	.06	Reject
	Free *Coding*	79.25	57	.03*	8.13 (4)	.087	.96	.007	.04	.06	Reject
	Free *Picture Concepts*	77.81	57	.04*	6.69 (4)	.015*	.96	.004	.04	.06	Reject
	Free *Matrix Reasoning*	79.62	57	.03*	8.50 (4)	.075	.96	.007	.04	.06	Reject
	Free Letter Number Seq.	78.94	57	.03*	7.82 (4)	.098	.96	.006	.04	.06	Reject
	Free *Digit Span*	78.94	57	.03*	7.82 (4)	.098	.96	.006	.04	.06	Reject
	Free *Similarities*	77.13	57	.04*	6.01 (4)	.198	.96	.003	.04	.06	Reject
	Free *Comprehension*	79.62	57	.03*	8.50 (4)	.075	.96	.007	.04	.06	Reject
	Free *Vocabulary*	75.36	57	.05	4.24 (4)	.374	.96	0.0	.04	.06	Accept

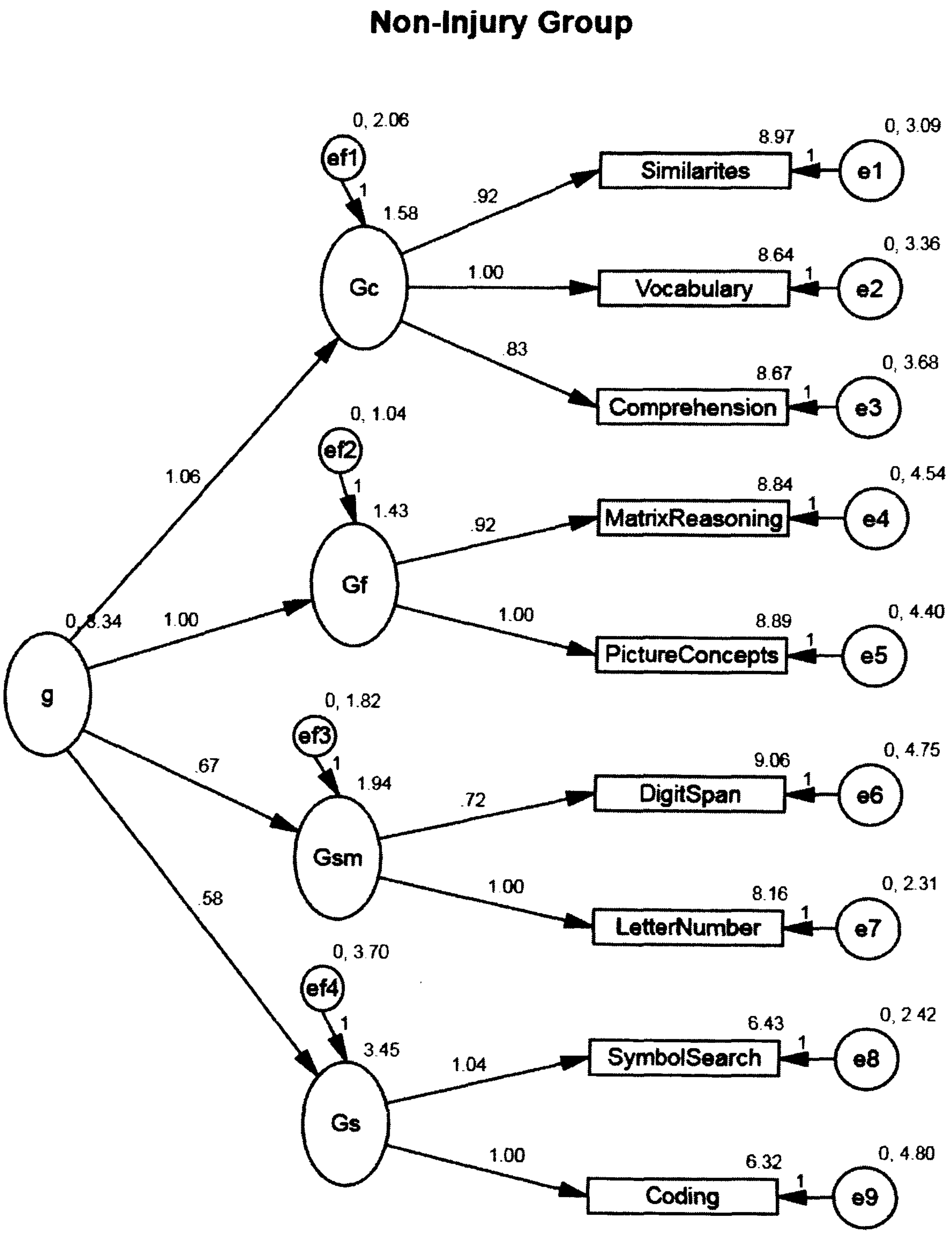
Note. *Significant at $p < .05$; CFI Cutoff >.95; RMSEA Cutoff <.06; SRMR Cutoff <.08

*All $\Delta\chi^2$ values compared to the accepted metric invariance model.

p^a = p value for Baseline comparison.

Figure 7

Path Diagram for Scalar Invariance-Latent Mean Differences- Non-Injury Group-Unstandardized



To further investigate the extent to which invariance may be maintained, invariance of error variances and residuals was analyzed. The 1st order error variances, which may also be called disturbances or uniquenesses, were then constrained across groups, resulting in an sufficient model fit ($\Delta\chi^2[4] = 2.19$, $\Delta\chi^2 p = .70$, ΔCFI = .00). Then, the variances of the 2nd order variable were constrained across groups, yielding a model with continued acceptable fit ($\Delta\chi^2[1] = 0$, $\Delta\chi^2 p = .99$, ΔCFI = .00). Constraining the 1st and 2nd order error variances supports structural invariance of the model, therein allowing a determination of whether the groups rely on a similar range of latent constructs. As such, the residuals of the intercepts were then constrained across groups, yielding a decrement in model fit ($\Delta\chi^2[9] = 17.37$, $\Delta\chi^2 p = .04$, ΔCFI = .02). Through employing the process of systematically releasing constraints at this level, when each of the subtests were released, acceptable fit resulted for four subtests, including *Similarities* ($\Delta\chi^2[8] = 13.78$, $\Delta\chi^2 p = .09$, ΔCFI = .01), *Vocabulary* ($\Delta\chi^2[8] = 15.35$, $\Delta\chi^2 p = .05$, ΔCFI = .01), *Picture Concepts* ($\Delta\chi^2[8] = 12.76$, $\Delta\chi^2 p = .12$, ΔCFI = .00), and *Letter-Number* ($\Delta\chi^2[8] = 13.58$, $\Delta\chi^2 p = .09$, ΔCFI = .01). The subtest *Picture Concepts* was found to account for significant error variance, revealing the most appropriate model fit when this constraint was released.

Table 5

Evaluation of Invariance of Structural Uniquenesses and Observed Residuals

Step	Constraint	χ^2	df	p^a	$\Delta\chi^2$		CFI	ΔCFI	RMSEA	SRMR	Accept
					$\Delta\chi^2$ (Δdf)	$\Delta\chi^2$ p					
Structural	1st Order Error Variance	82.19	62	.04*	2.19 (4)	.70	.965	.00	.04	.06	Accept
	2nd Order Error Variance	82.19	63	.05	0.00 (1)	.99	.967	.00	.04	.06	Accept
Residual	Error Variance- Observed Variables	99.56	72	.02*	17.37 (9)	.04*	.952	.02	.04	.06	Reject
	Free *Similarities*	95.97	71	.03*	13.78 (8)	.09	.957	.01	.04	.06	Accept
	Free *Vocabulary*	97.54	71	.02*	15.35 (8)	.05	.954	.01	.04	.06	Accept
	Free *Comprehension*	99.42	71	.02*	17.23 (8)	.03*	.951	.01	.04	.06	Reject
	Free *Matrix Reasoning*	98.87	71	.02*	16.68 (8)	.03*	.952	.01	.04	.06	Reject
	Free *Picture Concepts*	94.95	71	.03*	12.76 (8)	.12	.958	.00	.04	.06	Accept
	Free *Digit Span*	96.91	71	.02*	14.72 (8)	.07*	.955	.01	.04	.06	Reject
	Free *Letter number Seq.*	95.76	71	.03*	13.58 (8)	.09	.957	.01	.04	.06	Accept
	Free *Symbol Search*	99.34	71	.02*	17.15 (8)	.03*	.951	.01	.04	.06	Reject
	Free *Coding*	99.38	71	.02*	17.19 (8)	.03*	.951	.01	.04	.06	Reject

Note. $p > .05$; CFI Cutoff >.95; RMSEA Cutoff <.06; SRMR Cutoff <.08

$\Delta\chi^2$ for Structural was compared to Scalar model; Residuals were compared to Structural 2nd order error variance model. *Significant at $p<.05$.

p^a= p value for Baseline comparison.

Follow Up Analysis: g Factor Invariance

Follow-up analysis was performed to determine whether latent mean differences in *g* account for all of the mean differences in the observed subtest scores. It should be noted that in this model, it was assumed that the second-order factor loadings were invariant, although it could be argued that the *Gsm* loading was not invariant. To conduct this analysis, the mean for the factor *g* was released in the Non-Injury group to allow for mean estimation while three of the four factor means were set to 0. If this model was tenable, then differences in the *g* mean account for all the observed mean differences. This model was untenable, and thus, the first order intercepts were released individually and in combination with each other to determine whether the misfit could be localized to one or two first-order factor mean differences. The model where the *Gsm* and *Gs* factor means were released in addition to *g* (the 2nd order factor) demonstrated sufficient fit ($\Delta\chi2(59, N{=}210){=}\ 8.898$, $\Delta\chi2p = .179$) (See Table 6). This finding indicates that the mean differences in *Gsm* and *Gs* cannot be accurately accounted for by mean differences in *g* across groups.

Next, t-test values were obtained to determine whether the magnitude of difference in mean values between groups on the factors of *g*, *Gsm*, and *Gs* were statistically significant. The results indicate that the mean difference in the 2nd order factor *g* between groups is statistically significant at the $p<.05$ level, suggesting that the Non-Injury group (Mdiff= 1.450; SE=.336) performed significantly better in overall intelligence based on the four factors included in the present analysis (See Figure 8). The mean differences in the 1st order factors of *Gsm* (Mdiff=.963; SE=.392) and *Gs* (Mdiff=2.597; SE=.420) were also significantly different, indicating that the brain injured children performed significantly different on *Short Term Memory* and *Processing Speed* measures and that *Processing Speed* skills were lower in the Brain Injury group than *Short Term Memory* beyond differences in *g* (Table 6). Finally, for this model, the mean of the 2nd order factor *g* was constrained to zero to determine whether the differences in *Gsm* and *Gs* could explain differences in the subtest scores above and beyond the differences explained by *g*. This model fit was degraded compared to the model fit of the *g*, *Gsm*, and *Gs* model (See Table 7). Thus, all of the differences in the subtest scores were explained by differences in *g*, *Gsm*, and *Gs*.

Summary of CFA Findings

Several CFA and Multi-Group CFA analyses were reviewed above. The single group CFAs revealed that the brain injury data fit the CHC theory based 4 factor model well, and when the *Block Design* subtest is included and the error variance of *Block Design* is correlated with that of *Matrix Reasoning* to account for *Gv*, a superior fit over the WISC-IV inherent model results. These results supported the a priori and a posteriori hypotheses. Based on the findings of the Multi-Group CFAs, strong factorial invariance was supported, therein supporting the hypothesis, indicating that the constructs were measured in the same way. In reviewing the factor loadings, it becomes clear that *Gsm* is more strongly related to *g* in the Brain Injury group as compared to the Non-Injury group. With regard to the latent mean differences, the two final hypotheses were supported, indicating that the Brain Injury group's first order means of *Gsm* and *Gs* were significantly lower than the Non-Injury group. The *g* factor was also determined to be significantly lower but the differences in *Gs* and *Gsm* explain the differences in the subtest scores above and beyond the impact of *g*.

Table 6

Mean Difference, Means, and Standard Deviations of Clusters and Subtests

Factor	Subtest		Sig. Mdiff	Mdiff SD	Cluster/ Subtest Mean	Cluster/ Subtest SD
g			1.450	.336		
Gc			N/A	N/A		
	Similarities	Injury Group			9.08	2.623
		Non-Injury Group			10.27	2.812
	Vocabulary	Injury Group			8.49	2.711
		Non-Injury Group			10.43	2.99
	Comprehension	Injury Group			8.74	2.952
		Non-injury Group			9.90	2.651
Gf			N/A	N/A		
	Matrix Reasoning	Injury Group			8.72	2.662
		Non-Injury Group			10.30	2.885
	Picture Concepts	Injury Group			9.11	3.378
		Non-Injury Group			10.35	2.602
Gsm			.963	.392		
	Digit Span	Injury Group			9.21	3.186
		Non-Injury Group			10.35	2.602
	Letter-Number Sequencing	Injury Group			8.09	3.343
		Non-Injury Group			10.13	2.354
Gs			2.597	.420		
	Symbol Search	Injury Group			6.46	3.026
		Non-Injury Group			9.99	2.816
	Coding	Injury Group			6.28	3.112
		Non-Injury Group			9.82	3.053

Note. Sig. Mdiff indicates that the mean difference between groups on the cluster score is significant at the $p<.05$ level.

Table 7

Evaluation of Scalar Invariance Based on the g Factor with All Intercepts Constrained

Step	Constraint	χ^2	df	p^a	$\Delta\chi^2$		CFI	ΔCFI	RMSEA	SRMR	Accept
					$\Delta\chi^2$ (Δdf)	$\Delta\chi^2$ p					
Free 1 to 2 means of 1st Order Factors with *g* Factor mean free	Mean Free *Gc*	109.77	60	.00*	38.65 (7)	.00*	.913	.055	.06	.08	Reject
	Mean Free *Gf*	108.05	60	.00*	36.93 (7)	.00*	.916	.052	.06	.10	Reject
	Mean Free *Gsm*	119.28	60	.00*	48.16 (7)	.00*	.897	.071	.07	.08	Reject
	Mean Free *Gs*	85.89	60	.016*	14.74 (7)	.04*	.955	.013	.05	.06	Reject
	Mean Free *Gc* & *Gf*	83.95	59	.018*	12.83 (6)	.046*	.957	.011	.05	.06	Reject
	Mean Free *Gc* & *Gsm*	109.53	59	.00*	38.41 (6)	.00*	.912	.056	.06	.08	Reject
	Mean Free *Gc* & *Gs*	84.62	59	.016*	13.50 (6)	.04*	.955	.013	.05	.06	Reject
	Mean Free *Gf* & *Gsm*	108.03	59	.00*	36.91 (6)	.00*	.915	.053	.06	.10	Reject
	Mean Free *Gf* & *Gs*	85.02	59	.015*	13.90 (6)	.03*	.955	.013	.05	.06	Reject
	Mean Free *Gsm* & *Gs*	80.02	59	.036*	8.90 (6)	.18	.963	.005	.04	.06	Accept
g mean constrained	Mean Free *Gsm* & *Gs*	101.40	60	.001	21.32 (7)	.00*	.928	.035	.058	.06	Reject

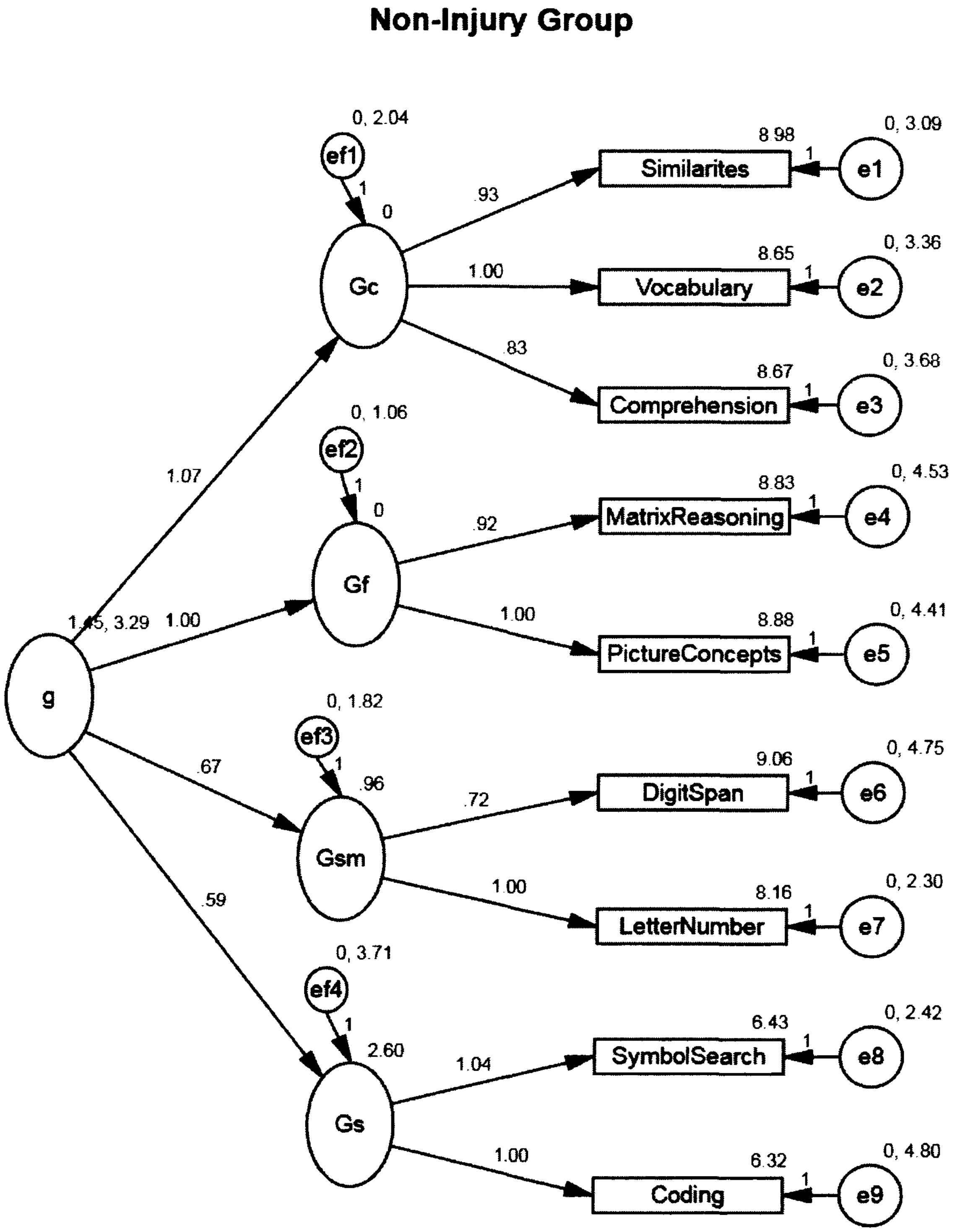
Note. *Significant at $p < .05$; CFI Cutoff >.95; RMSEA Cutoff <.06; SRMR Cutoff <.08

*All $\Delta\chi^2$ values compared to the accepted metric invariance model.

p^a= p value for Baseline comparison.

Figure 8

Path Diagram for g Factor Scalar Invariance Test- Unstandardized Estimates



Effects of Age on Subtest Performance

The a priori hypothesis regarding age stated that age at time of testing would significantly affect test results for children in the Brain Injury group, such that children tested during middle childhood would demonstrate the poorest results. Three age groups were defined to represent early, middle, and later childhood. The early childhood age group ranged from age 6:0 to 9:9 (n= 23), the middle childhood group range in age from 10:0 to 12:9 (n=27), and the later childhood group ranged in age from 13:0 to 16:9 (n= 55). A 3 (group: early, middle, late childhood) by 9 (subtest: *Similarities*, *Vocabulary*, *Comprehension*, *Matrix Reasoning*, *Picture Concepts*, *Digit Span*, *Letter-Number*, *Symbol Search*, *Coding*) multivariate analysis of variance (MANOVA) was performed. The Chi Squared test determined that the disproportionate amount of subjects per group was significant $\chi^2(2)=17.37$, $p<.05$, and thus, Pillai's multivariate statistic was analyzed instead of Wilks' lambda to adjust for unequal sample sizes. No significant differences were found for age among the groups on the dependent measures Pillai's Trace= .244, F (18,190) = 1.47, p=.11 (See Table 8).

At this point, an a posteriori hypothesis was developed, suggesting that perhaps alternate variables accounted for significant variance, contributing to the non-significant results. In order to test this hypothesis, ethnicity, sex, time since injury, and nature of injury were controlled to evaluate the remaining effect of the three age groups by using a 3 (group: early, middle, late childhood) by 9 (subtest: *Similarities*, *Vocabulary*, *Comprehension*, *Matrix Reasoning*, *Picture Concepts*, *Digit Span*, *Letter-Number*, *Symbol Search*, *Coding*) multivariate analysis of covariance (MANCOVA). Box's Test indicated that the observed covariance matrices were equal across groups and Levene's

Test revealed that the subtest *Picture Concepts* demonstrated unequal variance across the age groups, and thus, the results regarding this subtest must be interpreted with caution. The results indicated that time since injury accounted for significant variance, accounting for 36.2% of the variance in this analysis Pillai's Trace=.36, F(9, 49)=3.08, $p<.05$ (See Table 9). None of the other control variables accounted for significant variance. Furthermore, time since injury accounted for 16.4% of variance in the *Symbol Search* subtest and 10.7% of variance in the *Coding* subtest. Pairwise comparisons revealed that children in early childhood performed significantly better on *Symbol Search* than those in late childhood (See Table 11). Children in middle childhood did not demonstrate significant findings, indicating that the hypothesis was not supported. Please refer to Table 10 for the means and standard deviations of each age group.

Table 8

3x9 MANOVA- Effect of Age in Brain Injury Group

	Value	Hyp. df	Error df	F	Sig.	η^2
Pillai's Trace	.24	18	190	1.47	.11	.12

Note. η^2 = partial eta squared (effect size).

Table 9

3x9 MANCOVA for Age- Control for Ethnicity, Sex, Time Since Injury, Nature of Injury

IV	Value	Hyp. Df	Error df	F	Sig.	η^2
Ethnicity	.10	9	49	.61	.78	.10
Sex	.05	9	49	.29	.98	.05
Time Since Injury	.36	9	49	3.08	.01	.36
Nature of Injury	.14	9	49	.86	.57	.14
Age Group	.34	18	100	1.15	.32	.17

Note. η^2 = partial eta squared (effect size). Value= Pillai's Trace due to unequal sample sizes.

Table 10

Means and Standard Deviations of Age Groups

		Early Childhood		Middle Childhood		Late Childhood	
CHC Factor	Subtest	M	SD	M	SD	M	SD
Gc	*Similarities*	8.44	2.13	9.24	1.89	8.90	2.60
	Vocabulary	7.25	1.61	8.89	2.55	8.35	2.96
	Comprehension	7.13	2.06	9.29	3.10	8.74	3.14
Gf	*Matrix Reasoning*	7.44	2.42	8.71	2.54	8.84	2.49
	Picture Concepts	8.75	2.77	8.53	4.26	8.77	2.55
Gsm	*Digit Span*	8.00	2.78	9.41	2.96	8.94	3.68
	Letter-Number Sequencing	7.00	2.50	7.47	3.15	7.97	3.44
Gs	*Symbol Search*	7.13	2.00	6.24	3.77	5.13	2.79
	Coding	5.56	2.45	6.47	3.00	5.00	3.31

Note. M= Mean; SD= Standard Deviation. The WISC-IV assumes M=10, SD=3.

Table 11

Significant Findings From Pairwise Comparisons for Age Groups

Subtest	Group 1	Group 2	M Diff	SE	Sig.
Symbol Search	Early Childhood	Middle Childhood	1.430	.957	.140
		Late Childhood	2.487	.851	.005*
	Middle Childhood	Middle Childhood	-1.430	.957	.140
		Late Childhood	1.056	.808	.196
	Late Childhood	Early Childhood	-2.487	.851	.005*
		Middle Childhood	-1.056	.808	.196

Effects of Time Since Injury

In order to address the hypothesis that time since injury significantly affects test performance such that children tested later in recovery would show stronger skills, a 2 (time since injury: less than six months, more than 6 months) by 9 (subtests: *Similarities*, *Vocabulary*, *Comprehension*, *Matrix Reasoning*, *Picture Concepts*, *Digit Span*, *Letter-Number*, *Symbol Search*, *Coding*) MANOVA was conducted using the Brain Injury group data. The subjects obtained from the WISC-IV Special Group TBI sample did not include any subjects who were injured within 6 months and no specific information existed regarding how far beyond six months the children were tested. Based on the data obtained from the rehabilitation hospital, the time of testing was missing for one subject. The time of testing following injury ranged from .33 to 36.1 months (M= 5.43; SD: 7.07) for the remaining 64 subjects in the rehabilitation hospital dataset. Thus, a total of 104 subjects ($\leq$6 months: n= 48; >6 months: n=56) were included for this analysis. A Chi-

Squared test indicated that the proportion of children in each subgroup was acceptable ($\chi^2(1)=.615$; p=.43). Additionally, Box's Test determined that the assumption of normality of covariance matrices are equal across groups was supported and Levene's Test of determined that the assumption that each subtest has similar variance across subgroups was supported. Non-significant results were found Wilks' λ= .08, F(9,94)= .90, p=.53 (See Table 12). Thus, the null hypothesis was accepted, indicating that time since injury was not found to significantly impact the results.

Table 12

2x9 MANOVA- Time Since Injury

	Value	Hyp. df	Error df	F	Sig.	η^2
Wilks' λ	.92	9	94	.90	.53	.08

Note. η^2 = partial eta squared (effect size).

An a posteriori hypothesis was then generated that other factors may significantly account for the variance of the test results, impacting the non-significant findings of the MANOVA. Thus, a 2 (Time Since Injury: <6 months, ≥6 months) by 9 (Subtests: *Similarities*, *Vocabulary*, *Comprehension*, *Matrix Reasoning*, *Picture Concepts*, *Digit Span*, *Letter-Number*, *Symbol Search*, *Coding*) MANCOVA was conducted while controlling for age, sex, ethnicity, and nature of injury. Box's Test determined that the assumption of normality of covariance matrices are equal across groups was supported and Levene's Test determined that the assumption that each subtest has similar variance across subgroups was supported. Significant results were found only for the effect of time since injury Wilks' λ= .64, F(9,50)= 3.12, p<.05 (See Table 13). This indicates that, when other variables are held constant, the unique effect of time since injury accounts for 35.9% of variance, and this was particularly notable in the subtests *Symbol Search* and *Coding*, such that 16.4% and 10.8% of variance was accounted for by the amount of time since injury, respectively. Please refer to Table 14 for the means and standard deviations of each group. It is interesting to note that, in viewing the means of each group, children who had greater time since injury performed more poorly on subtests of *Gc*, *Gsm*, and *Gs*. This is not consistent with prior research or with the hypothesis presented in this analysis and results may be in part due to an inability to control for severity of injury.

Table 13

2x9 MANCOVA for Time Since Injury- Control for Age, Sex, Ethnicity, Nature of Injury

IV	Value	Hyp. Df	Error df	F	Sig.	η^2
Age	.76	9	50	1.61	.14	.23
Sex	.95	9	50	.32	.96	.06
Ethnicity	.90	9	50	.62	.77	.10
Nature of Injury	.86	9	50	.90	.53	.14
Time Since Injury	.64	9	50	3.12	.01	.36

Note. η^2 = partial eta squared (effect size). Value= Wilks' λ

Table 14

Means and Standard Deviations of Each Time Since Injury Group

		≤ 6 months		>6 months	
CHC Factor	Subtest	M	SD	M	SD
Gc	*Similarities*	9.02	2.39	8.44	2.00
	Vocabulary	8.54	2.78	7.25	1.77
	Comprehension	8.81	3.12	7.50	2.28
Gf	*Matrix Reasoning*	8.69	2.44	7.75	3.70
	Picture Concepts	8.35	3.69	9.75	2.84
Gsm	*Digit Span*	9.02	3.35	8.25	3.11
	Letter-Number Sequencing	7.79	3.12	7.00	3.18
Gs	*Symbol Search*	6.52	2.87	4.13	2.68
	Coding	6.06	3.03	3.94	2.60

Note. M= Mean; SD= Standard Deviation. The WISC-IV assumes M=10, SD=3.

Nature of Injury

The hypothesis regarding nature of injury dictated that diffuse injuries would account for more variance than focal injuries. Diffuse injuries will be herein identified as injuries that do not involve skull fractures, while focal injuries are defined as resulting in skull fractures. This description was determined based on the information provided within the WISC-IV regarding the clinical sample for TBI subjects, as Open Head Injury was defined as involving skull fractures. A 2 (Nature: Fracture, Non-Fracture) by 9 (subtests: *Similarities*, *Vocabulary*, *Comprehension*, *Matrix Reasoning*, *Picture Concepts*, *Digit Span*, *Letter-Number*, *Symbol Search*, *Coding*) MANOVA was performed using data from 100 subjects (n(Fracture)= 32; n(Non-Fracture)=68). The information regarding whether fractures were involved in the brain injury was not available for 5 of the subjects in the rehabilitation hospital dataset. A Chi-Squared test determined that the disproportionate amount of subjects in each subgroup was significant $\chi^2(1)=12.96$; $p<.05$ and thus the Pillai adjustment was chosen over the Wilks' Lambda as the multivariate statistic to correct for unequality of sample sizes. Box's Test supported that the observed covariance matrices are equal across groups but Levene's test of equality in error variances was significant for the subtests *Picture Concepts* and *Symbol Search* at the $p<.05$ level, and thus, the results for these subtests must be viewed with caution. This analysis did not yield significant results Pillai's Trace= .20, F(18,190)= 1.18, p=.29 (See Table 15).

Given the disproportionate sample sizes, a third group was identified to further assess the impact of the nature of head injuries on the present subtest level data. Within the Non-Fracture group, non-traumatic injuries were identified, therein creating a third group that was identified as ABI (n=26). This group was relatively proportionate in size to the TBI Fracture group (n=32) and the TBI Non-Fracture group (n=42) as supported by the Chi Squared test $\chi^2(2)=3.92$; p=.14, thus the Wilks' lambda test statistic was analyzed. This follow-up analysis included a 3 (Nature: TBI Fracture, TBI Non-Fracture, ABI) by 9 (subtests: *Similarities*, *Vocabulary*, *Comprehension*, *Matrix Reasoning*, *Picture Concepts*, *Digit Span*, *Letter-Number*, *Symbol Search*, *Coding*) MANOVA. Box's Test supported that the observed covariance matrices were equal across groups but Levene's Test was significant for the variance evident in the *Symbol Search* subtest at the $p<.05$ level when dividing data into these three groups. The results of this analysis were non-significant Wilks' $\lambda= .84$, F(18,178)= .88, p=.61 (See Table 16). Thus, the null hypothesis regarding the effect of the nature of brain injuries on test performance was accepted.

One additional analysis was performed to determine whether demographic factors may contribute significantly to these non-significant results. A 3 (Nature: TBI Fracture, TBI Non-Fracture, ABI) by 9 (subtests: *Similarities*, *Vocabulary*, *Comprehension*, *Matrix Reasoning*, *Picture Concepts*, *Digit Span*, *Letter-Number*, *Symbol Search*, *Coding*) MANCOVA was performed while controlling for age, sex, ethnicity, and time since injury. A significant main effect was found for age Wilks' λ= .80, F(9,85)= 2.40, $p<.05$ (See Table 17), indicating that age accounted for 20.3% of the variance. When viewing the between subjects effects based on age, significant effects were noted for *Symbol Search* and *Matrix Reasoning* such that age accounted for 4.9% of variance in test performance and *Symbol Search* accounted for 6.3% of variance. However, as previously stated, when dividing data into these three subgroups of injury, there is excessive variance in the *Symbol Search* subtest distribution as noted by Levene's Test at the $p<.05$ level, and thus, results related to this subtest must be interpreted with caution. The interactions between the subgroups of the nature of injury revealed fascinating findings, such that those with ABI performed significantly worse than those with TBI without fractures on *Matrix Reasoning* and *Symbol Search*. The ABI group also performed significantly worse on *Coding* when compared to the TBI with skull fracture group. Given that age did not contribute to the variance in *Coding*, it is likely that the significant difference in performance found on this subtest was due to having an ABI versus other forms of brain injury. Please refer to Table 18 for the means and standard deviations of each group and Table 18 for the pairwise comparisons by group.

Table 15

2x9 MANOVA for Nature of Injury

	Value	Hyp. Df	Error df	F	Sig.	η^2
Pillai's Trace	.20	18	190	1.18	.29	.10

Note. η^2 = partial eta squared (effect size).

Table 16

3x9 MANOVA for Nature of Injury

	Value	Hyp. Df	Error df	F	Sig.	η^2
Wilks' λ	.84	18	178	.88	.61	.08

Note. η^2 = partial eta squared (effect size).

Table 17

3x9 MANCOVA for Nature of Injury- Control for Age, Sex, Ethnicity, Time Since Injury

IV	Value	Hyp. Df	Error df	F	Sig.	η^2
Age	.80	9	85	2.40	.02	.20
Sex	.93	9	85	.76	.66	.07
Ethnicity	.95	9	85	.51	.87	.05
Time Since Injury	.90	9	85	1.12	.36	.11
Nature of Injury	.81	18	170	1.07	.34	.10

Note. η^2 = partial eta squared (effect size). Value= Wilks' λ

Table 18

Means and Standard Deviations for Nature of Injury

		TBI- No Fracture		TBI- With Fracture		ABI	
CHC Factor	Subtest	M	SD	M	SD	M	SD
Gc	*Similarities*	9.12	2.86	9.50	2.59	8.77	2.25
	Vocabulary	8.79	2.66	8.75	2.82	8.27	2.20
	Comprehension	8.62	2.81	9.28	3.51	8.50	2.37
Gf	*Matrix Reasoning*	8.74	2.43	9.59	2.79	7.88	2.57
	Picture Concepts	9.05	3.26	9.97	3.01	8.58	3.26
Gsm	*Digit Span*	9.71	2.66	9.59	3.29	7.88	3.75
	Letter-Number Sequencing	8.14	3.49	8.63	3.42	7.19	2.97
Gs	*Symbol Search*	6.95	2.24	6.63	3.92	5.62	2.80
	Coding	6.38	3.21	6.81	3.13	5.50	2.73

Note. M= Mean; SD= Standard Deviation. The WISC-IV assumes M=10, SD=3.

Table 19

Significant findings from Pairwise Comparisons- Nature of Injury

Subtests	Group 1	Group 2	M Diff	SE	Sig.
Matrix Reasoning	TBI-No Fracture	TBI- Fracture	-.989	.613	.110
		ABI	.667	.676	.326
	TBI- Fracture	TBI- No Fracture	.989	.613	.110
		ABI	1.657	.703	.021*
	ABI	TBI- No Fracture	-.667	.676	.326
		TBI- Fracture	-1.657	.703	.021*
Symbol Search	TBI- No Fracture	TBI- Fracture	.583	.705	.411
		ABI	1.855	.778	.019*
	TBI- Fracture	TBI- No Fracture	-.583	.705	.411
		ABI	1.272	.809	.119
	ABI	TBI- No Fracture	-1.855	.778	.019*
		TBI- Fracture	-1.272	.809	.119
Coding	TBI- No Fracture	TBI- Fracture	-.392	.719	.587
		ABI	1.367	.793	.088
	TBI- Fracture	TBI- No Fracture	.392	.719	.587
		ABI	1.759	.825	.036*
	ABI	TBI- No Fracture	-1.367	.793	.088
		TBI- Fracture	1.759	.825	.036*

Note. Sig.= Significance at p<.05. SE= Standard Error.

Further Analysis: Nature of Injury

To further analyze why differences exist in the performance of children with TBI versus those with ABI on subtests of *Matrix Reasoning*, *Coding*, and *Symbol Search*, it was necessary to consider the injuries that accounted for the majority of ABIs. Of the 26 subjects in the ABI group, 10 had sustained tumors while 9 experienced hemorrhages, hematomas, or strokes. A 2 (ABI Type: Tumors, Hemorrhages/Hematomas/Strokes) x 3 (Subtest: *Matrix Reasoning*, *Symbol Search*, *Coding*) MANOVA was performed. Means and standard deviations of each type of injury subgroup are presented in Table 20. Box's test of covariance matrices was non-significant, indicating that covariance matrices of the dependent variables are consistent across groups, and Levene's test of equality of error variances was non-significant for subtests, indicating that error variances were equal across subgroups. MANOVA results were non-significant Wilks' λ= .68, F (3, 15) = 2.341, p=.114 (See Table 21). This suggests that the mean differences between the types of ABI injuries were comparable and not significantly different.

Table 20

Means and Standard Deviations for ABIs

		Tumors		Hemorrhages, Strokes, & Hematomas	
CHC Factor	Subtest	M	SD	M	SD
Gf	*Matrix Reasoning*	8.70	2.79	6.56	2.07
Gs	*Symbol Search*	5.40	3.10	5.56	3.21
	Coding	4.80	2.82	6.33	2.40

Note. M= Mean; SD= Standard Deviation. The WISC-IV assumes M=10, SD=3.

Table 21

2x3 MANOVA for ABI Group

	Value	Hyp. Df	Error df	F	Sig.	η^2
Wilks' λ	.68	3	15	2.34	.11	.32

Note. η^2 = partial eta squared (effect size).

Chapter 6

Discussion

Major Findings

The present study significantly contributes to the fields of school psychology and neuropsychology due to several unique findings. Perhaps the most significant finding is that of the invariance and model fit noted among the four CHC theory based factors with a brain injured pediatric population. Five major hypotheses were addressed in the current study.

The first hypothesis stated that the Brain Injury group would fit the classification taxonomy of the CHC theory based on the core subtests of the WISC-IV that could accurately represent each broad factor. This hypothesis was supported by the data using a higher order four factor model where the 2nd order factor, *g*, represented general intelligence, and the 1st order factors were *Crystallized Knowledge*, *Fluid Reasoning*, *Short Term Memory*, and *Processing Speed*, each of which was represented by two subtests of the WISC-IV core battery. This finding indicates that the CHC theory can be applied to a purely brain injured population. This is also the first study to our knowledge that directly addressed the performance of a brain injured population on *Fluid Reasoning*. Further analysis compared the inherent WISC-IV model to a model supported by CHC theory. To improve the comparability of this analysis, the subtest *Block Design* was ultimately included in the CHC theory based model and the error variance was correlated with that of the subtest *Matrix Reasoning* to account for the shared variance of these two subtests of visual processing. The CHC model provided a preferable fit, however, it must be considered that *Block Design* was not loaded onto a factor, and thus, this comparison should be viewed with caution. Nonetheless, the WISC-IV model fit was significant, indicating less appropriate overall model fit for the Brain Injury group. The significance of the present study is further illuminated by the fact that a purely brain injured population was utilized for these analyses, rather than a mixed clinical sample that has been employed in previous studies.

The next hypothesis suggested that *Short Term Memory* and *Processing Speed* would demonstrate latent mean differences between the brain injured and Non-Injury group such that these constructs would be lower in the Brain Injury group. A higher order multi-group confirmatory factor analysis was performed to investigate the similarities and differences in model fit between the brain injured and typically developing groups. Considering factor loadings, *Short Term Memory* factor loadings accounted for the most variance due to very strong loadings between *g* and *Gsm* in the Brain Injury group compared to moderate loadings in the Non-Injury group, suggesting that *g* is different between groups due to the differences in relationship with *Gsm*, therein supporting partial metric invariance. Furthermore, full scalar invariance was supported, but the *Vocabulary* subtest intercept was noted to account for a large amount of variance, therein indicating that it may not be appropriate to compare the means of brain injured children and non-injured children on this subtest. To establish scalar invariance at the higher order factor level, the optimal model fit was achieved by permitting the means of *Short Term Memory* and *Processing Speed* to be estimated in the control group. The latent mean differences demonstrated that *Short Term Memory* and *Processing Speed* were significantly lower in the Brain Injury group than in the Non-Injury group. Strict factorial invariance was only established when the residual of the subtest *Picture*

Concepts was released, indicating that this subtest may have items that are biased to the brain injured population.

A test of *g* factor invariance indicated that the proposed hypothesis was supported by investigating the mean difference between groups when allowing the mean of the higher order factor *g* to be estimated between groups as all of the variance in the subtest scores could be accounted for by the general intelligence factor, *Short Term Memory*, and *Processing Speed*. Mean difference testing indicated that the Brain Injury group performed significantly worse on general intelligence and the factors of *Short Term Memory* and *Processing Speed*. This indicates that, even when children with brain injury have an equivalent level of general intelligence to children without brain injuries, the brain injured children demonstrate relative weaknesses in *Short Term Memory* and *Processing Speed* as compared to their same aged peers.

Deficits in aspects of *Short-Term Memory* and *Processing Speed* have been well documented in the literature (Driscoll, 1994; Ariza et al., 2006; DiStefano et al., 2000; Catroppa, Anderson, Morse, Haritou, & Anderson, 2011; Shiehser et al., 2011; Tonks, Williams, Yates, & Slater, 2011; Beauchamp et al., 2011). Historically, brain injured individuals' performance on verbal *Short Term Memory* tasks has been found to be influenced by sidedness and whether prefrontal or frontal injuries were evident (Driscoll, 1994; DiStefano et al., 2000; Ariza et al., 2006). Time since injury and severity have also been implicated as contributing to progress or worsening of *Short-Term Memory* skills. Of note, one study found that children with no identified premorbid neuropsychiatric diagnoses who had sustained brain injuries demonstrated continuous growth compared to initial weakness in working memory skills following brain injuries (Levin et al., 2004).

Performance deteriorated following one year post injury for those with severe TBI but continued improvement was found for those with mild to moderate TBI (Levin et al., 2004). Likewise, weaknesses in *Processing Speed* have been consistently documented, and age at time of injury in addition to time since injury typically predicted the severity of deficits (Catroppa, Anderson, Morse, Haritou, & Rosenfeld, 2007; Beauchamp et al., 2011; Schiehser et al., 2011; Tonks, Williams, Yates, & Slater, 2011). However, the relationship to general intelligence has not yet been documented in the literature to our knowledge.

The effects of age, time since injury, and nature of injury were then evaluated to determine whether these factors significantly impacted subtest performance for brain injured children. When considering age, time since injury, and nature of injury independently, significant findings were not noted. Regarding age, it was hypothesized that children in middle childhood would perform poorest of the three age groups. This hypothesis was not supported when controlling for ethnicity, sex, time since injury, and nature of injury, as children in early childhood performed significantly better on *Symbol Search* than those in late childhood, and no significant effects were noted in middle childhood. Thus, these findings are not consistent with prior research, as children in late childhood generally have more positive cognitive outcomes and children in middle childhood generally have the worst (Crowe, Catroppa, Babl, Rosenfeld, & Anderson, 2012). However, prior research also indicates that recovery in middle childhood is best predicted by SES, and because this information was not noted in the current study, the effect of SES could not be investigated (Catroppa & Anderson, 2003). The effect found in the present study, when viewed in context of the WISC-IV, may be related to the fact that the forms for *Symbol Search* and *Coding* are different for children ages 6-7, and thus, bias may exist due to use of different forms. Yet, this form effect does not diminish the significant finding that children in late childhood performed significantly worse across measures of *Processing Speed.*

Additionally, in the present analysis for age, time since injury accounted for 32.6% of the overall variance in this analysis, suggesting an interaction between time since injury and age. Alternatively, when considering the analysis for time since injury, it was hypothesized that children later in recover, herein defined as greater than six months post-injury, would exhibit stronger skills than those tested earlier in recovery, herein defined as less than six months post-injury. When controlling for age, sex, ethnicity, and nature of injury, time since injury was found to account for 35.9% of variance, accounting for 16.9% of variance in *Symbol Search* and 10.8% of variance in *Coding*. Interestingly, again, the *Processing Speed* subtests were noted to be significantly affected, and this indicates that the significant weakness in *Processing Speed* noted in the multi-group analysis may be in part due to the large quantity of children who were in late childhood, as they performed significantly worse on *Processing Speed* subtests, and the variability in time since injury evident in the brain injury sample. These results raise the question of why *Processing Speed* would be strongly influenced by time since injury and age. It is possible that executive dysfunction may be contributing to weaknesses, however, this is not possible to conclude given that the WISC-IV subtests are poor indicators of executive functioning skills. As such, examiners must be aware of the limitations of the WISC-IV by employing more comprehensive assessment techniques, such as supplementing the WISC-IV with a measure of executive functioning for children who have injuries which are likely to coincide with executive dysfunction. Thus, in lieu of this limitation, the present results are generally consistent with prior research indicating, as stated above, that children with brain injuries perform significantly worse on measures of *Processing Speed.*

Finally, the effects of nature of injury were analyzed under the hypothesis that children with diffuse injuries, presently identified as traumatic brain injuries without skull fractures, would perform worse than children with focal injuries, herein identified by two groups, children with acquired brain injuries and children with traumatic brain injuries with skull fractures. When controlling for age, sex, ethnicity, and time since injury, age accounts for 20.3% of the variance above and beyond the effects of the other variables, with findings particularly evident in *Symbol Search* and *Matrix Reasoning*. Specific interactions were noted between the levels of nature of injury, such that children with acquired medically based injuries (ABI) performed significantly worse than the diffuse TBIs (No Fracture subgroup) on *Matrix Reasoning* and *Symbol Search*, while they performed significantly worse on *Coding* as compared to the focal TBIs (Fracture subgroup).

One confound to this finding is that having a TBI with a fracture does not preclude a child from having a diffuse axonal injury, and thus, diffuse findings may be evident in some children in each group. Also, in the ABI group, we could not account for treatment methods, such as chemotherapy, tumor resection, evacuation of hematomas, shunt placement, and radiation treatments. In an attempt to explain these findings, one must consider what the subtests are measuring, the demands of the subtests, and the nature of the medically based acquired injuries through viewing the brain regions affected. The largest portions of the ABI group included children with tumors and those who have sustained hemorrhages, hematomas, and strokes.

To more fully comprehend the possible causes for children with ABI to perform significantly lower on these subtests than each of the TBI groups, a follow-up analysis of differences in means was conducted between the tumor subgroup and the hemorrhage, hematoma, and stroke subgroup, yielding no significant differences between groups on these three subtests. This is significant to note considering that the tumor subgroup consisted of primarily posterior tumors, including posterior fossa tumors, fourth ventricle tumors, and other tumors near the cerebellar region, while the hemorrhage, hematoma, and stroke subgroup consisted primarily of insults affecting the frontal region, including frontal bilateral cerebral infarcts, MCA aneurisms, parietal, frontal infarcts/hemorrhages, thalamic strokes, and temporal lobe hemorrhages/strokes. Thus, differences in performance were not necessarily related to location of ABI, but it is likely that the cause for poorer performance compared to the TBI group was due to weakness of different skills in the frontal versus posterior injury groups.

In order to identify the skills that may be weak in ABIs on *Matrix Reasoning*, *Symbol Search*, and *Coding*, it is necessary to consider the broad and narrow abilities measured in each task. The subtest *Matrix Reasoning* measures inductive reasoning, which is the ability to discover underlying characteristics or rules that govern a problem, and general sequential reasoning, which involves starting with a stated premise or rule and follow steps sequentially to reach a solution (Flanagan, Ortiz, & Alfonso, 2007). The subtest *Symbol Search* measures perceptual speed, which is the ability to rapidly search and compare possible responses to reach a solution, and rate of test taking, which is the speed of completing simple problems (Flanagan, Ortiz, & Alfonso, 2007). The subtest *Coding* only measures rate of test taking (Flanagan, Ortiz, & Alfonso, 2007). It is interesting to note that the subtests *Matrix Reasoning* and *Symbol Search* involve dual narrow abilities, and it is possible that the integration of skills necessary may have contributed to the relative weakness of ABI children as compared to the diffuse non-fracture TBI subgroup's performance. It is also necessary to consider the input and output skills required to successfully complete these tasks. All of these tasks involve some component of visual scanning as input, and the *Processing Speed* subtests involve motor output, while the *Fluid Reasoning* task, *Matrix Reasoning*, involves verbal or motor output. From a neuropsychological perspective, the domains measured by the *Processing Speed* subtests include measures of sensory-motor skills, speed and efficiency, attention, visual-spatial skills, and executive functions, while the subtest *Matrix Reasoning* includes visual-spatial and executive skills (Flanagan, Alfonso, Ortiz, & Dynda, 2010).

Thus, considering the types and locations of ABIs in light of the CHC based broad and narrow abilities, input/output skills required, and neuropsychological domains being measured, meaningful explanations for performance weaknesses on the *Processing Speed* subtests and *Matrix Reasoning* subtests can be speculated. First, the *Matrix Reasoning* subtest measuring the narrow abilities of inductive and deductive (general-sequential) reasoning will be discussed in light of studies using patients with highly isolated, focal injuries. Left frontal lateral lesions that coincide with working memory deficits, as demonstrated previously in the brain injury group's multi-group CFA, often also present with weak deductive reasoning abilities (Reverberi, Shallice, D'Agostini, Skrap, & Bonatti, 2009), while individuals with frontal medial lateral lesions that coincide with working memory weaknesses demonstrate weak inductive reasoning skills (Reverberi, Lavaroni, Gigli, Skrap, & Shallice, 2005). These frontal medial lesions also demonstrate deductive weaknesses (Reverberi, Shallice, D'Agonstini, Skrap, & Bonatti, 2009). Right lateral frontal lesions tend to demonstrate weak inductive reasoning due to impaired monitoring processes, suggesting executive functioning weaknesses that affect the inductive process (Reverberi, Lavaroni, Gigli, Skrap, & Shallice, 2005). The medial frontal cortex has been linked to meta-deduction as well (Reverberi, Shallice, D'Agostini, Skrap, & Bonatti, 2009). In sum, it seems appropriate to assume that left and right frontal injuries often present with deductive and/or inductive reasoning weaknesses primarily due to executive function difficulties. Therefore, given that the frontal lesion ABI injuries in the present study were affected in the left, right, and medial frontal regions, it seems reasonable that greater difficulty will be demonstrated in these focal injuries as compared to the TBI non-fracture group, which would likely present with more diffuse rather than focal injuries. Moreover, deductive reasoning can be further distinguished as involving aspects of visuo-spatial reasoning, which primarily involves activation of posterior structures, especially the posterior parietal cortex, and categorical reasoning, which primarily involves activation frontal and medial structures, especially the left frontal gyrus and basal ganglia (Prado, Chadha, & Booth, 2011). Likewise, deductive reasoning with unfamiliar information has been found to activate a large bilateral network, frontal and posterior regions, including occipital, parietal, temporal, frontal, basal ganglia, and cerebellar regions (Goel, 2003). In general, there is evidence that complex reasoning tasks would be especially difficult for both frontal and medial to posterior ABIs as compared to the more diffuse TBIs such that the frontal injuries are affected by executive dysfunction, while the posterior injuries are affected by the visuo-spatial aspects of the task.

In general, *Processing Speed* challenges for the tumor ABIs are qualitatively different than the challenges faced in the frontal injury ABIs, however, both types of ABIs yield the same results of poor performance across Processing Speed tasks as compared to the TBI groups. Tumors affecting the fourth ventricle, posterior fossa tumors, strokes in the midbrain, and conditions affecting the cerebellum can account for significant fine motor difficulties, which would therein significantly impact the speed of completing *Processing Speed* tasks (Hale & Fiorello, 2004; Lezak, Howieson, & Loring, 2004; Carter, 2009). Alternatively, the frontal ABIs, which include hematomas, hemorrhages, and strokes, likely perform poorly across *Processing Speed* tasks due to executive dysfunction. Executive functions are associated with the frontal lobe and include five major loops responsible for these functions (Hale & Fiorello, 2004). These include the motor circuit, which is related to pre-motor, supplementary motor, and primary motor functions, the oculomotor circuit, which is related to the frontal eye field (scanning), prefrontal and parietal cortex functions, the dorsolateral prefrontal circuit, which is related to the anterior-lateral prefrontal executive functions, the orbital prefrontal circuit, which is related to inferior-medial prefrontal functions, and the anterior cingulate circuit, which is related to the anterior cingulate and associated with completing work in a timely manner (Hale & Fiorello, 2004). Thus, the demand of efficiency and sustained attention on the *Processing Speed* tasks is responsible for the poor performance of children with frontal lobe lesions.

Therefore, it appears that across all three subtests encompassing *Gf* and *Gs* skills, the types of ABI performed similarly weak in comparison to TBIs, yet likely due to different underlying reasoning. For the *Gf* and *Gs* subtests, the frontal group was speculated to have performed weaker in part due to executive functioning challenges based on task demands. The more posterior ABIs likely performed weaker on the *Gf* subtest in part due to visuo-spatial task demands, whereas these children likely performed weaker on the *Gs* tasks in part due to weaknesses in motor skills.

Clinical Significance

Although the present study is complex, the clinical significance of the present findings must be illuminated. As stated eloquently by Flanagan, Alfonso, Ortiz, & Dynda (2010), "nowhere is theory-based testing and interpretation more critical than in the schools where high stakes decisions regarding the future of many children are made daily." First, this is the first study to our knowledge to apply the CHC theory based model to a purely brain injured population and to establish strong factorial invariance. As such, this study has established a pattern of performance based on CHC theory based constructs for application to brain injured populations. The present study has demonstrated that the CHC constructs of *Gc*, *Gsm*, *Gs*, and *Gf* are measured in the same way across brain injured and typically developing populations. This study has offered the understanding that the *Gsm* ability is strongly associated with general intelligence in children with brain injury and that *Gsm* and *Gs* are generally lower in children with brain injury when compared to typical children, and thus, these factors tend to account for the variance evident in all subtests above and beyond *g*. This study is also unique in highlighting the importance of considering the effects of the nature of the brain injury on performance. In addition, this study elucidates the fact that, by using only the core subtests of the WISC-IV and not adhering to Cross-Battery Assessment principles, merely four of the seven broad cognitive abilities are accounted for and when assessing brain injured children, it is particularly noteworthy to consider the disservice that may be provided by ignoring additional constructs that should be part of a comprehensive assessment, namely *Auditory Processing*, *Visual Processing*, and *Long-Term Memory*. Typically, neuropsychological assessment will address aspects of long-term memory, however, often times, a thorough investigation of visual and auditory pathways are not conducted. Thus, the present study urges mental health professionals who work with brain injured children to more thoroughly assess general cognitive skills in addition to the specific areas addressed within the neuropsychological evaluation.

Limitations

There were several limitations to the current study. Many of these limitations related to sample characteristics and the manner in which the samples were obtained. First, the study was conducted using archived data that was gathered by several separate qualified examiners. The comparison group was not obtained from direct assessment, but rather, from the normative sample which included children from all across the country. Additionally, the Brain Injury group's sample was created from assessment results of a database of patients who were primarily from New York whereas the additional subjects for the Brain Injury group included children and adolescents from across the country. Socioeconomic status, severity of injury, and linguistic background could not be accurately documented, and these factors may have impacted the subtest results. Specific information regarding time since injury was unavailable from the WISC-IV brain injury special group norms, as the only information available was that all subjects were injured over six months following their injury. Following a brain injury, continued progress may be made up to two years post injury in most patients (Dykeman, 2009), and this factor could not be controlled in the analyses. Likewise, the cause of injury and brain regions affected were not documented among the WISC-IV special group for TBI, and rather, the only factor indicated included whether a fracture was involved with the injury, but information was not available regarding where the fracture occurred on the skull or whether diffuse injuries were noted beyond just sustaining a skull fracture. Additionally, sample sizes were limited, particularly for the MANOVAs and MANCOVAs. Restricted sample size did not appear to significantly affect the results. However, using a larger sample size may have produced results that could be more easily generalized to a larger variety of children and adolescents.

Perhaps the most significant limitation is that the seven CHC cognitive factors that are typically measured according the CHC theory could not be included in the current analysis given that for many of the children from the brain injury database of the rehabilitation hospital, only the ten core subtests of the WISC-IV were administered. Thus, the current findings can only be applied to the factors *Gc*, *Gf*, *Gsm*, and *Gs*.

Directions for Future Research

Given the findings of the current research, future research directions are herein recommended. First and foremost, the literature should reflect the performance of children and adolescents with various forms of brain injury across all CHC theory factors to more thoroughly address the patterns of performance demonstrated in a full cognitive profile. This research should also extend the current findings by using other instruments in addition to the WISC-IV and to the use of Cross-Battery Assessment methodology so that empirically based methods can be further identified for implementation to practice. This would allow for specification of patterns of performance among children affected with different types of brain injuries, and despite many children being currently classified in the educational system merely as just having a brain injury, the current results indicate that the various causes and regions of brain injury affected will yield divergent patterns of strengths and weaknesses. Using the empirically based approach to assessment and interpretation of CHC based methods will prove particularly invaluable considering the recent shift in attention to focusing on concussions and other brain injuries in education as a result of the Concussion Management and Awareness Act that was passed in New York state in 2012 (NYSED, 2012). In addition, larger sample sizes should be used across all ages of children and adolescents so that developmental trends can be identified.

Fascinating findings may also be found from gathering accurate information regarding the linguistic and cultural background of children and adolescents who have sustained brain injuries in order to provide more culturally sensitive evaluations. This research would perhaps prevent over-identification of disabilities by determining what a typical pattern of performance may be for children based on their verbal and cultural knowledge with respect to the linguistic and cultural loadings inherent in the tests being used. These findings would be especially intriguing considering the different patterns of performance that may be found when individuals have one primary and one secondary language versus when they are equally proficient in two languages. Moreover, this research would be particularly useful if pre-morbid data were collected to determine changes in performance across various domains in children who are culturally and linguistically different as a result of brain injury.

Chapter 7

Implications for School Psychologists

Although children with moderate to severe brain injuries often receive their initial post-injury assessment prior to returning to school, school psychologists must then monitor, reassess, and provide interventions for these children. Thus, school psychologists must be familiar with the general strengths and weaknesses that these children will likely return to school with and how these strengths and weaknesses may change over time as they continue to recover. Specific focus on mild brain injuries is prevailing due to the Concussion Management and Awareness Act that was passed in 2012 (NYSED, 2012), however, this legislation neglects to recognize or highlight the significant role that a school psychologist will play in the child's education. Rather, school coaches, physical education teachers, nurses, and certified athletic trainers are mandated to complete an educational course every two years regarding concussions and concussion management (NYSED, 2012). When managing children within the educational system who have suffered some degree of brain injury, the present study serves to highlight the importance of school psychologists.

The present study has provided evidence for the use of a CHC theory based model with the most commonly used cognitive assessment tool, the WISC-IV, in the assessment of children who have suffered brain injuries. Because all seven CHC broad abilities cannot be measured through the WISC-IV alone, the present study indicates that using a Cross-Battery Assessment approach can be a highly useful tool when assessing children who have sustained brain injuries. Evidence based assessment methods can now begin to be applied by those who work with children who have sustained brain injury. When planning and interpreting an assessment, school psychologists must consider the age of the child that they are assessing, the amount of time that has passed since their injury, and the type of injury that the child has sustained. Additionally, this study provides a basis for understanding the fact that children with different forms of brain injury may display weaknesses with varying severity, primarily in subtests of *Processing Speed* and with the *Fluid Reasoning* subtest of *Matrix Reasoning* such that children with acquired brain injuries may display relative weaknesses in these areas as compared to children who have sustained traumatic brain injuries. Therefore, regardless of the amount of time that has passed since a child has sustained a brain injury, school psychologists must view the children as individuals in light of their own unique experience and consider that the brain injury may pose specific challenges to the children as they progress through school.

Implications for Psychologists and Neuropsychologists

Mental health professionals conducting psychoeducational and/or neuropsychological measures should remain aware of several aspects affecting assessment results as well as the pattern of skills herein noted when assessing children who have sustained a traumatic or acquired brain injury. More specifically, rather than merely relying on neuropsychological domains to assess cognitive performance, theoretical and empirically based assessment methods should be employed to increase the validity of the findings. The present study serves to elucidate the use of a CHC theory based method rather than relying on the WISC-IV structure, particularly because this structure does not permit distinction between *Visual Processing* and *Fluid Reasoning*, but rather, these skills are combined in the WISC-IV structure. Furthermore, Keith, Goldenring Fine, Taub, Reynolds, & Kranzler (2006) demonstrated that these skills represent distinctly different constructs in the normative population. Given the differences in performance on one *Fluid Reasoning* task that measures deductive and inductive reasoning based on the regions affected in the present study, particular attention must be paid to the actual skills being measured in addition to the underlying functional processes that may be impacting test results. The importance of the CHC abilities must not be underestimated or underutilized, as much more information can be gained from a thorough cognitive assessment including Auditory Processing and Long-Term Memory. Thus, a Cross-Battery Approach can be utilized within a neuropsychological battery to improve validity of the findings by limiting the amount of total batteries employed, as neuropsychological assessments may often employ excessive amounts of batteries when the skills intended to be measured can typically be measured adequately using fewer batteries.

In order to improve the continued cognitive rehabilitation efforts, appropriate placement determination, and development of compensatory skills among children affected with brain injuries, neuropsychologists and psychologists alike must consider the broad and narrow abilities, input and output skills necessary for tasks, and region of the brain affected. For instance, in the present study, the performance of children with frontal lesions on *Matrix Reasoning* can be generally explained by deductive and executive function weaknesses, whereas the weakness of the children with posterior injuries can be explained by deductive and visuo-spatial weaknesses. Thus, interventions can be developed to be focused on the specific skills affecting performance, namely, an intervention that employs both executive and deductive strategies for frontal injuries and deductive strategies with a visuo-spatial emphasis for posterior injuries. This point is further highlighted by viewing the results based on the *Processing Speed* subtests. For the *Processing Speed* subtests, interventions for the frontal group would be focused on executive remediation and compensatory strategies for fluency and efficiency, whereas the interventions recommended for the posterior group would be focused on improving fine motor skills and employing program modifications, such as incorporating the use of a computer or word processor. Thus, as a profession, psychologists should not rely on generic recommendations based on subtest or Index findings, but rather, we should consider the reason why the child has performed poorly in some specific area of functioning in conjunction with the specific skill that is being measured by the tasks in order to improve the child's ability to receive and respond to educational stimuli while considering the manner in which these challenges will affect the child in their daily life.

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