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Determining predictors of outcome on factors of attention following paediatric arterial ischemic stroke

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Abstract

Attention is a facet of cognition that is responsible for the development of most cognitive processes. Insult to the brain prior to or during the development of attention can be detrimental to various aspects of cognitive development and, as a result, to a child's ability to acquire new knowledge and skills. One example of cerebral insult in childhood is stroke. Given the importance of attention for the development of cognitive skills, identifying the factors of attention is critical to understanding cognitive outcomes in children with stroke.

In the present investigation, a three-factor and a four-factor model of attention were tested using confirmatory factor analysis on a set of neuropsychological tests purported to measure various aspects of attention, in order to determine the model of attention best represented by a sample of children with arterial ischemic stroke. It was determined that both a three- and four-factor model of attention fit the data equally well when the same measures were included in both models. Despite similarities between the models, the four-factor model of attention was argued to be the best fit, due to theoretical, neuroanatomical, and developmental considerations. When the four-factor model was used to determine predictors of outcome, both Age at Stroke and Age at Testing were significant predictors of outcome on the Shift and Focus/Execute factors of attention, but not on the Encode and Sustain factors. The findings are discussed within the framework of a vulnerability vs. a plasticity model. Implications for clinical practice are also considered.

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List of Abbreviations

AD(H)D	Attention Deficit (Hyperactivity) Disorder
AIS	Arterial Ischemic Stroke
AMOS	Analysis of Moment Structure
ANT	Attention Network Test
BASC	Behavioural Assessment System for Children
BRIEF	Behaviour Rating Inventory of Executive Function
CFA	Confirmatory Factor Analysis
CFI	Comparative Fit Index
CMIN/DF	Minimum Discrepancy/Degrees of Freedom
CPT	Continuous Performance Test
CSVT	Cerebral Sinovenous Thrombosis
D-KEFS	Delis-Kaplan Executive Function System
FASD	Fetal Alcohol Spectrum Disorder
FIML	Full Information Maximum Likelihood
fMRI	Functional Magnetic Resonance Imaging
FPN	Fronto-Parietal Network
MAR	Missing at Random
MCA	Middle Cerebral Artery
MCAR	Missing Completely at Random
ML	Maximum Likelihood
NFI	Normed Fit Index
NINDS	National Institute of Neurological Disorders and Stroke
PCLOSE	Probability Value for Closeness of Fit
PIQ	Performance Intelligence Quotient
PSOM	Paediatric Stroke Outcome Measure
RMSEA	Root Mean Square Error of Approximation
SEM	Structural Equation Model
SS	Sky Search
SS DT	Sky Search Dual Task
TBI	Traumatic Brain Injury
TEA-Ch	Test of Everyday Attention for Children
Trails	Trail Making Test

VIQ	Verbal Intelligence Quotient
WAIS	Wechsler Adult Intelligence Scale
WCST	Wisconsin Card Sorting Test
WISC	Wechsler Intelligence Scale for Children
WPPSI	Wechsler Preschool and Primary Scale of Intelligence

CHAPTER 1

Introduction

Attention is a facet of cognition that is necessary for the development of many other cognitive processes. Although attention is often referred to as a singular process, it is in fact recognized as consisting of a network of inter-related processes. Several models of attention exist, but all have limited application to children. Identifying a representative model of attention is particularly important for understanding how attention is affected by early cerebral insult. Children who experience an acquired brain injury typically have a variety of cognitive sequelae as a result, among which difficulty with attention is often a primary concern. Impairment in attention has been relevant in research investigating the cognitive consequences of acquired brain injuries, including pre-frontal lesions, treatment with cranial radiation and chemotherapy, as well as stroke (Anderson, Jacobs, & Harvey, 2005; Anderson, Godber, Smibert, Weiskop, & Ekert, 2004; Westmacott, MacGregor, Askalan, & deVeber, 2009). The challenge with assessing attention in children is that there is currently no clear developmental model of attention.

In the current investigation, a model of attention is identified for children with paediatric arterial ischemic stroke (AIS) by testing two of the most commonly accepted models of attention from the literature. Predictors of outcomes on the individual factors of attention are also investigated in order to add to the understanding of the development of attentional abilities. In the following introductory section, an overview of attention models is presented, including an explanation of the factors of attention within a developmental framework. Next, a brief overview of paediatric stroke is outlined, describing how cognitive processes, including attention, are commonly affected in this population. Factors contributing to differential outcomes in children are also considered.

Attention Overview

Posner and Rothbart (2007) provide a broad definition of attention, stating that it "serves as a basic set of mechanisms that underlie our awareness of the world and the voluntary regulation of our thoughts and feelings." (p. 6). Attentional networks are connected to all other neural networks, and play a major role in the development of different cognitive abilities (Posner & Rothbart, 2007). Research on brain maturation has long suggested that cerebral and cognitive development are intertwined; they develop through a nonlinear process of stages, where periods of growth are separated by plateaus of limited change (Hudspeth & Pribram, 1990). Recent imaging research has demonstrated that more basic functions (e.g., sensory and motor processes) mature earlier in life with the development of sensorimotor cortices, while the association cortices responsible for more complex processes (e.g., prefrontal cortex) develop later in life (Casey, Tottenham, Liston, & Durston, 2012).

Cerebral and cognitive maturation also appear to influence each other in a reciprocal manner, whereby cerebral growth can affect cognitive outcome and cognitive development can, in turn, produce cerebral growth (Hudspeth & Pribram, 1990). The act of attending to a stimulus changes brain activity by increasing the neural processing in the areas involved in the responses to stimuli (Colombo, 2004); for example, as an individual attends to a visual stimulus, neural activity in the visual cortex is enhanced. Attention has a direct, and somewhat disproportionate, influence on outcomes of the physical structure of the brain and its functions. Attending to different stimuli, either repeatedly or over extended periods of time, during early maturation has a direct and significant influence on the development of specific neural regions and their related cognitive processes (Colombo, 2004). In addition, attention may influence the development of other cognitive abilities by mediating the brain's interaction with various experiences and different environments (Colombo, 2004).

Basic attention skills can be assessed very early in young infants (Posner, 2004) and are likely present from birth. Early attentional abilities appear to have a direct influence on the outcomes of other cognitive abilities (Richards, 2004). Some investigators have measured attention skills in infants, and have suggested that early attentional abilities are a good indicator of general intellectual functioning later in life (Colombo, 1993). Children's brains may be more vulnerable to attention deficits than those of adults, given that their immature brains are in the process of developing and cognitive skills are only beginning to emerge (Anderson, Anderson, & Anderson, 2006). An inability to attend appropriately, in a child with a cortical impairment, may subsequently affect the acquisition of new skills in other cognitive domains, resulting in a global impairment in cognitive skills (Anderson et al., 2006). Overall, attention appears to be one of the most fundamental processes involved in cognitive development. There are, however, a variety of theories regarding the factors of attention and the network of brain regions responsible for different aspects of attentional processing.

Factors of Attention

Several different types of attention have been identified and relied on in research and clinical practice. *Selective attention* is considered the ability to focus on a specific target stimulus, regardless of its location in space and despite competing stimuli.

Selective attention processes are considered to be mediated by temporal, parietal, and striatal regions of the brain (Posner & Cohen, 1984). *Sustained attention* is considered the ability to attend to a stimulus or set of events that occur over an extended period of time; this aspect of attention is also known as *vigilance* (Stuss, Shallice, Alexander, & Picton, 1995). A right lateral midfrontal system has been attributed to the process of sustained attention (Posner & Petersen, 1990).

In attention research, it is also considered valuable to acknowledge processing speed as a form of executive-level attention. There is no consistent definition of *processing speed* used throughout the literature, although it is generally defined as the rate at which tasks are completed. It is unclear whether or not all speeded tasks tap into the same type of cognitive processes (e.g., attention), nor whether speed of processing is more a measure of the rate of input or output of information (Shanahan et al., 2006). Regardless of the difficulty in pinpointing a clear definition, processing speed appears to have a significant influence on the ability to effectively attend to stimuli and thus acquire new information. The connection between processing speed and attention has been identified in research on Attention Deficit Hyperactivity Disorder (ADHD), noting impairment in processing speed in this population of children (see Shanahan, 2006 for a review). Processing speed is thought to be mediated by subcortical and anterior brain regions (Anderson et al., 2006).

Attention often falls under the broader heading of *executive functioning*, making the two concepts difficult to tease apart (Mirsky, Anthony, Duncan, Ahearn, & Kellam, 1991). There is quite a bit of overlap among measures of *attention* and what is considered *executive functioning*, therefore typical measures of attention and measures of executive functioning that rely on attention are often both examined within the same body of literature (Mirsky et al., 1991). Executive aspects of attention are sometimes referred to as *attentional control* (Manly et al., 2001). The three primary executive-level attention processes are: 1) *response inhibition*, which is the process of inhibiting automatic responses to specific stimuli; 2) *divided attention*, which is the ability to attend to multiple stimuli simultaneously; and 3) *shifting attention*, which is the ability to change the focus of attention easily from one stimulus to another. These executive-level attention processes are thought to be mediated primarily by the frontal lobes (Anderson et al., 2006).

Models of Attention

Although individual researchers tend to argue that there are different attentional domains (such as those mentioned previously) the most widely accepted models suggest that the concept of *attention* can be divided into separate factors of attention (Heaton et al., 2001). Most researchers agree that attention is mediated by a distributed neural network, made up of multiple anatomical regions (Mirsky et al., 1991; Posner & Petersen, 1990). The exact neural structures and the extent of their participation in the attention process, however, are greatly debated.

Mirsky was one of the first researchers who attempted to establish cognitive constructs and behavioural outcomes related to specific brain regions (Koziol, Joyce, & Wurglitz, 2014). His original four-factor model of attention consisted of sustained attention, selective or focused attention, attention shift, and divided attention (Mirsky et al., 1991). Since his original investigations, numerous researchers have supported his theory and conducted research within the four-factor model framework (e.g., Cooley & Morris, 1990; Sergeant & Van der Meer, 1990).

In contrast, Posner originally proposed a dual-factor model of attention, controlled by different neuroanatomical regions, which are interconnected and directly influence one another. Posner argued that one aspect of attention involved in the model was selective and shifting attention, which he suggested was controlled by the posterior cortical regions, most notably the parietal lobes. The second aspect of attention was thought to be involved primarily in higher-order functions, which were controlled by the anterior system, including the prefrontal cortex (Posner & Petersen, 1990).

More recently, researchers have argued for more complex models of attention, with multiple components that interact with one another. Posner reconsidered his original attention model, suggesting a three-factor network that takes more of the subtleties of attentional processes into account. Posner labeled the three factors: Orienting, Alerting, and Executive Attention. Supporters of Posner's three-factor model have identified variants of a similar structure (e.g., Manly et al., 2001; Anderson et al., 2005; Anderson et al., 2006), labelling the three factors: 1) Focus/Select, 2) Sustain/Vigilance, and 3) Attentional Control/Switching/Shifting/Response Inhibition/Divide/Processing Speed.

Kavros and colleagues (2008) compared and contrasted Posner's three-factor and Mirsky's four-factor models of attention and suggested that, despite some overlap in the neuroanatomical regions identified in the models, the researchers demonstrate very little agreement with respect to the types of attention involved in those regions. The three- and four-factor models will be delineated further in the following paragraphs.

Posner's Three-Factor Model of Attention. Posner and Petersen (1990) first described attention as a network of separate neuroanatomical regions responsible for individual attention networks, which they derived from an overview of studies examining visual orientation, alertness and vigilance, as well as conscious signal detection in both animals and adults with typical cognitive processes and acquired injuries (see Posner & Petersen, 1990 for a review). Posner's most recent description of the attentional network model identifies three individual systems, described as Orienting, Alerting, and Executive attention. Numerous studies have since followed, providing evidence in support of the theory, further defining the three factors of attention (e.g., Posner & Fan, 2008; Posner & Rothbart, 2007) and supporting the neuroanatomical correlates outlined by Posner, through fMRI findings (Fan, McCandliss, Fossella, Flombaum, & Posner, 2005). In addition, researchers have examined these factors in a developmental context, suggesting that the attention networks rely on one another, with individual aspects of the attention network developing at different stages over time (see Posner & Rothbart, 2007 for a review).

Given the theoretical nature of Posner's model of attention, researchers have developed an experimental task called the Attention Network Test (ANT), which is a combination of a cue target and flanker test (based on Eriksen and Eriksen, 1974), and is used in experimental settings to examine the three attention networks using measures of reaction time (Fan, McCandliss, Sommer, Raz, & Posner, 2002). The ANT has been developed for use with both adults and children (Fan et al., 2002; Rueda et al., 2004). In clinical practice traditional neuropsychological assessment measures can be used to represent Posner's three factors of attention.

Although the terms used by Posner have changed throughout various versions of the model, the theoretical basis of each factor has remained consistent over time. In the most recent account of Posner's model, the *Orienting* attention network is responsible for responding to changes in the perceptual field or sensory cues, by disengaging from a stimulus, shifting attention, and engaging in a new stimulus (Mezzacappa, 2004). Posner (1980) suggested that these responses can either be overt or covert orientations to a stimulus, given that an individual can orient attention without overtly making eye movements towards the stimulus. Orienting attention appears to be controlled by the frontal eye field, superior parietal lobe, temporoparietal junction, pulvinar, and the superior colliculus (Posner & Fan, 2008; Posner & Rothbart, 2007).

In order to assess Posner's Orienting attention, researchers have relied on neuropsychological tests requiring the individual to direct their attention to a cued location, such as cancellation tasks or the Trail Making Test (Kavros et al., 2008). In the process of developing the Test of Everyday Attention for Children (TEA-Ch), Manly and colleagues (2001) determined that the Sky Search subtest correlates with the Trail Making Test, representing what the authors termed Focused or Selective attention, which maps onto Posner's Orienting attention.

Posner's *Alerting* attention is considered the process of maintaining a state of vigilance or alert arousal during prolonged mental activity, which is mediated by the right prefrontal and lateral parietal regions, the locus coeruleus, and the thalamus (Posner & Fan, 2008; Posner & Raichle, 1994; Posner & Rothbart, 2007). Mezzacappa (2004) further elaborates on Alerting attention, noting that it can also refer to a state of being prepared for effortful information processing. In research, continuous performance and vigilance tasks have been used to evaluate Posner's Alerting attention network (Fan et al., 2002). As mentioned previously, Manly et al.'s (2001) Score! and Sky Search Dual Task (SSDT) subtests of the TEA-Ch represent factors of sustained attention that map onto Posner's Alerting attention network.

Posner's *Executive Attention* network involves a variety of processes related to executing goal-directed behaviour, such as: planning; anticipating outcomes; selecting among competing responses (i.e., conflict resolution); initiating, monitoring, and maintaining behaviour; and interrupting or modifying behaviour (i.e., inhibiting unwanted responses; Mezzacappa, 2004; Posner & Rothbart, 2007; Rueda et al., 2004). The processes involved in Executive Attention are purported to be mediated by the anterior cingulate gyrus, the lateral and dorsolateral prefrontal cortex, the ventral tegmental area, as well as the basal ganglia (Posner & Rothbart, 2007; Posner & Raichle, 1994). Variations of the Stroop test have historically been used to assess conflict resolution in research; the Stroop test is therefore considered a test of Executive Attention (Posner & Rothbart, 2007).

Mirsky's Four-Factor Model of Attention. Mirsky's model of attention appears to be primarily based on an "evolutionary developmental perspective" (Kavros et al., 2008, p. 1571); Mirsky considers the ability to attend to stimuli a skill that is consistent in all animals, and therefore particular neuroanatomical structures are considered to be responsible for aspects of attention across species (Mirsky et al., 1991). The components of Mirsky's theory were initially empirically-derived through factor analysis of neuropsychological test performance, compared to imaging data, in a typical sample of adults and individuals with a variety of neurological or psychiatric diagnoses (i.e., eating disorder, epilepsy, schizophrenia, affective disorder, and head injury), as well as typically-developing elementary school children. Mirsky's model therefore provides a framework for conceptualizing attention that corresponds with more traditional measures of attention within clinical neuropsychology.

Mirsky's *Focus/Execute* is the process of maintaining attention to a particular stimulus despite distraction from competing stimuli, which has been recognized as a feature of processing speed, given the rapid response output component of the attentional process (Koziol et al., 2014). The inferior parietal lobe and corpus striatum are considered to be responsible for both focusing and executing attention, whereas the superior temporal cortex is involved in focusing attention alone (Mirsky, 1996; Mirsky et al., 1991). Mirsky suggests that performance on the Coding and Digit- Symbol Substitution subtests from the Wechsler scales, the Trail Making Test (parts A and B), the Stroop test, and cancellation tests, are all mediated by the Focus/Execute process of attention (Mirsky, 1996). Some investigators have used the Wechsler Symbol Search task as a measure of Focus/Execute (Koziol et al., 2014).

Although the more complex version of the Trail Making Test (Trails B) is defined as a test of cognitive flexibility (see Appendix A for a description), and is traditionally clinically relied upon as a measure of executive functioning, Trails B did not load with the Wisconsin Card Sorting Test (WCST) on Mirsky's Shift factor in the original factor analysis (Mirsky et al., 1991). Despite the executive component necessary to complete the task (i.e., switching between stimuli, inhibiting unwanted responses), when examining time to completion as the measure of interest, Trails B is more a test of speeded control of attention than shifting attention (Koziol et al., 2014).

Sustain represents the process of maintaining *vigilance*, which Mirsky describes as the ability to maintain focus and alertness over time. Structures of the brainstem – including the tectum and mesopontine regions of the reticular formation – are suggested to be responsible for Sustain, along with thalamic nuclei. These brainstem and thalamic regions are the more evolutionarily primitive of the brain structures, which explains why they are responsible for the most basic of the attention processes (Mirsky, 1996; Mirsky et al., 1991). In establishing the original model, Mirsky relied on subscales of the Continuous Performance Test (CPT; Rosvold & Delgado, 1956) to assess Sustain, including number of correct hits, number of commission errors, and reaction time. In developing the TEA-Ch, Manly and colleagues (2001) identified several subtests that represent sustained attention, including Score! and Sky Search Dual Task (SSDT).

Shift is described as the ability to move attention from one stimulus or part of a stimulus to another. Mirsky and colleagues suggested that Shift is related to the dorsolateral prefrontal cortex, based on Milner's work (1963), as well as the medial frontal cortex and anterior cingulate gyrus, as evidenced through their animal models (Mirsky et al., 1991). The WCST is relied on to assess Mirsky's Shift factor (Mirsky, 1996). In their original model, Mirsky and colleagues included the number of categories successfully achieved, the numbers of errors made, and the number of correct responses (Mirsky, 1996) as indicators of attentional shifting. Mirsky recognized that Shift is also a feature of executive functioning, acknowledging that there is no clearly defined distinction between attention and executive functioning (Mirsky, 1996).

Encode is a process similar to the concept of working memory, involving the act of holding and manipulating information in mind (Mirsky, 1996). Mirsky relied on the

Digit Span and Arithmetic subtests from the Wechsler scales to assess Encode. In more recent research, investigators have relied on measures of immediate memory (e.g., sentence repetition, the first trial of a list-learning task, or immediate story recall) as measures of Mirsky's Encode (Koziol & Budding, 2009). Mirsky and his colleagues argued that the hippocampus and amygdala (both subcortical structures) are responsible for Encode, based on Scoville and Milner's (1957) as well as Mishkin's (1978) research demonstrating that these areas may be involved in the mnemonic or encoding aspects of language (Mirsky, 1996; Mirsky et al., 1991). More recently Koziol et al. (2014) suggested that the neuroanatomical substrates of Encode are much more widespread in the brain than previously thought, and they make up a network that includes neuroanatomical structures connected through the Fronto-Parietal Network (FPN), including the dorsolateral prefrontal cortex, the inferior parietal lobe, the anterior cingulate cortex, the cerebellum, and the medial occipital cortex.

In a 1995 book chapter, Mirsky reported that he and his colleagues had identified a fifth factor of attention, which was referred to as *Stability,* and represented the consistency of responses to a target stimulus. Mirsky suggested that this factor of attention was linked to Sustain, and the brain regions responsible for both factors likely overlapped. Mirsky reported that this factor of attention could be assessed by examining an individual's consistency of responses across trials of the CPT. Although Stability is mentioned in subsequent articles written by Mirsky (e.g., Mirsky, Pascualvaca, Duncan, & French, 1999), there was no published research demonstrating how the fifth factor of attention was developed; references suggested that the work was made available through an unpublished dissertation. Due to the limited availability of evidence supporting the existence of the factor, and the fact that a single subtest was identified as a measure this type of attention, the current investigation will not consider the fifth factor of attention. From this point on, Mirsky's original four-factor model of attention will be evaluated.

Kavros et al. (2008) compared Mirsky's and Posner's models of attention. They noted that there are only a few theoretical similarities between the two models: Mirsky's Focus/Execute factor most closely resembles a combination of Posner's Alerting and Orienting networks of attention. Mirsky's Shift appears to resemble the Orienting attention network described by Posner, given that Orienting refers primarily to the visual fields and shifting eye movements; however, Mirsky's Shift also relates to shifting between concepts. Kavros and colleagues reported limited overlap between Mirsky's Encode and Sustain factors and Posner's model of attention. Overall, the researchers reported that the two theories take different theoretical approaches to classifying the underlying components of attention.

Despite differences in opinion regarding the types of attention that exist, and to what extent attention overlaps with other cognitive processes, all theorists appear to be in agreement with the fact that attention is not a unitary cognitive ability (Stuss et al., 1995). Different aspects of attention are developed over time and interact with the mastery of other cognitive processes. The age of a child at the time of the cerebral insult is a critical piece of information when considering how different cognitive abilities will be affected by a particular lesion.

Developmental Theories of Attention. In a review of the history of developmental neuropsychology, Morgan & Ricker (2008) suggested that first attempts at understanding paediatric neuropsychology focused on a top-down approach, using adult models to help represent outcomes in children with acquired injuries. The authors suggested that the push toward a "child-up" approach to studying paediatric neuropsychology has been a long time coming. Research focusing on the factors of attention described previously suggests that individual components of attention vary in the rate at which they are first acquired and they are also mastered at different developmental stages. Despite varying ages at which certain skills are acquired, children in general tend to show increases in the development of all aspects of attention between the ages of 8 to 10 years (McKay, Halperin, Schwartz, & Sharma, 1994).

When examining the developmental aspects of Posner's attention processes, Orienting attention appears to be one of the earliest attentional processes to develop and become established in children. Infants as young as 3 to 4 months of age can be taught to orient to places in the environment, and this can be accomplished without moving their eyes (Colombo, 2004; Rothbart & Posner, 2001). Typically, the ability to disengage, shift, and re-engage attention to a new stimulus is present by 6 to 9 months of age in most individuals (Colombo, 2004; Posner & Raichle, 1994). Rueda et al. (2004) reported that Orienting attention continues to develop until 6 years of age when it can be considered mastered; however, voluntary orienting of attention (i.e., goal-directed behaviour) is argued to continue developing into adolescence (Posner & Raichle, 1994). Similarly, Rueda et al. (2004) found that Alerting attention is present by the age of 3 months, but suggested that this aspect of attention continues to develop into adolescence.

On the other hand, Executive Attention appears to have a relatively late development. Rueda et al. (2004) suggested that particular aspects of Executive Attention may be established at different points throughout an individual's development.

For example, Rueda et al. (2004) found that conflict resolution begins to develop around 2 to 4 years of age, and by the age of 10 years children obtain scores that are equivalent to those of adults. Inhibition, on the other hand, does not appear to begin to develop until between 6 and 13 years. Rueda et al. (2004) suggested that age 7 years is a reasonable cutoff for Executive Attention to be considered established overall.

Researchers have investigated the development of some aspects of attention that are considered to be equivalent to Mirsky's factors of attention. Several aspects of attention fall under the general umbrella of Mirsky's Focus/Execute factor; these processes have been investigated separately. McKay et al. (1994) found that children tend to have early development of selective attention, and are able to master the skill by the age of 6 years. Processing speed, on the other hand, tends to show a gradual development throughout childhood, increasing steadily with age (Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001; McKay et al., 1994; Rueda et al., 2004).

Richards (2004) found that children tend to master the process of sustaining attention within the first few months of infancy, and the skill appears to remain stable throughout childhood (McKay et al., 1994). Rueda et al. (2004) found very little difference between children and adults in terms of their ability to shift attention between cues, but they noted that the ability to disengage from a particular stimulus improves with age. Anderson et al. (2001) found that around the age of 15 years there is a "growth spurt" for attention control and processing speed, aspects of attention measured through tests of digit span (both forward and backward), which fall under Mirsky's Encode factor.

Despite the extensive research that has been conducted on factors of attention and attempts to understand how various attentional processes develop over time, there remain significant discrepancies among models of attention. In particular, there is a lack of consensus regarding whether attention can be conceptualized as a three-factor or a four-factor model. Identifying the factor structure of a model of attention that fits within a developmental framework would provide a valuable tool to understanding the clinical consequences of impairment to individual attentional processes, such as the outcomes of attention following paediatric stroke.

Paediatric Stroke Overview

A *stroke* is a cerebrovascular event characterized by a sudden disturbance of central nervous functioning caused by a disruption of blood supply in the brain. *Ischemic strokes* occur when there is a disruption in the blood supply to a specific region of the brain that lasts long enough to cause an infarct (i.e., death of the tissue; Blumenfeld, 2011). Ischemic strokes can be further subdivided into arterial ischemic stroke (AIS) and cerebral sinovenous thrombosis (CSVT), depending on the location of the blockage (Blumenfeld, 2011); ischemic strokes are therefore a result of either an embolism or thrombosis (deVeber, MacGregor, Curtis, & Mayank, 2000). The most common location of ischemic strokes in children is in the Middle Cerebral Artery (MCA), most often in the left cerebral hemisphere (Raju, Nelson, Ferriero, & Lynch, 2007). *Hemorrhagic strokes* refer to death of tissue due to either intracerebral or subarachnoid bleeding (Amlie-Lefond, Sébire, & Fullerton, 2008).

Paediatric stroke is an umbrella term, encompassing all cerebrovascular events occurring from the prenatal period *in utero* to the age of 18 years. The term *perinatal stroke* is used in literature to refer to a stroke that occurs during very early life. According to the National Institute of Neurological Disorders and Stroke (NINDS) perinatal strokes occur between 28 weeks of gestation and 28 days of life after birth (Lynch, Hirtz, deVeber, & Nelson, 2002). Although the terms *perinatal* stroke and *neonatal* stroke are often used interchangeably, by definition the term *neonatal* applies exclusively to events that occur after birth. Because of the difficulty in reliably establishing the timing of stroke onset during the neonatal period, the term *perinatal* stroke is more encompassing and preferred by many authors (Amlie-Lefond et al., 2008). From this point forward, the term *perinatal* will be used to refer to the pre- and post-natal period, up to 28 days of life.

The NINDS has determined that a stroke occurring between 29 days and 18 years of life is considered a *childhood stroke* (Lynch et al., 2002). In the stroke literature, childhood strokes have been further subdivided into *early childhood stroke* (29 days to 5 years) and *late childhood stroke* (5 to 18 years; Westmacott, Askalan, MacGregor, Anderson, deVeber, 2010).

The clinical presentation of paediatric stroke tends to be quite subtle and has a wide range of possible symptoms (Lynch et al., 2002). Often, signs of perinatal stroke do not become apparent until infants begin to move on their own and appear to favour one limb over another (Hartel, Schilling, Sperner, & Thyen, 2004). When motor function is spared, symptoms may not present until later in childhood, when demands on a child's complex cognitive skills are increased, such as language or problem-solving abilities (Westmacott et al., 2009).

Prevalence

Given recent advances in neuroimaging, the identification of childhood strokes has been increasing consistently since the 1970s. The most recent estimates suggest that approximately 5 to 8 in every 100 000 children will have a stroke, up to 50% of which are ischemic (Agrawal, Johnston, Wu, Sidney, & Fullerton, 2009; Lynch et al., 2002). Strokes are among the top 10 causes of death in children; the highest mortality rates due to stroke are among those under 1 year of age (Lynch et al., 2002). Paediatric strokes are more likely to occur during the perinatal period than any other period throughout childhood; in fact, approximately 32% of paediatric AIS and 43% of paediatric CSVT occur within the first 28 days of life (deVeber et al., 2000; deVeber et al., 2001). More than 50% of children who survive paediatric strokes subsequently develop motor difficulties (e.g., hemiparesis) and/or cognitive deficits (e.g., attention impairment; Lynch et al., 2002).

The majority of the paediatric stroke literature has focused on ischemic strokes, partly since the neonatal brain is particularly vulnerable to damage as a result of ischemia (Lynch et al., 2002). A recent review has suggested that between 39% and 54% of childhood strokes are hemorrhagic; although they remain an understudied half of the paediatric stroke population (Warren, 2011). The current investigation will focus on ischemic strokes, exclusively examining patients with AIS, due to the greater availability of this population within the clinical sample.

Causes

Although the mortality rate in infants has been consistent over the past 40 years, the causes of paediatric strokes have changed over time (Lynch et al., 2002). Prior to the influenza vaccination, this virus was a common cause of strokes in children. More recent analyses suggest that the most common known causes of paediatric stroke include: congenital/acquired heart disease; sickle cell anemia; coagulation disorders; extracranial carotid dissection; varicella or other similar infections; trauma; Down's or Williams' Syndromes; and a wide range of other viruses and bacteria (Lynch et al., 2002; Kirkham, 1999). Despite the wide range of possible causes of paediatric stroke, in more than one third of all cases, there is no evident source (Lynch et al., 2002).

Sex Differences

Paediatric strokes are more common in males than females, regardless of age at stroke, type of stroke, or history of trauma (Golomb, Fullerton, Nowak-Gottl, & deVeber, 2009). Westmacott et al. (2009) found that males with perinatal AIS showed a more significant cognitive impairment by the time they reached school age than a matched group of females, in terms of overall intellectual ability, nonverbal reasoning, and processing speed. This finding suggests that not only are males more likely to suffer strokes, but they are more likely to experience emerging cognitive impairments throughout development. The sex difference in cognitive outcomes may be explained by the relative immaturity of the male brain at birth, compared to the female brain; the male brain may thus be more susceptible to impairment following perinatal stroke (Westmacott et al., 2009). See the following vulnerability theory explanation for an elaboration of this idea.

Outcomes

Vulnerability vs. Plasticity Theories. An often debated question in paediatric neuropsychology is whether or not earlier damage results in better outcomes than later insult, given either the plasticity or vulnerability of the young brain. Theories appear to fall along a spectrum; at one extreme is the theory of *plasticity*, which is the process by which neural circuitry is modified in response to environmental impact or experience

(Anderson, Spencer-Smith, & Wood, 2011). Based on her research with infant and adult monkeys, Margaret Kennard (1938; 1942) suggested that functional reorganization of the brain is greater following early injury, due to the plasticity of the young brain. She found that adult monkeys tended to show greater impairment than infant monkeys following comparable lesions (Kennard, 1938). Researchers who support what has been dubbed the "Kennard Principle" argue that damage tends to be less severe and result in fewer functional impairments following a focal brain injury in younger children, compared to the results seen when the injury occurs in older children and adults. Proponents of the theory of early brain plasticity suggest that the young brain may, in fact, be more malleable in early life and able to reorganize more effectively than an older brain (Anderson et al., 2005). As a result, one would expect better recovery following early insult than might be seen in an older individual with that same injury.

On the other end of the spectrum is the theory of *vulnerability*. Hebb (1947) found that children with frontal lobe injuries had worse outcomes and greater functional impairment than adults following equivalent brain insult. Hebb hypothesized that early cerebral insult might prevent the normal development of certain cognitive abilities, which may result in impairment within particular cognitive domains. Young children whose cognitive skills are not fully established at the time of insult may have trouble acquiring those skills and will experience poorer recovery (Biltigua et al., 2004; Giza & Prins, 2006). Some argue that younger brains are less mature and are underdeveloped; therefore the frontal regions and myelinated fibers in particular tend to be more vulnerable to damage than a mature adult brain (Hudspeth & Pribram, 1990).

Some proponents of the vulnerability theory have since suggested that there can be a cumulative effect of early cerebral insult, sometimes referred to as a “snowball effect” (McLinden, Baird, Westmacott, Anderson, & deVeber, 2007); not only do young children have a very limited set of acquired skills at the time of the early injury, but damage may also impair their ability to consolidate new skills in the future (Anderson, Catroppa, Morse, Haritou, & Rosenfeld, 2005). Children with cerebral insults tend to struggle more with complex cognitive processes as the demands of recovery exacerbate the usual challenges of development (Dennis, 2000).

Recent evidence in stroke literature tends to support the theory of vulnerability and age effects, demonstrating that the functional outcome of insult to a young brain may be disproportionately affected by strokes compared to a more mature brain (Hartel et al., 2004), especially in respect to cognitive functioning. For example, Hartel et al. (2004) found that children with paediatric strokes show a general trend toward having a weaker Performance Intelligence Quotient (PIQ) than Verbal Intelligence Quotient (VIQ) on Wechsler Intellectual Scales (i.e., WPSSI, WISC, and WAIS), and the discrepancy is significantly greater for children who have a stroke before the age of 5 years, during the period when the brain is still in the early stages of development, than for children who have an equivalent stroke after the age of 5 years. McLinden et al. (2007) found that when significant intellectual deficits are present, they can be identified as early as 12 to 24 months post-stroke. Not only is younger age at stroke associated with poorer scores on measures of intellectual functioning, but this trend is also present across a broad range of cognitive domains, including: memory, language, visuospatial skills, and academic functioning (Max, Bruce, Keatley, & Delis, 2010).

Based on their studies of rat models, Kolb, Gibb, and Gorny (2000) believe that there are “windows of opportunity” during which the best outcomes might occur following cerebral insult, due to specific developmental periods during which the greatest neural generation occurs. Kolb and colleagues (2000) suggested that the most severe neurological deficits result from insults occurring during the perinatal period (i.e., the gestational period up to the first month of life), as is evidenced through cases of cerebral palsy; whereas the window for the best outcomes appears to be during the second year of life (i.e., between 12 and 24 months).

In their research with paediatric stroke populations, Allman and Scott (2011) found that when examining performance across a range of neuropsychological tests, children who suffered a stroke between the ages of 1 to 6 years had relatively spared performance, compared to greater impairment for children with stroke onset before the age of 1 year or after the age of 6 years. This finding is consistent with Kolb’s argument for critical periods of development, suggesting that both younger and older ages may be associated with greater risk of impairment across cognitive domains.

Anderson et al. (2011) suggested that rather than choosing sides in the vulnerability vs. plasticity debate, these processes should be considered along a continuum of recovery potential, with plasticity and vulnerability as opposing processes at the extremes of the spectrum. Anderson and her colleagues note that outcomes along this continuum likely depend on a variety of contributing factors, including: injury factors (e.g., age at injury, severity of insult); constitutional factors (e.g., genetic makeup, sex of the child); and environmental factors (e.g., social status, access to rehabilitation). Anderson et al. (2011; 2005) also suggest that early neural recovery does not always translate into behavioural (or functional) recovery. Behavioural recovery tends to differ depending on the complexity of the ability in question and is based on both the ability to implement compensatory strategies and the brain's plasticity (i.e., its ability to reorganize).

Neurological Outcomes. Neurological impairment and seizures occur in approximately 50-75% of children with ischemic strokes (including both AIS and CSVT; Raju et al., 2007). deVeber et al. (2000) found that over 41% of children with ischemic strokes demonstrated moderate to severe deficits on neurological outcome measures. Children with AIS tended to have worse outcomes than those with CSVT; "poor outcome" was found in 46% of children with AIS and 18% with CSVT. deVeber et al. (2000) also found that unilateral sensorimotor deficits were present in 57% of children with AIS and 18% with CSVT. Speech, behavioural, and cognitive deficits, on the other hand, were less common, only present in 15% of children with AIS and 11% with CSVT.

Seizures are a common symptom of ischemic stroke (Chabrier, Husson, Dinomais, Landrieu, & Nguyen The Tich, 2011; Kirkham, 1999). When children show signs of an early onset stroke (i.e., within the first 28 days of life), they are most likely to present with seizures (Chabrier et al., 2011). Children who suffer from seizures associated with early cerebral insult are more likely to have cognitive impairment, and these deficits are likely to be more severe than in children with paediatric stroke who do not experience recurring seizures, due to secondary functional impairments (Hartel et al., 2004; Murias, Brooks, Kirton, & Iaria, 2014). For this reason, children with recurring seizures are often excluded in research investigating the outcomes of paediatric strokes (e.g., Westmacott et al.).

Motor Outcomes. Hemiparesis is the most common clinical symptom of unilateral stroke (Hogan, Kirkham, & Isaacs, 2000), and is often the first sign of stroke in children who do not present with seizures (Kirkham, 1999). Most strokes occur in regions of the brain where sensorimotor systems are represented, and therefore motor difficulties are common and quite variable in paediatric stroke cases; symptoms may include abnormal reflexes, tone asymmetry, action tremors, hemiparesis, and hemiplegia (Hogan et al., 2000). Paresis (motor weakness) tends to be the most prevalent and distressing motor outcome following paediatric stroke, especially in the perinatal stroke group (Hartel et al., 2004); hemiparesis occurs in approximately 30% of children following paediatric strokes (Ricci et al., 2008).

Cognitive Outcomes. There have been mixed results in the research attempting to determine the extent to which children demonstrate cognitive impairment following paediatric stroke (Hartel et al., 2004). Westmacott et al. (2009) found that children who had unilateral AIS during the perinatal period were more likely to demonstrate impairment in higher-level cognitive skills once they reached school age, even if they showed no deficits during the toddler or preschool years. This finding suggests that children with perinatal strokes tend to make slower cognitive gains than typically-developing children. Alternatively, Ricci et al. (2008) found that children with perinatal middle cerebral artery (MCA) strokes tended to have average IQ by their preschool years, as long as they did not present with additional confounding features (e.g., parent with cognitive impairment, developmental delays, etc.), which predisposed them to greater cognitive impairment following paediatric stroke.

Perhaps the discrepancies in results among studies can be related to the populations being compared; children with paediatric stroke may not perform in a significantly impaired range, but tend to show a lag in cognitive development, when compared to the average child. In a large sample of children with unilateral AIS, Westmacott et al. (2010) found that despite falling within the average range on all subscales of the WISC, children with strokes had significantly lower scores overall when compared to a normative group of children.

The global cognitive deficits present in children with paediatric stroke are quite a contrast to the common consequences of strokes that occur later in life. Adults who suffer strokes tend to experience very specific high-level cognitive impairments following focal lesions. These most commonly include aphasia (language impairment), amnesia (memory impairment), or apraxia (movement impairment; Vargha-Khadem, Isaacs, & Muter, 1994). For example, in adults, speech/language impairments are common following unilateral strokes localized to the left medial temporal lobe; however, studies have consistently shown that children do not have the same pattern of deficits following unilateral lesions (Vargha-Khadem et al., 1994; Mosch, Max, & Tranel, 2005). In fact, researchers have found that there are no significant effects of lesion laterality in cognitive outcomes following paediatric stroke (e.g., Hetherington, Tuff, Anderson, Miles, & deVeber, 2005; Hogan, Kirkham, & Isaacs, 2000; Westmacott et al., 2010).

Children who have strokes tend to present with more generalized cognitive impairments than adults with strokes to similar locations, who present with quite localized impairments. Vargha-Khadem et al. (1994) reported that the consequences of childhood strokes tend to be more widespread within the brain than similar injuries in adults, which explains the lack of localized impairment. Vargha-Khadem and colleagues (1994) suggested that there are two possible – yet opposing – explanations to support the idea that insult tends to be less focal in children. The first is that damage to a particular region can result in a decrease in potential for the acquisition of abilities within fully intact associated regions, when the relationship between the two regions is necessary for learning. This first explanation is consistent with the vulnerability theory, and would suggest that early cerebral damage results in more global deficits. A second explanation offered by Vargha-Khadem et al. (1994) is that the effects of focal lesions is less pronounced in children due to the plasticity of the early developing brain, which can compensate for the damaged regions and preserve function. The second explanation is consistent with the plasticity theory, and would suggest that early cerebral damage results in greater overall preservation of function across skills.

Not only do outcomes vary based on the age at which the stroke occurred, but the location of lesions plays a role in the outcomes as well. Westmacott et al. (2010) found that children with strokes affecting both cortical and subcortical regions of the brain had poorer scores on IQ measures (WISC-III/-IV) than children with strokes occurring only in either the cortical or the subcortical region. The researchers also noted that age of stroke significantly affected performance on the WISC; however, this effect was influenced by the location of the lesion. The children with earliest stroke onset (i.e., prior to one month of age) had the poorest outcomes when the lesions were localized to the subcortical regions; while children with strokes that occurred between the ages of 1 month and 5 years had the worst outcomes when their lesions involved only cortical regions. In addition, the impact of lesion location and age at stroke depend on the cognitive domain being measured; for example, children tended to have greater impairment in academic functioning following stroke than adults, while there was no difference between the two groups in terms of memory ability (Mosch, Max, & Tranel, 2005).

The severity of lesions also plays a role in the outcome measures of paediatric cerebral insult. Anderson, Jacobs, et al. (2005) found that for mild and moderate childhood traumatic brain injury (TBI), sustained between 3 and 12 years of age, children made significant recovery within the first 12 months post-injury. For more severe injuries, children with earlier insult (i.e., age 3-7 years) made poorer gains than children who had suffered similar injuries later in childhood (i.e., 8-12 years; Anderson, Jacobs, et al., 2005). There appears to be a "double hazard" effect of the combination of severe injury and younger age leading to the poorest outcomes (Anderson, Catroppa, et al., 2005). Similarly, paediatric stroke research has noted lesion severity as a contributing factor of poorer cognitive outcome (e.g., Banich, Levine, Kim, & Huttenlocher, 1990). However, conclusions based on TBI research may not be generalizable to stroke patients, due to the less focal nature of TBI compared to stroke.

Behavioural and Emotional Outcomes. There have been conflicting results in research related to the behavioural and emotional consequences of paediatric stroke (see Hartel et al., 2004 for a review). Children do not tend to show behavioural outcomes similar to those demonstrated in adults with unilateral cerebral insults, such as deficits in emotional expression following right hemisphere injury or increased risk for depression following left cerebral insult (Hartel et al., 2004). Some studies have identified impairment in social skills, emotional expression, irritability, and hyperactivity in children with a history of stroke (Hartel et al., 2004). However, interpreting these findings is complicated by research demonstrating the impact of psychosocial factors on behavioural outcomes. Laucht et al. (2000) demonstrated that children with behavioural consequences following early cerebral insults in general (e.g., aggression, delinquency, etc.), tend to also have negative psychosocial risk factors such as early family adversity present at birth (e.g., maternal depression). These psychosocial adversities into which children are born tend to outweigh any influence that early cerebral insult will have on behavioural consequences (Laucht et al., 2000).

Max et al. (2002b) found that children who have had a stroke are at greater risk for experiencing a comorbid psychiatric disorder, even when controlling for a variety of related factors, such as: age, gender, socioeconomic status, race, family functioning, family history of psychiatric disorder, and comorbid medical conditions. The researchers found that protective factors included: average intellectual functioning of the child; a typical neurological exam (i.e., no comorbid seizures, hemiparesis, coordination difficulty, etc.); and a limited family psychiatric history (Max et al., 2002b).

Although there appears to be a general consensus within the adult literature about the outcomes following localized infarcts, there is no clear understanding of how a child's brain is affected by a stroke. There is continued debate over whether the young brain is more susceptible to injury than an older brain (i.e., vulnerability theory) or is more available for reorganization and preservation of function (i.e., plasticity theory), given the varying outcomes that have been identified in children following early acquired brain injuries. Throughout the literature, the consensus appears to be that neurological, motor, cognitive, behavioural, and emotional outcomes are influenced by a wide range of factors, including the timing, severity, and location of the lesion, as well as comorbid medical conditions and psychosocial risk factors.

Attention Deficits Following Paediatric Stroke

Despite the wide range of possible neurological, behavioural, and emotional outcomes that may result from paediatric strokes, an area of increasing interest in the field has been on the impact that cerebrovascular insults have on cognitive abilities, and attention, in particular. In the past decade, researchers have highlighted a specific need for more a comprehensive neuropsychological profile to be developed – including a more in-depth assessment of cognitive functioning – following paediatric strokes (Max et al., 2005). Researchers have identified attention disturbances in paediatric stroke patients, across a variety of different investigative approaches. In the past, researchers have examined individual cognitive measures, to assess outcomes of attention following paediatric stroke. Aram & Ekelman (1986) found that task persistence on the Freedom From Distractibility index of the WISC-R (i.e., the sum of scores on the arithmetic and digit span subtests) was impaired following right-sided focal lesions. Block, Nanson, & Lowry (1999) found divided attention impairment on the Symbol-Digit Modalities Test for children with left-sided focal lesions.

Max et al. (2004) examined performance on the Starry Night task (Rizzo & Robin, 1990), a test designed specifically to tap into Posner's factors of Orienting and Alerting attention. The researchers found impairment on this test for individuals who had focal lesions to the Orienting or Alerting network regions identified by Posner, while no significant impairment was found on this test for children with lesions of the Executive Attention network (Max et al., 2004). MRI findings were relied on to pinpoint the

Orienting network (bilateral parietal lobes, bilateral thalamus, and bilateral precentral gyri), the Alerting network (right inferior parietal lobe, right precentral and superior frontal gyri, and right thalamus), and the Executive Attention network (bilateral anterior cingulum, posterior cingulum, superior frontal gyrus, paracentral lobule, caudate, lentiform, and claustrum). In this investigation, attention deficits tended to be more severe for children identified in the early stroke group (i.e., onset of stroke before 12 months of age) compared to the late stroke group (i.e., onset at 12 months of age or older), regardless of the size of the lesion (Max et al., 2004).

Although some researchers have examined specific cognitive measures of attention (Aram & Ekelman, 1986; Block et al., 1999; Max et al., 2004), a common research approach in this area of study is to focus on behavioural measures of attention, such as those consistent with Attention Deficit (Hyperactivity) Disorder (ADD/ADHD). Given the limited consistency in terms of the measurement tools used in attention research, there tends to be some confusion over the definition of *attention* within the literature (see Kavros et al., 2008 for a review). The Diagnostic and Statistical Manual of Mental Disorders (5th ed.; DSM–5*;* American Psychiatric Association, 2013) definition of ADD/ADHD states that an individual has symptoms of inattention (e.g., makes careless mistakes, is easily distracted, has difficulty sustaining attention) and/or hyperactivity-impulsivity (e.g., fidgets, talks excessively, interrupts) that are present prior to the age of 12 years and that occur in two or more settings (e.g., school, home, work). This disorder is usually diagnosed through parent or teacher report.

A common behavioural questionnaire used to make a diagnosis of ADD/ADHD is the Conners (3rd ed.; Conners 3; Conners, 2008). Other measures of behaviour that can contribute to a differential diagnosis of ADHD include: the Behavioural Rating Inventory of Executive Function (BRIEF; Gioia, Isquith, Guy, & Kenworthy, 2000), a measure designed to assess executive function behaviours, which includes measures of behavioural regulation and metacognition; and the Behaviour Assessment System for Children, Second Edition (BASC-2; Reynolds & Kamphaus, 2004), a measure designed to assist in differential diagnoses of disorders (i.e., ADHD, Depression, etc.) that includes internalizing and externalizing behaviour scales.

In their research, Max and his colleagues have investigated ADD/ADHD symptoms in relation to lesions acquired specifically to brain regions identified in Posner's Executive Attention network. Max et al. (2002a) found behavioural expression of attention deficits and symptoms consistent with ADHD in paediatric stroke patients with lesions of the putamen. In a later study, Max et al. (2005) found similar outcomes in children with stroke lesions localized to the mesial prefrontal and orbital frontal regions.

A concern with focusing on post-stroke ADD/ADHD symptoms is that cognitive test batteries are not designed to assess the behaviours required for a diagnosis of ADD/ADHD, nor are they specific to any one behavioural disorder; therefore, neuropsychological tests are not recommended as diagnostic tools for identifying ADD/ADHD (Swanson et al., 2004). Children diagnosed with ADD/ADHD tend not to show deficits on standardized cognitive measures of inhibition or other executive functioning measures (Shanahan et al., 2006). In fact, criteria in the DSM-5 for diagnosing ADD/ADHD are based on behavioural impairment, as observed by parents, teachers, or the clinician, and not on any cognitive measures of attention/executive functions. As Kavros et al. (2008) state, ADD/ADHD "is a subjective report of observed behavior... it is not synonymous with attention impairment" (p. 1571). Children with strokes who are involved in studies of attention are therefore being labelled with ADD/ADHD-type symptoms based on their scores on behavioural self-report measures and observation; cognitive attention impairments are not being taken into account. Given that attention impairments identified through cognitive testing have consistently been reported for children with other acquired cerebral insults (e.g., Anderson et al., 2005; Anderson et al., 2006; Catroppa, Anderson, & Stargatt, 1999), it is important to turn the focus of research towards test-based measures of attention.

Despite the extensive research conducted over the years, aiming to provide a better understanding of attentional processes, the current literature lacks a consistent model through which to understand the development of the attention network. Given the nature of paediatric strokes, such that the timing of an insult can often be pinpointed, children with strokes make up a valuable population for research; children with a history of stroke can be relied on to investigate the development of attention over time, by examining the consequences of cerebrovascular injuries at various stages in development.

Purpose of the Current Investigation

Given that there is no universally-accepted model of attention in the cognitive literature, the purpose of the present investigation was to determine whether a three-factor or a four-factor model of attention is best represented by a sample of children with arterial ischemic stroke (AIS). Neuropsychological assessment measures of attention are included in the current investigation, chosen based on their presence in the original models of attention being compared, as well as their psychometric properties, with regard to the aspects of attention each test is purported to measure. In addition, developmental aspects of the model of attention will be examined, taking into account how a child's age at the time of their stroke (Age at Stroke) and age at the time that they were assessed (Age at Testing) can be used as predictors of outcome on the factors of attention in the model of choice.

Goals

1. ***To determine whether a three-factor or four-factor model of attention best represented attentional processes in children from a clinical sample of arterial ischemic stroke (AIS).*** To fulfill the primary goal of this investigation, the factors of attention confirmed by factor analysis were used to determine which theory of attention best described outcomes following paediatric AIS. It was expected that if a three-factor model of attention best describes attention in the clinical sample, the data would fit well in a model with three major factors of attention that correspond with the following types of attention: 1) Orient/Select; 2) Alert/Sustain/Vigilance; and 3) Executive Attention. If a four-factor model of attention best describes attention in the clinical sample, the data was expected to fit well in a model with four major factors of attention that correspond with the following types of attention: 1) Focus/Execute; 2) Sustain; 3) Shift; and 4) Encode.
2. ***To determine whether Age at Stroke or Age at Testing are significant predictors of outcome on factors of attention, based on the model selected in Goal #1.*** To fulfill the second goal, a full latent variable model was developed based on the chosen model from Goal #1. Age at Stroke and Age at Testing were included in the model as predictors of outcome on the factors of attention in separate

regression models. In addition, Age at Stroke was included as a predictor of outcomes on factors of attention when Age at Testing was controlled for. Age at Testing was subsequently included as a predictor of outcomes on factors of attention when Age at Stroke was controlled for.

CHAPTER 2

General Methods

Participants

All data were collected retrospectively. Participants were selected from the Children's Stroke Outcome Study sample at the Hospital for Sick Children in Toronto, Ontario. This study was approved by the Research Ethics Board at the Hospital for Sick Children and, at the time of testing, consent was obtained from all participants or their caregivers for clinical data to be used in future research. All children being treated by the Paediatric Stroke Clinic who are referred for a neuropsychological assessment are asked to participate in the ongoing outcome study.

Participants who met inclusion criteria for the current investigation were born between 1977 and 2006, with a history of stroke diagnosed before the age of 18 years, who had received at least one of the measures of interest, including an intelligence test, before the age of 25 years. For a graphical representation of Age at Stroke across participants in the current investigation, see Appendix B. A breakdown of Age at Stroke across the tests of interest can be found in Appendix C. Data from 291 children who were tested on or before October 2011 were originally collected from the database. Children with hemorrhagic or cerebral sinovenous thrombosis (CSVT) were excluded from the present investigation due to the relative scarcity within the given sample, and potential for differing clinical presentation. Based on radiographic report, an event was classified as AIS by an experienced paediatric neurologist if definite evidence of vascular focal infarction was present. In an attempt to limit the extent to which a combination of neurological conditions might influence the outcomes on measures of attention, children with comorbid disorders were excluded from the study. Exclusion criteria included the presence of: preterm birth (<36 weeks gestation), moyamoya disease, sickle cell disease, CNS vasculitis, Down Syndrome, and recurrent seizures. As a result, 196 children (126 male, 70 female) met inclusion criteria for the current investigation and remained in the sample for study. See Table 1 for a description of the patient demographics.

Table 1

Patient Demographics

	Demographics			
	All Participants	**Perinatal Stroke**	**Early Childhood Stroke**	**Late Childhood Stroke**
Number of Participants	196	58	75	63
Males/Females	126/70	36/22	46/29	44/19
IQ [a]	91.58	85.93	93.38	94.33
Age at Stroke	4.66	0.0018	2.80	11.16
Age at Testing	11.51	9.71	10.18	14.74
Time since Stroke	6.85	9.71	7.38	3.58

[1] Perinatal Stroke: before 28 days of life; Early Childhood Stroke: between 29 days and 5 years of life; Late Childhood Stroke: after 5 years of life.
[2] Age/Time: mean number of years.
[a] Mean Full Scale IQ

Procedures

The data used in this model are archival. The primary investigator was involved in the data collection for some of the children included in the study, while administering neuropsychological assessments during a clinical practicum placement in the Paediatric Stroke Clinic at the Hospital for Sick Children. The remaining data were accessed through an archival database, collected by other clinical researchers in the same clinic.

Test Administration. During the initial neuropsychological assessment, demographic and neurological characteristics of the children were determined based on a review of health records (including MRI reports), questionnaires completed by parents prior to the assessment, and structured parent interviews. The neuropsychological assessments took place at the Hospital for Sick Children, and were administered either by a clinical neuropsychologist, a supervised psychometrist, or a supervised student. In the Paediatric Stroke Clinic there are different core test batteries depending on the age of the child (4-5-year-olds; 6-16-year-olds; or 17-year-olds and up), based on the norms available for particular age ranges. Often, tests are omitted or added to the core test batteries, given the discretion of the clinical neuropsychologist, based on a child's limitations or a particular clinical referral question. All participants and/or caregivers were provided with a full neuropsychological assessment report with recommendations. The clinical neuropsychologist conducted feedback sessions with the participants and/or caregivers following all assessments.

Sampling Procedures. Several children in the study were assessed through the Paediatric Stroke Clinic on multiple occasions. In general, children tend to be assessed every 2 to 5 years, depending on the individual clinical question (Kitchen et al., 2012).

Whenever possible, assessments were scheduled at times of academic transition (e.g., beginning elementary school, beginning high school, or preparing for post-secondary life), when children will benefit most from the identification or reassessment of accommodations and supports.

In the current investigation, scores from the most recent assessment were selected for participants with multiple test sessions, based on the precedent set by previous stroke research (e.g., Kitchen et al., 2012). Selecting the test data most remote from the acute stroke increases the probability that children have reached their potential for recovery, and therefore relies on the most stable scores. In addition, given that children tend to show greater cognitive deficits as they get older even if their abilities appear relatively spared during toddler or preschool years (Westmacott et al., 2009), it is important to assess attention later in development. Assessments of children during the acute stages of post-stroke recovery may either reflect impairments that are likely to improve with time or fail to identify impairments in skills that have yet to begin developing (Anderson et al., 2011). For a graphical representation of Age at Testing across participants, see Appendix D. A breakdown of Age at Testing across tests of interest can be found in Appendix E. Mean time since stroke was 6.85 years and ranged from less than one month to 17.44 years. A breakdown of Time since Stroke across tests of interest can be found in Appendix F.

Materials

The following cognitive measures of attention were included in the current investigation: Delis-Kaplan Executive Function System (D-KEFS: Colour-Word Interference, Trail Making Test); Test of Everyday Attention for Children (TEA-Ch; Sky

Search (SS), Score!, and Sky Search Dual Task (SS DT); Trail Making Test (Trails A and Trails B); Wechsler Adult Intelligence Scale (WAIS-R, WAIS-III, WAIS-IV) and Wechsler Intelligence Scale for Children (WISC-III, WISC-IV), including Digit Span, Coding, and Letter-Number Sequencing subtests, when available; and Wisconsin Card Sorting Test (WCST). See Appendix A for complete descriptions of the tests investigated in the current study and rationale for their inclusion as a measure of attention. See Appendix G for descriptive statistics of each test of attention.

CHAPTER 3

Statistical Analyses

Analysis of Missing Data

According to Narhi, Laaksonen, Hietala, Ahonen, and Lyvti (2001), there is a significant challenge when attempting to use data collected during clinical assessment for research purposes. Inherently, clinical testing has a different purpose than collecting data for research. In a clinical setting, test measures were added or removed from an assessment battery, based on the individual's presenting concerns and needs, whereas for research purposes (in the case of a prospective study) fixed batteries are administered. For this reason, data collected in a clinical setting and used in a retrospective study (as is the case in the current investigation) will likely be affected by missing data. Simply eliminating cases with missing data will reduce the statistical power (Narhi et al., 2001; McCleary, 2002); therefore, as long as there is a reasonable amount of data present in the sample, methods of estimation can be used to determine relationships in the data. Unfortunately, there are no set standards for the amount of missing data that is acceptable in a given data set (Tabachnik & Fidell, 2007).

In the present investigation, an Analysis of Missing Data was conducted after eliminating any individuals who were missing 100% of the data of interest. Of the remaining 196 participants who met the inclusion criteria outlined in the *participants* section above, 165 had missing data, with an average of 38% missing data overall within the sample. Individual tests may not have been administered to any particular child in this sample for a variety of reasons, including age cutoffs in the norms, time restrictions during testing, or specific referral questions that dictated the test battery. Little's Missing Completely at Random (MCAR) test was statistically nonsignificant (X^2 [505] = 533.50, p = .184), suggesting that the data appear to be missing at random. Note that because the reasons for the missing data are known, data cannot be considered missing *completely* at random, despite Little's MCAR value being significant. Rather, data can be considered statistically missing at random (MAR), suggesting that there is no predictable pattern of missingness that might influence the outcome of the results.

Dealing with Missing Data: Maximum Likelihood Estimation

There has been a recent interest in relying on statistical software that estimates means and variances of a dataset based on the underlying pattern of missing data. In structural equation modeling, the most widely used statistical criterion is the maximum likelihood (ML) algorithm (Byrne, 2010). ML is the statistical process of identifying parameter estimates, by determining estimates that maximize the likelihood that the sample data are from a normal population. All of the estimates are calculated simultaneously; therefore, the estimation process is considered to be a full-information method, and is also referred to as Full Information Maximum Likelihood (FIML; Kline, 2005).

The AMOS (Analysis of Moment Structure) software relies on the ML approach to deal with missing data in modelling. Mueller and Hancock (2010) provide a rule of thumb for using ML, which suggests that there should be at least five cases per model parameter for ML to be considered trustworthy. Given that the current sample had a maximum of 39 model parameters in the confirmatory factor analyses for Goal #1, the sample of 196 participants was considered reasonable. When conducting the full latent variable models for Goal #2, there were 50 parameters for the sample of 196 participants, resulting in limited power of the models.

Testing Assumptions

Normality. Analyses of skewness and kurtosis in SPSS demonstrated that WCST Errors, Trails A, and Trails B tests had non-normal data. Outliers from WCST were removed, which provided a normal distribution for the WCST Errors test. The ranges of standardized scores were restricted for Trails A and B using the winsorization method, which resulted in a normal distribution of data. Normality of the sample of children was assessed, based on factors of Age at Stroke and Age at Testing. The distribution of Age at Stroke is positively skewed, such that 38% of children in the sample had strokes before the age of 1 year (see Appendix B), while the distribution of Age at Testing is normal (see Appendix D). These factors need to be taken into consideration when making inferences about the effects of the predictors on the outcome variables.

Multicollinearity. The correlations among all variables of interest in the model were calculated. Although Tabachnik and Fidell (2001) consider a correlation above r = .90 to be a sign of multicollinearity between two variables, Meyers, Gamst, and Guarino (2006) caution against including variables with a correlation above r = .80. Because the

WCST Numbers of Errors and Number of Perseverative Errors variables were above the recommended cutoff (*r* = .859), there was concern about the possibility of multicollinearity in the model. As a result, the WCST Perseverative Errors variable was not included in the analysis; instead, only the WCST Number of Errors variable (standardized score) and the Number of Categories variable (raw score) were analysed; these variables had a more reasonable correlation (*r* = .766). None of the other independent variables were correlated above the *r* = .80 cutoff.

Severity of Injury

In order to examine the severity of impairment across ages, a Pearson correlation was conducted between the Full Scale IQ (FSIQ) scores and three age factors (Age at Stroke, Age at Testing, and Time since Stroke). Of the 196 children in the sample, 41 had FSIQ scores below the average range (in the Borderline to Extremely Low ranges), while 27 of the children had FSIQ scores above the average range (ranging from High Average to Very Superior). Results of the Pearson correlation suggested that there was not a significant correlation between FSIQ and Age at Stroke (*r* = .149, *ns*), nor was there a significant correlation between FSIQ and Age at Testing (*r* = -.102, *ns*). There was, however, a significant correlation between FSIQ and Time since Stroke (*r* = -.276, *p* =.000).

The findings of this analysis of severity suggest that the longer the time since a child's stroke, at their most recent testing, the lower their FSIQ tends to be. The negative correlation exists despite a lack of significant relationship between severity and Age at Stroke as well as severity and Age at Testing. This finding provides support for the theory that children tend to grow into their impairments. Despite potential gains in raw scores on the IQ tests as the children develop, they may demonstrate a decrease in standardized scores over time as the gap in development of skills increases between the child and his or her peers. In the subsequent analyses, the relationship between FSIQ and Time since Stroke was taken into consideration.

In addition to examining the relationship with FSIQ, a Pearson correlation was conducted between an overall Attention Composite and three age factors (i.e., Age at Stroke, Age at Testing, and Time since Stroke). The Attention Composite was calculated by taking the mean standardized score for each of the tests of attention. Of the 196 participants included in the sample, 16 children had an Attention Composite score in the Mildly to Moderately impaired range ($z \leq -1.0$).

Once an overall Attention Composite was determined for each child, the scores were correlated with the three age factors. There was no significant correlation between the Attention Composite and Age at Stroke ($r = .119$, *ns*), nor was there a significant correlation between the Attention Composite and Age at Testing ($r = -.045$, *ns*). There was, however, a significant negative correlation between the Attention Composite and Time since Stroke ($r = -.194$, $p = .008$). Once again, this finding appears to support the theory that children tend to grow into their impairments, such that a child's overall attention abilities may continue to decrease the longer it has been since the child's stroke.

CHAPTER 4

Goal #1: Confirmatory Factor Analysis

Method

The first goal of the investigation was to identify whether a three- or four-factor model of attention best fit a sample of children with AIS. Confirmatory Factor Analysis

(CFA) was used to test the fit of the models, using the AMOS software. The first step in the analysis was to test the validity of the two measurement models, prior to evaluating the structural model. CFA was used to test the validity of the factors under consideration, determining the extent to which observed variables (i.e., performance on tests of interest) represent the underlying factors under consideration (Byrne, 2010). Once a model was identified, the next step in the process of assessing model fit was to examine the significance of the parameter estimates. In order for the model to the considered properly specified, the nonsignificant paths of the parameters were removed prior to determining fit (based on Byrne, 2010).

Byrne outlined the most important goodness-of-fit statistics as: CMIN/DF (< 3.0 = good fit); NFI (between 0-1 is good fit); CFI (> .95 is good fit, .80-.95 is reasonable fit); RMSEA (< .05 is good fit, .05-.10 is reasonable fit, > .10 is bad fit); and PCLOSE (> .05 is good fit). Ideally, the probability of the model will be nonsignificant ($p > .05$); however, this is a rare occurrence with a relatively large sample size (Byrne, 2010).

In order to replicate the three- and four-factor models of attention, a combination of tests used in the development of the original models were considered. In order to represent Mirsky's model of attention, the tests used in Mirsky's (1991) original factor analysis were included (see Appendix H for a list of Mirsky's original factors). For the tests that were not available in the present sample, assessment measures deemed to be theoretically equivalent (based on the test descriptions outlined in Appendix A) were selected for analysis. See the Introduction subheading entitled *Mirsky's Four-Factor Model of Attention* (p. 9) for a discussion of the original tests used, as well as theoretically equivalent tests that have been more recently developed. A set of tests were also selected to represent aspects of attention outlined in Posner's model (based on descriptions by Posner & Rothbart, 2007, and Manly et al., 2001). See the Introduction subheading entitled *Posner's Three-Factor Model of Attention* (p. 6) for a discussion of the tests purported to measure aspects of Posner's attention.

In the current study, all tests of interest were combined in the factor analyses. The final tests of attention included in the present study were: Trail Making Test A (Trails A) and Trail Making Test B (Trails B), Stroop Inhibition test (Stroop), Wisconsin Card Sorting Test Number of Errors variable (WCST Errors) and Number of Categories variable (WCST Categories), Coding, Digit Span, Letter-Number Sequencing, Test of Everyday Attention for Children (TEA-Ch) Sky Search Attention (SS), Sky Search Dual Task (SS DT), and Score! subtests.

Results

Three-factor model of attention. In an attempt to best replicate the three-factor model of attention described by Posner, three iterations of the model were analyzed, ultimately maximizing the fit. When the originally selected tests of attention were first analyzed (see Table 2), the model was not identified, due to a Heywood Case (i.e., negative error variance), for the WCST Errors variable. Respecification of the model was therefore required. Error variance for the WCST Errors variable was constrained, based on the reliability estimate of WCST Errors. Given the reliability coefficient of WCST Errors ($\alpha = .71$; Heaton, Chelune, Talley, Kay and Curtiss, 1993), the residual variance is 29%. The residual variance was multiplied by the variance of the WCST Errors variable in the model (49.62), to determine the error variance (14.39). The error variance was then assigned to the WCST Errors variable.

Table 2

Factor Matrix for the Original Three-Factor Model of Attention (Posner)

Orient	Alert	Executive
TEA-Ch SS	TEA-Ch Score!	Stroop
Trails A	TEA-Ch SS DT	WCST Errors
Trails B	Digit Span	WCST Categories
Coding	Letter-Number Sequencing	

The respecified model was subsequently analyzed, and was considered to be properly identified. With respect to model fit, however, none of the Executive Attention factor parameters had significant estimates, suggesting that some (or all) of the variables did not load well on the Executive Attention factor. In an attempt to better fit the three-factor model, the Stroop test was moved to the Orient factor of attention (based on evidence from Manly et al., 2001), instead of the Executive Attention factor as proposed by Posner. The resulting three-factor matrix, updated based on Manly's (2001) description of a three-factor model of attention, can be found in Table 3.

Table 3

Factor Matrix for the Final Three-Factor Model of Attention (Manly)

Focus_Select	Sustain_Vigilance	Switching_Control
TEA-Ch SS	TEA-Ch Score!	WCST Errors
Trails A	TEA-Ch SS DT	WCST Categories
Trails B	Digit Span	
Coding	Letter-Number Sequencing	
Stroop		

The respecified model – based on Manly's descriptions of the three factors – was subsequently analyzed and the model was identified. All of the parameter estimates were feasible and statistically significant in the third iteration of the model (see Table 4 for a description of parameter estimates from the three-factor model). The goodness-of-fit statistics suggest that the model has a relatively good fit overall; some of the statistics represent a reasonable fit (p = .016; CFI = .943; RMSEA = .052), while others represent a good fit (CMIN/DF = 1.526; NFI = .859; PCLOSE = .425). There is no evidence of model misfit (see Figure 1 for a representation of the three-factor model of attention).

Four-factor model of attention. A four-factor model of attention was determined based on Mirsky's (1991) factor analysis (see Table 5 for the four-factor matrix). The error variance for the WCST Errors variable was constrained to 14.39 in this model, consistent with the previous three-factor model. A single iteration of the model was needed in order to be specified. The four-factor model was analyzed using CFA and the model was identified. All of the parameter estimates were feasible and statistically significant (see Table 6 for a description of parameter estimates for the four-factor model). The goodness-of-fit statistics suggest that the model has a relatively good fit overall; some of the statistics represent a reasonable fit (p = .019; CFI = .948; RMSEA = .052), while others represent a good fit (CMIN/DF = 1.521; NFI = .870; PCLOSE = .431). There is no evidence of model misfit (see Figure 2 for a representation of the four-factor model).

Table 4

Parameter Estimates for the Three-Factor Model of Attention

Parameters			Unstandardized Estimates	Standard Error	Standardized Estimates
			Factor Loadings		
TEA-Ch SS	←	Focus_Select	1.000[a]	---	0.621
Stroop	←	Focus_Select	1.182***	0.287	0.712
Coding	←	Focus_Select	1.1***	0.223	0.732
Trails B	←	Focus_Select	0.475***	0.099	0.668
Trails_A	←	Focus_Select	0.406***	0.083	0.658
TEA-Ch Score!	←	Sustain_Vigilance	1.000[a]	---	0.405
TEA-Ch SS DT	←	Sustain_Vigilance	1.539**	0.563	0.513
Digit Span	←	Sustain_Vigilance	1.97***	0.579	0.858
Letter-Number	←	Sustain_Vigilance	1.759**	0.537	0.763
WCST Categories	←	Switching_Control	1.000[a]	---	0.832
WCST Errors	←	Switching_Control	8.864***	0.695	0.950
			Variances and Covariances		
Focus_Select			4.917**	1.739	
Sustain_Vigilance			2.000	1.167	
Switching_Control			1.711***	0.334	
			Errors		
err10			14.390[a]	---	
err5			7.85***	1.343	
err4			6.669***	1.502	
err3			5.16***	0.947	
err2			1.377***	0.232	
err1			1.063***	0.171	
err9			10.173***	1.519	
err8			13.263***	2.355	
err7			2.773**	0.846	
err6			4.431***	0.824	
err11			0.758***	0.129	

* $p \leq .05$. ** $p \leq .01$. *** $p = .00$. [a] not tested for significance.

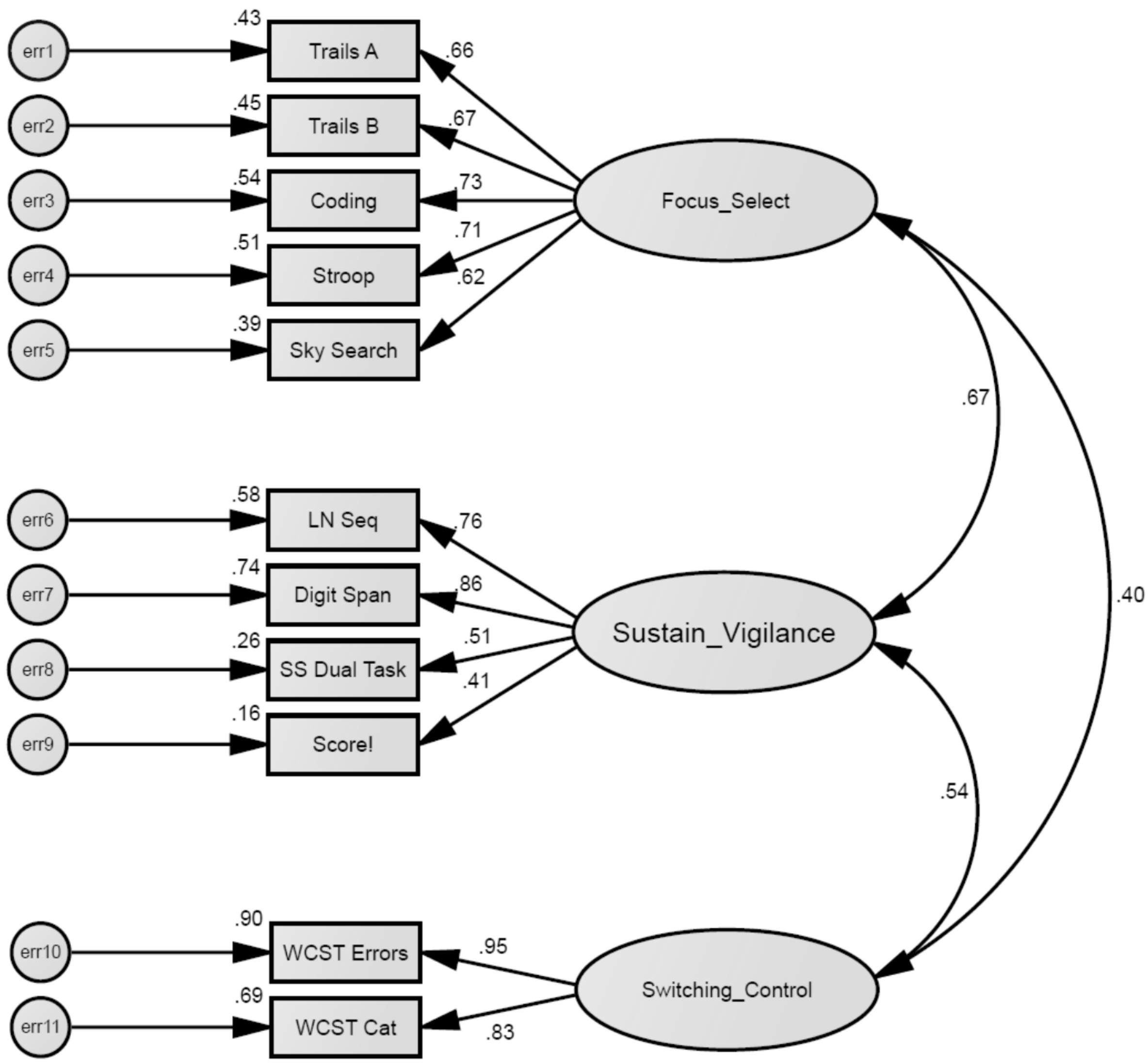

Figure 1. Three-factor model based on Manly's model of attention.

Table 5

Tests of Attention Used for the Four-Factor Model (Mirsky)

Focus/Execute	Sustain	Shift	Encode
Coding	TEA-Ch Score!	WCST Errors	Digit Span
Stroop	TEA-Ch SS DT	WCST Categories	Letter-Number
Trails A			
Trails B			
TEA-Ch SS			

Table 6

Parameter Estimates for the Four-Factor Model of Attention

Parameters			Unstandardized Estimates	Standard Error	Standardized Estimates
			Factor Loadings		
Stroop	←	Focus_Execute	1.000[a]	---	0.721
Coding	←	Focus_Execute	0.92***	0.174	0.734
TEA-Ch SS	←	Focus_Execute	0.835***	0.200	0.623
Trails B	←	Focus_Execute	0.388***	0.087	0.654
Trails A	←	Focus_Execute	0.338***	0.077	0.657
TEA-Ch Score!	←	Sustain	1.000[a]	---	0.509
TEA-Ch SS DT	←	Sustain	1.602**	0.563	0.679
WCST Categories	←	Shift	1.000[a]	---	0.830
WCST Errors	←	Shift	8.881***	0.698	0.950
Arithmetic	←	Encode	1.289***	0.256	0.777
Digit Span	←	Encode	1.000[a]	---	0.753
			Variances and Covariances		
Focus_Execute			7.057**	2.537	
Sustain			3.108**	1.601	
Shift			1.679***	0.325	
Encode			6.015***	1.492	
			Errors		
err8			14.390[a]	---	
err5			6.527***	1.503	
err4			5.126***	0.939	
err3			7.776***	1.333	
err2			1.416***	0.234	
err1			1.063***	0.172	
err7			8.898***	1.637	
err6			9.298**	3.032	
err9			0.761***	0.130	
err11			6.562**	2.163	
err10			4.586***	1.170	

* $p \leq .05$. ** $p \leq .01$. *** $p = .00$. [a] not tested for significance.

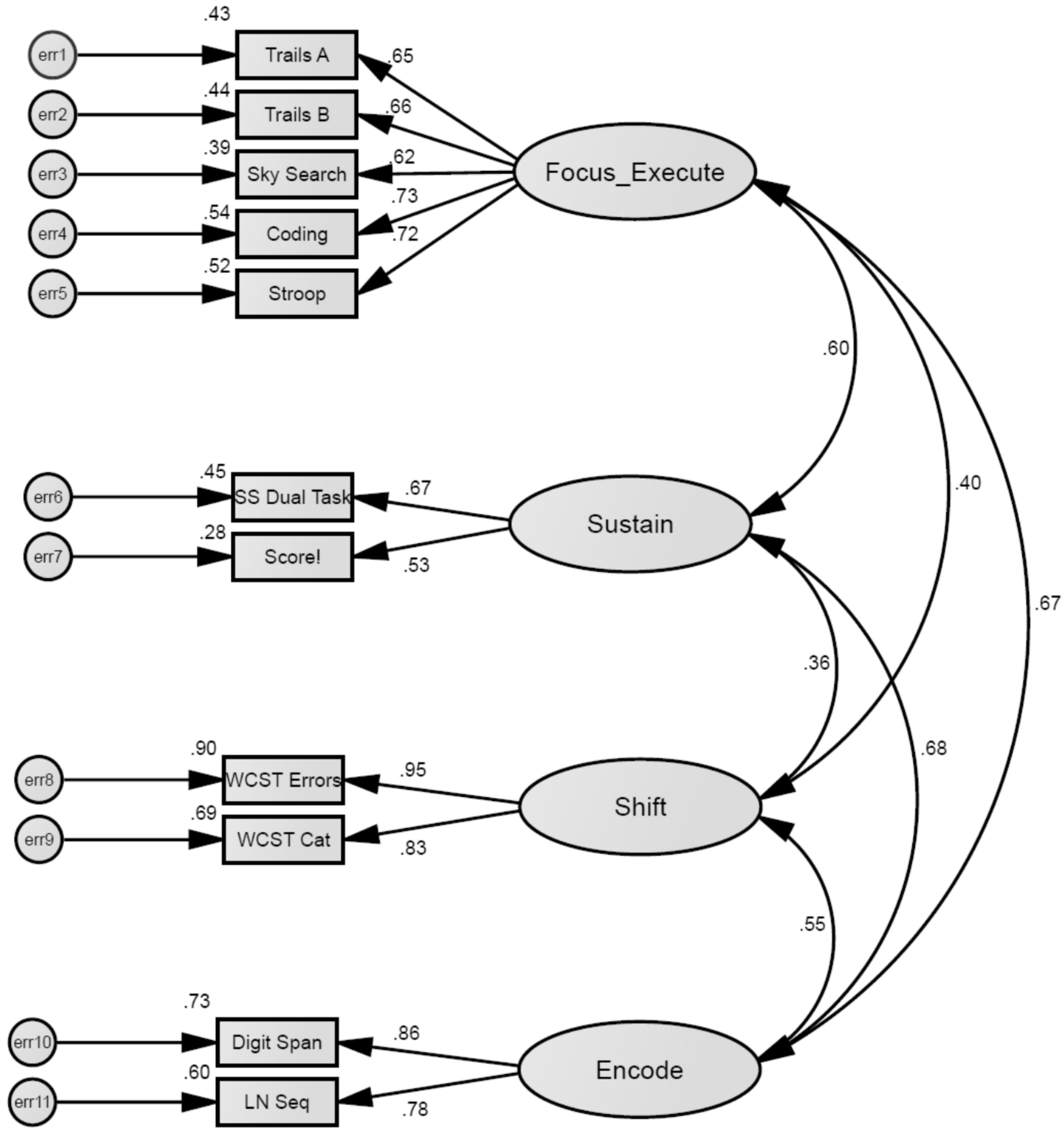

Figure 2. Four-factor model of attention based on Mirsky's model.

Discussion

Two prominent theories of attention were compared using a sample of children with AIS. A three-factor model and a four-factor model were analyzed using confirmatory factor analysis (CFA) and the parameter estimates and fit statistics were compared. The three-factor model representing Posner's theory of attention did not fit with the given data. However, a similar three-factor model proposed by Manly et al. (2001) did fit the data reasonably well. The four-factor model of attention described by Mirsky also had a reasonable fit with all of the tests of interest. Although the three- and four-factor models of attention had equivalent fit indices, the four-factor model was more consistent with the theoretical constructs, neuroanatomical substrates, and developmental processes related to the attentional factors under consideration, as discussed below.

Posner's three-factor model did not represent a good fit with the data. The primary difficulty with Posner's model was that none of the tests included in the Executive Attention factor had significant parameter estimates with the factor of attention they were considered to be representing. Posner and his colleagues (2007) have suggested that Executive Attention is represented by attention measures such as the Stroop Inhibition test. Kavros et al. (2008) stated that the Wisconsin Card Sorting Test (WCST) would fall under the same factor of Executive Attention. However, in the current investigation, the Stroop test and the WCST subtests were not significantly correlated with one another; small, nonsignificant correlations were identified between Stroop and both WCST Errors (r = .215, *ns*) and WCST Categories (r = .186, *ns*). These findings suggested that Stroop test and the WCST subtests do not load onto the same factor, and therefore do not both represent Posner's factor of Executive Attention.

When Manly and colleagues (2001) were establishing their Test of Everyday Attention for Children (TEA-Ch), they examined some of the most traditional neuropsychological tests used to measure attention and determined their relationship both to one another and to the newly developed subtests of the TEA-Ch. Although their terminology varied, Manly and colleagues identified a three-factor model of attention that maps onto Posner's original three-factor model. Manly referred to the three factors as: 1) Focus/Selective Attention; 2) Sustained Attention/Vigilance; and 3) Attentional Control/Switching. Manly and colleagues found that although the WCST subtests loaded on the Attentional Control/Switching factor of attention (similar to Posner's Executive Attention), the Stroop test had a higher correlation with tests of Focus/Selective Attention (similar to Posner's Orient), such as the Trail Making Test (see Table 4 for the factors of attention represented by Manly's three-factor model). In the current investigation, when the Stroop test was moved to the factor equivalent to Manly's Focus/Selective Attention and Posner's Orient, the model represented a good fit for the data. In fact, the fit statistics were comparable (showing nearly identical values) to those found when replicating Mirsky's four-factor model.

Given that the two models (i.e., Manly's three-factor and Mirsky's four-factor models) fit the data equally well, the question becomes: why separate out the factors of attention to create a four-factor model if a more parsimonious, three-factor model is available? In other words, do the four factors represent a more accurate description of different theoretical functions, or an unnecessary elaboration of the three-factor model? These questions can be addressed by interpreting the current findings in light of psychometric, neuroanatomical, and developmental perspectives.

One possibility for the equivalence among models in terms of fit indices is that the three-factor model is simply a condensed version of the four-factor model, such that Manly's Alerting/Sustained attention factor represents a combination of Mirsky's Sustain and Encode factors. In order to make this judgment, the theoretical constructs of the psychometric tests considered to be responsible for the factors of attention were considered. One of the primary theoretical differences between Sustain and Encode, as defined by Mirsky, is that Sustain is a process of vigilance (i.e., sustaining attention over time), while Encode is considered to be equivalent to working memory, which involves holding the information in mind in order to work with it in some way. Vigilance and working memory are arguably very different cognitive processes that should be measured by tests specific to their underlying attentional constructs. This conclusion is consistent with the four-factor model, which suggests that Sustain and Encode are individual factors, representing unique aspects of attention.

The neuroanatomical correlates of the attentional network can also be taken into account in order to guide the selection of the three- vs. the four-factor model of attention. Posner and his colleagues have reported that Alerting attention is regulated by the prefrontal and lateral parietal cortical regions, as well as subcortical structures, such as the locus coeruleus (a nucleus in the pons of the brainstem) and the thalamus (a structure at the base of the cerebral hemispheres that projects to the cortex). Similarly, Manly and colleagues suggested that the prefrontal regions are primarily responsible for regulation of sustaining attention or maintaining vigilance. Mirsky's Sustained attention was originally reported to be regulated by structures of the brainstem, such as the tectum and mesopontine regions of the reticular formation, as well as the thalamic nuclei. However, Koziol et al. (2014) have since outlined the literature suggesting that the dorsolateral prefrontal cortex, the ventral medial frontal cortex, and several subcortical structures (i.e., basal ganglia, striatum, globus pallidus, and thalamus) have all been associated with sustained attention.

The findings from the studies, demonstrating neuroanatomical correlates of attentional processes, suggest some overlap in the structures responsible for the *vigilance* aspect of attention found in both the three-factor models (e.g., Posner's Alert, Manly's Sustained Attention), and the four-factor models (e.g., Mirsky's Sustain). In fact, Mirsky et al. (1991) concluded that the Sustain factor of attention is similar to Posner's Alerting attention (or what Manly referred to as Sustained Attention/Vigilance), because the sustained attention processes rely on areas of the brainstem and the medial thalamic region.

Koziol et al. (2014) suggested that the neuroanatomical substrates of Encode make up a network that includes neuroanatomical structures connected through the Fronto-Parietal Network (FPN; including the dorsolateral prefrontal cortex, inferior parietal lobe, anterior cingulate cortex, cerebellum, and the medial occipital cortex). As the demands of the attentional task change – Koziol and colleagues (2014) report – the brain regions within the FPN appear to rapidly update their functional patterns of connectivity.

There appears to be some overlap between the structures involved in both Encoding and Sustained Attention (e.g., both have some involvement of the dorsolateral prefrontal cortex), a finding consistent with the theory that attention is a network of interrelated structures and cognitive processes. Evidence for the distinction between factors of Encoding and Sustained Attention comes from the fact that there are exclusive neuroanatomical structures that only appear to be responsible for the activation of certain attentional processes and not others. For example, the subcortical structures (e.g., basal ganglia, thalamus, etc.) appear to play a role in Sustained Attention, but not in the Encoding attention, which involves a network of largely cortical structures. This dissociation suggests that the two constructs are separable based on a functional neuroanatomical perspective.

When examining individual factors of attention in children it is also important to consider the developmental context. Given that aspects of Encode (or working memory) and Sustained Attention (or vigilance) are mediated by different neuroanatomical regions, these neurological structures are also expected to be established at varying stages throughout a child's development. Processes that are moderated by a network that includes subcortical cerebral structures (i.e., Sustained Attention or vigilance) are reportedly the earliest to develop in a child's life (Richards, 2004). In contrast, processes mediated primarily by the cortical structures (i.e., Encode or working memory) develop later in life and are not entirely established early in childhood (Rueda et al., 2004). The development of Encode is therefore distinct from the development of Sustained Attention, which is controlled by earlier developing cerebral structures. The evidence demonstrating that factors of Sustain and Encode are established at different stages in development suggests that the four-factor model of attention (which delineates these two factors) is a better representation of the attentional network than a three-factor model.

Thus, when examining 1) the theoretical constructs of the tests traditionally used to evaluate attentional processes; 2) the neuroanatomical correlates responsible for the development and activation of the factors of attention; and 3) the development of individual factors of attention over time, a strong case can be made for the argument that Mirsky's Encode and Mirsky's Sustain/Manly's Vigilance represent two unique factors of attention, rather than representing a variety of tests of attention that are grouped together within Posner's Sustain factor. Therefore, the four-factor model can be considered the best representation of the attentional network.

Challenges and Further Considerations. Despite the evidence suggesting that the four-factor model best represents attention in this sample, there were a number of challenges encountered throughout this investigation that may have influenced the findings. First, there is considerable conceptual overlap in the literature about what constitutes attention, working memory, and executive functioning (Klenberg, Korkman, and Lahti-Nuuttila, 2001). Certain neuropsychological tests are considered to be measures of attention by some and executive functioning (or even aspects of memory) by others. In the current sample, the WCST scores did not load well with other factors in the models of interest. An argument can be made that the WCST is not truly a test of attention and therefore does not load well with the other measures of attention. Through the process of model specification, it was determined that the models with the fit best (i.e., those with equivalent fit to one another) were those in which WCST subscales represented an exclusive factor (i.e., Mirsky's Shift or Manly's Attentional Control/Switching). The finding that the WCST did not load well with the Stroop subtests may suggest that Stroop and WCST are tapping into different cognitive processes altogether, such as attention and executive functioning for example, and therefore should not both be considered measures of attention.

Executive attention is considered to be a measure of response inhibition, attentional control, switching, shifting, and conflict resolution (Posner, 2007; Manly, 2001; Anderson et al., 2001). The WCST is, by definition, a measure of executive function, requiring strategic planning, searching, relying on feedback to shift cognitive set, and inhibiting impulsive behaviour (Strauss, Sherman, & Spreen, 2006). Although there is a significant overlap between executive aspects of attention and the definition of executive functioning, there appears to be an added problem-solving or metacognitive component to the WCST that exceeds the definitions of attentional functioning.

As Anderson et al. (2001) described, executive functions make up several factors, including attention control (i.e., selective and sustained attention), cognitive flexibility (i.e., working memory, shifting attention, and self-monitoring), and goal setting (i.e., initiating, planning, problem-solving). Therefore, executive functions encompass some (but not all) factors of attention. For instance, Klenberg et al. (2001) found that although inhibition, attention, and executive functions are highly interrelated cognitive processes, their developmental trajectories are separate from one another, identifying them as unique aspects of cognition. As the investigators noted, there is a lack of conceptual clarity throughout the research on the development of attentional and executive functions. There appears to be significant overlap across the concepts, which makes it difficult to distinguish between them in order to operationalize and measure attentional or executive functions.

Given Anderson's (2001) argument that the WCST is not a measure of attention after all, but more of a pure executive functioning task, one could argue that Posner's three-factor model of attention would be theoretically sound, as long as the WCST subtests did not represent aspects of Executive Attention. In fact, in the current investigation, when the Stroop Inhibition and Switching subtests from the D-KEFS were substituted for the WCST Errors and Number of Categories in Posner's model, the fit estimates were reasonable, suggesting that Posner's three-factor model represents the data of interest, as long as WCST is not included in the model.

Difficulties with testing the models in the current investigation arose as several issues with the data from the WCST subtests were encountered, which resulted in problems initially identifying the models. One issue was multicollinearity among the subscales of the WCST (i.e., between the Number of Errors and Number of Perseverative Errors variables), which was eliminated by removing the Number of Perseverative Errors variable and replacing it with the Number of Categories achieved, a variable that taps into different aspects of the WCST. Another issue that arose in the analysis was the negative error variance of the WCST Errors variable, which was subsequently constrained in order to identify the model.

One possible explanation for the challenges with the negative error variance is that the range of responses in the WCST was not as wide as that of other tests, and there was a much higher variance in the WCST scores. It is possible that the subtests of the WCST do not fit with the sample because the data specific to the WCST are not missing at random. In fact, the WCST is rarely given to young children, likely due to the fact that executive aspects of attention are not expected to be developed before the age of 10 years (Rueda et al., 2004). When looking at the sample of 196 participants, the age at testing ranges from 3.42 through 23. 26 years of age for the entire sample (i.e., a 19 year range), with a mean of 11.50 years, a median of 10.94 years, and a mode of 7.32 years (see

Appendix E). When examining the WCST data in isolation, however, the age at testing ranges from 6.88 through 23.26 years (i.e., a 16 year range), with a mean of 13.05 years, a median of 13.13 years, and a mode of 17 years, which is much higher than the mode of the entire sample. Unfortunately, the restricted age range within this set of data is a factor of using archival data.

Despite the challenges presented within the data, the analyses demonstrated that both a three- and four-factor model of attention were identified, and therefore both effectively represented the data from the group of children with AIS. In reference to the competing theories of attention, Mirsky et al. (1991) suggested that:

> The nature of the neuropsychological model of attention that is created depends upon the behavioural data that are used to generate it. Since all these conceptions deal with fundamentally the same database, there is a fair degree of communality among them; the differences seem to be a function of which part of the database the authors have chosen to emphasize (p. 140).

Given that the emphasis, in the present investigation, was on the theoretical constructs measured by various neuropsychological tests, the unique neuroanatomical correlates associated with each attentional process, and an understanding of the development of attentional networks throughout childhood, the four-factor model was determined to be the best fit for the data. As such, the data suggest that performance on the four factors of attention can be used to examine predictors of outcome in a clinical sample of children with AIS.

CHAPTER 5

Goal #2: Full Latent Variable Model

Method

The second goal of the investigation was to determine whether Age at Stroke or Age at Testing are predictors of outcome on factors of attention, and whether the predictors modify the relationship with one another within the model. Given that the four-factor model of attention was determined to be the best fit for the data in Goal #1, the second goal was to determine the full latent variable model, including both the measurement model (i.e., the previously determined factor analytic model) and the structural model (i.e., the predictor variables included for regression). This process first involved examining Age at Stroke as a predictor for each factor of attention. Secondly, Age at Stroke was considered a predictor of each factor of attention while controlling for Age at Testing.

Although the control variable of interest is Age at Testing (given that aspects of attention are established at different ages) there was concern that examining both Age at Stroke and Age at Testing within the model may result in significant multicollinearity among the variables, as they both represent an individual's age. Time since Stroke (a variable representing number of years, but not age) was thus included in the model to control for Age at Testing. Age at Testing was also examined as a predictor of outcome on each factor of attention. In the final step Age at Testing was considered as a predictor of outcome while controlling for Age at Stroke, by including Time since Stroke as the control variable.

In summary, four versions of the full latent variable model were considered in Goal #2: 1) Age at Stroke as a predictor of attention; 2) Age at Stroke as a predictor of attention while controlling for Age at Testing; 3) Age at Testing as a predictor of attention; and 4) Age at Testing as a predictor of attention while controlling for Age at Stroke.

Results

When Age at Stroke was included as a predictor variable, the model was identified (Figure 3). The parameter estimates between Age at Stroke and the attention factors are found in Table 7. There was a significant positive relationship between Age at Stroke and Shift. In addition, there was a significant positive relationship between Age at Stroke and Encode. Neither Focus/Execute nor Sustain were significantly predicted by Age at Stroke.

Table 7

Parameter Estimates of Age at Stroke from the Structural Equation Model for the Four-Factor Model of Attention with Age at Stroke as a Predictor

Parameters			Unstandardized Estimates	Standard Error	Standardized Estimates
Factor Loadings					
Focus_Execute	←	Age at Stroke	0.002	0.047	0.005
Sustain	←	Age at Stroke	0.077	0.060	0.239
Shift	←	Age at Stroke	0.509*	0.200	0.229
Encode	←	Age at Stroke	0.089*	0.046	0.166

* $p \leq .05$. ** $p \leq .01$. *** $p = .00$. [a] not tested for significance.

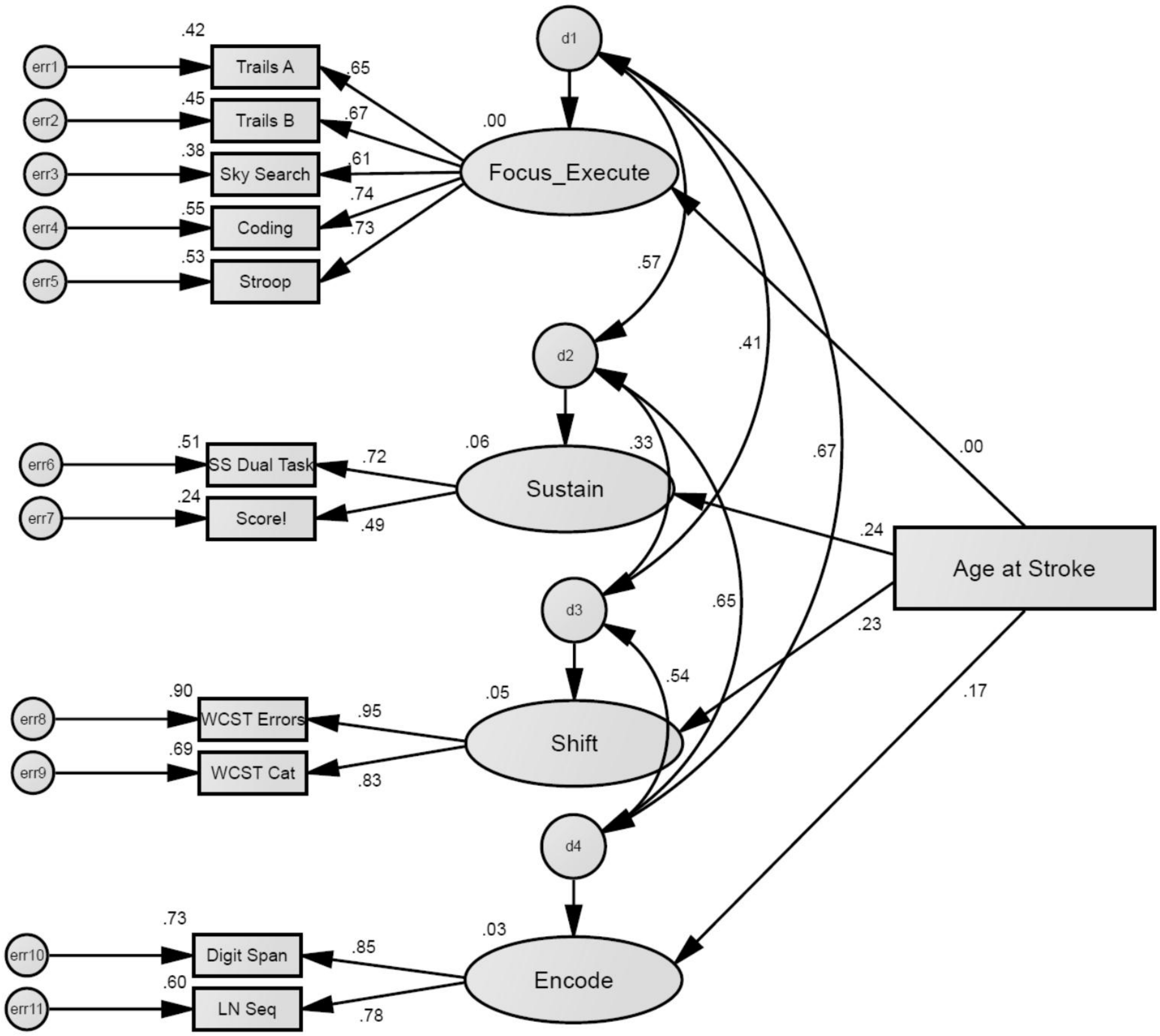

Figure 3. Structural equation model of four-factor model of attention with Age at Stroke as predictor variable.

To control for the effects of the child's Age at Testing, the model was analyzed with both Age at Stroke and Time since Stroke as predictor variables (see Figure 4). When the two predictor variables were included, the model was identified; however, there were 50 parameter estimates in the model, suggesting that the total power would be limited if one attempted to interpret model fit statistics. The parameter estimates between Age at Stroke and the four factors of attention, when Age at Testing was controlled for, can be found in Table 8. There was a slight increase in the parameter estimate between Age at Stroke and Shift, with the relationship remaining significant. The relationship between Age at Stroke and Focus/Execute became significantly more pronounced; when controlling for Age at Testing, there is a significant negative relationship between Age at Stroke and Focus/Execute. The relationship between Age at Stroke and Encode decreased, and is no longer significant when controlling for Age at Testing. The relationship between Age at Stroke and Sustain remained nonsignificant, even after controlling for Age at Testing.

Table 8

Parameter Estimates of Age at Stroke from the Structural Equation Model for the Four-Factor Model of Attention with Age at Stroke as a Predictor while Controlling for Age at Testing

Parameters		Unstandardized Estimates	Standard Error	Standardized Estimates
	Factor Loadings			
Focus_Execute	← Age at Stroke	-0.131 *	0.064	-0.248
Sustain	← Age at Stroke	0.034	0.082	0.107
Shift	← Age at Stroke	0.094 **	0.035	0.357
Encode	← Age at Stroke	0.008	0.059	0.017

* $p \leq .05$. ** $p \leq .01$. *** $p = .00$. [a] not tested for significance.

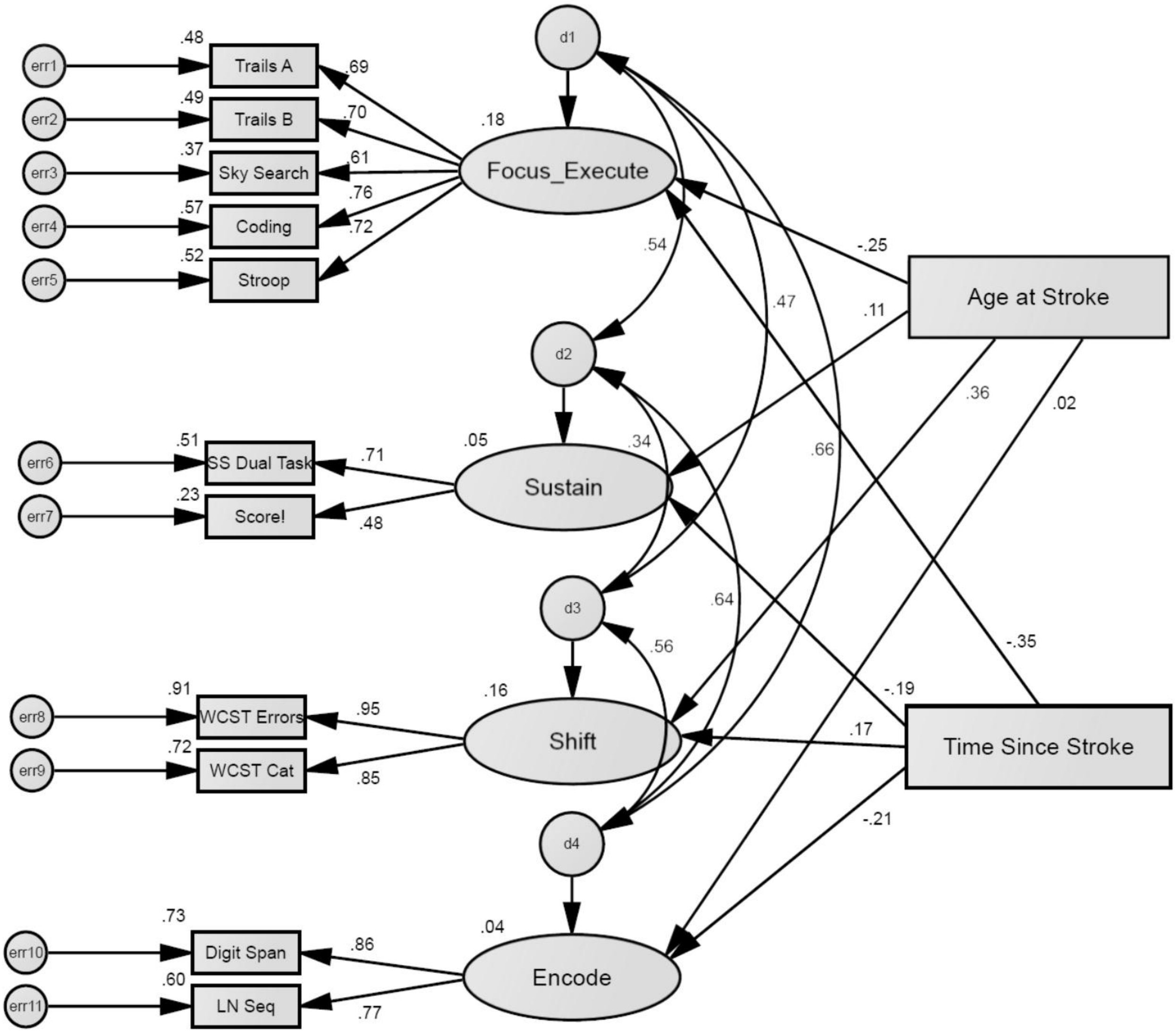

Figure 4. Structural equation model of four-factor model of attention with Age at Stroke and Time since Stroke as predictor variables.

When the model was analyzed with Age at Testing as a single predictor variable, the model was identified (see Figure 5). The parameter estimates for the relationships between Age at Testing and the four factors of interest can be found in Table 9. There was a significant positive relationship between Age at Testing and Shift. There was a significant negative relationship between Focus/Execute and Age at Testing. Neither Encode nor Sustain was significantly predicted by Age at Testing as the sole predictor variable.

Table 9

Parameter Estimates of Age at Testing from the Structural Equation Model for the Four-Factor Model of Attention with Age at Testing as a Predictor

Parameters			Unstandardized Estimates	Standard Error	Standardized Estimates
			Factor Loadings		
Focus_Execute	←	Age at Testing	-0.147*	0.066	-0.222
Sustain	←	Age at Testing	-0.008	0.085	-0.018
Shift	←	Age at Testing	0.091**	0.035	0.274
Encode	←	Age at Testing	-0.007	0.061	-0.010

* $p \leq .05$. ** $p \leq .01$. *** $p = .00$. [a] not tested for significance.

To control for the effects of the child's Age at Stroke, the model was analyzed with both Age at Testing and Time since Stroke as predictor variables (see Figure 6). When the two predictor variables were included, the model was identified; however, there were 50 parameter estimates in the model, suggesting that the total power would be limited if one attempted to interpret model fit statistics. The parameter estimates between Age at Testing and the four factors of attention, when Age at Stroke was controlled for,

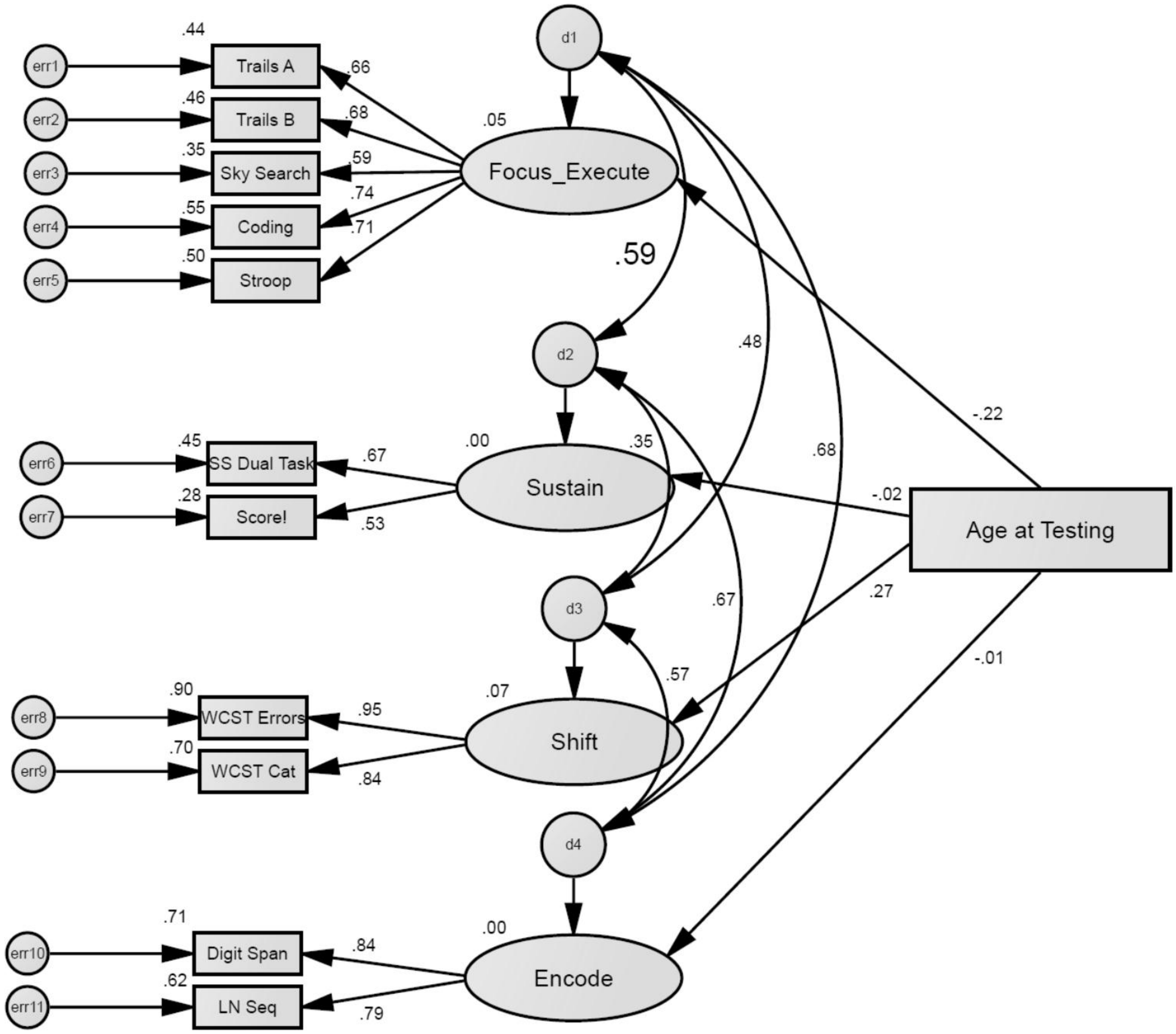

Figure 5. Structural equation model of four-factor model of attention with Age at Testing as predictor variable.

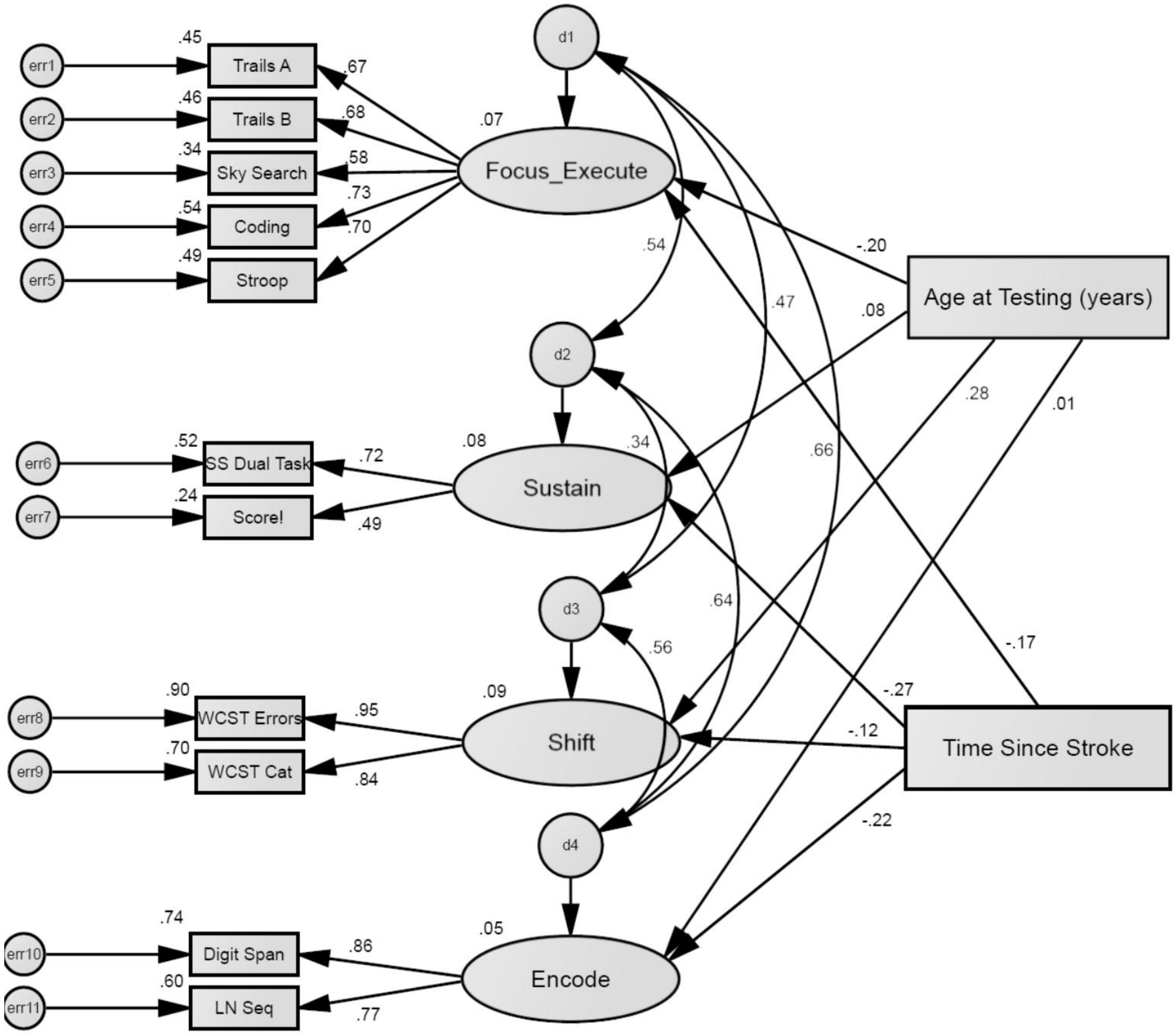

Figure 6. Structural equation model of four-factor model of attention with Age at Testing and Time since Stroke as predictor variables.

can be found in Table 10. The parameter estimate between Age at Testing and Shift remained significant; there was no change in the estimate values or the level of significance when Age at Stroke was controlled for. The negative relationship between Focus/Execute and Age at Testing also remained significant; there was no change in the estimate values or the level of significance when Age at Stroke was controlled for. Although the estimates for Sustain and Encode increased slightly when Age at Stroke was controlled for, neither factor was significantly predicted by Age at Testing.

Table 10

Parameter Estimates of Age at Testing from the Structural Equation Model for the Four-Factor Model of Attention with Age at Testing as a Predictor while Controlling for Age at Stroke

Parameters		Unstandardized Estimates	Standard Error	Standardized Estimates
Factor Loadings				
Focus_Execute	← Age at Testing	-0.131 *	0.064	-0.202
Sustain	← Age at Testing	0.034	0.082	0.08
Shift	← Age at Testing	0.094 **	0.035	0.283
Encode	← Age at Testing	0.008	0.059	0.013

* $p \leq .05$. ** $p \leq .01$. *** $p = .00$. [a] not tested for significance.

Post-Hoc Analyses

In an attempt to begin to tease apart the relationship between different lesion characteristics and the timing of strokes, an analysis of variance (ANOVA) was conducted to compare Age at Stroke to particular lesion characteristics of interest in the stroke literature: severity of injury (single vs. multiple infarcts); laterality (left- vs. right-sided lesions); and lesion location (cortical, subcortical, and combined cortical/subcortical strokes).

There was no main effect of injury severity, $F(2,180) = 2.94$, *ns*; Age at Stroke did not differ significantly for children with single vs. multiple infarcts. There was no main effect of laterality, $F(2,180) = .917$, *ns*; Age at Stroke did not differ significantly for children with strokes localized to the left vs. right cerebral hemisphere. There was, however, a significant main effect of lesion location, $F(2,180) = 6.35$, $p = .002$. A Tukey post hoc test revealed that Age at Stroke was statistically significantly older for children with strokes localized to the subcortical regions ($M = 6.55$, $SD = 5.23$) compared to those with strokes localized to the cortical regions (2.11 ± 4.45 years, $p = .000$) and those with combined cortical and subcortical strokes (4.26 ± 2.29 years, $p = .018$). There was no statistically significant difference between children with cortical strokes ($M = 2.11$, $SD = 4.07$) and those with a combination of cortical and subcortical strokes ($M = 4.26$, $SD = 5.13$), in terms of Age at Stroke (2.11 ± 2.15 years, *ns*).

Discussion

In the present investigation, Age at Stroke and Age at Testing were examined as predictors of outcome on the four-factor model of attention. At one end of the spectrum of cerebral recovery, the vulnerability theory suggests that the young brain is more susceptible to impairment following cerebral insult than an older, more developed brain (Hebb, 1947). As a result, proponents of the vulnerability theory argue that younger Age at Stroke would be associated with greater impairment across factors of attention than later Age at Stroke. As an extension of the vulnerability model, researchers have also suggested that children with early acquired brain injuries tend to grow into their impairments, due to the “snowball” effects of early compromise (McLinden et al., 2007). Following this line of reasoning, children with later Age at Testing would be expected to have the greatest impairment in cognitive abilities. An interaction effect might also be expected between the two age variables, such that children with earlier Age at Stroke who have later Age at Testing would be expected to have the most pronounced deficits in cognitive abilities.

At the other end of the recovery spectrum, proponents of the plasticity theory (based on Kennard’s early findings) argue that the young brain is more amenable to reorganization following cerebral insult than the older brain, given that skills are more likely to be fully established and no longer as plastic in an older child or adult. Based upon the theory of plasticity, children with later Age at Stroke would be expected to have worse outcomes than children with earlier strokes. In order to describe the relationship between Age at Stroke and Age at Testing with the factors of interest in the present investigation, each factor of attention will be considered individually in the following section.

Focus/Execute. Age at Stroke did not significantly predict outcome on Focus/Execute when included in the model as the sole predictor variable (Figure 3); however, when Age at Testing was controlled for (Figure 4), there was a significant negative relationship between Age at Stroke and Focus/Execute. This finding suggests that Age at Testing is modifying the relationship between a child’s Age at Stroke and his or her performance on Focus/Execute. Similarly, Age at Testing had a significant negative relationship with Focus/Execute, whether or not Age at Stroke was controlled for in the model (Figures 5 and 6).

The results demonstrate that younger Age at Stroke is associated with better outcomes on measures of Focus/Execute, regardless of the age of a child at the time of testing. In addition, older Age at Testing is associated with worse outcomes on measures of Focus/Execute. The findings of the present investigation are not consistent with the vulnerability theory, given that Focus/Execute is less vulnerable to insult during the earlier years of life, when the skill is not established or is only in the beginning stages of development. Focus/Execute appears to be more vulnerable to insult later in life, when damage inflicted upon a more mature brain affects the already established skill, or when the stroke occurs during a critical period of development for that skill. The findings may be more consistent with a plasticity theory, such that insult earlier in life does not tend to have a negative impact on the Focus/Execute skills to the same extent as later insult. The Focus/Execute aspect of attention appears to be relatively plastic, and demonstrates resilience following early stroke.

Focus/Execute is argued to fall under the umbrella of speed of processing, which is considered by some to be an executive aspect of attention (Shanahan et al., 2006). Processing speed appears to have a significant influence on an individual's ability to attend to stimuli, and is thought to be mediated by subcortical structures and anterior brain regions (Anderson et al., 2006). Processing speed tends to develop gradually throughout childhood (Anderson et al., 2001; McKay et al., 1994; Rueda et al., 2004), with a sudden increase in proficiency of both processing speed and attention control (as measured through digit span tasks for example) around age 15 years (Anderson et al., 2001).

The findings in the present investigation are consistent with the theory that the skills required for Focus/Execute tasks develop later in childhood, and are therefore more vulnerable to impairment later in childhood or adolescence. As the demands for a particular skill increase over time, it becomes more difficult for a child to compensate for an area of weakness, especially as his or her peers are continuing to make gains and beginning to show skills equivalent to adult levels of proficiency. Perhaps these skills are still plastic earlier in childhood, and impairment prior to the establishment of the skill is not as detrimental as with damage due to later insult that occurs either during the ongoing process of developing or after the establishment of the skill. In addition to vulnerability to later insult, the findings suggest that the later in childhood or adolescence an individual is assessed, the more likely his or her impairments are to be noticeable, as the gap between typically-developing children and those with strokes continues to widen.

Sustain. The Sustain factor of attention was not significantly predicted by Age at Stroke, whether or not Age at Testing was controlled for in the model (Figures 3 and 4). Similarly, performances on measures of the Sustain factor were not significantly predicted by Age at Testing, whether or not Age at Stroke was controlled for in the model (Figures 5 and 6). Taken together, these findings demonstrate that performance on tests of Sustain is not significantly impacted by a child's age at the time of stroke or the time of testing. The finding that Age at Stroke does not predict outcomes on Sustain suggests that impact of an injury to the Sustain factor of attention will be similar, regardless of the age of the child. Sustain does not appear to be particularly vulnerable to early insult, nor is there a greater likelihood of impairment following injury after the establishment of the skill, later in childhood. The theory of plasticity may explain these results, such that

Sustain is not vulnerable to insult, and the brain is able to reorganize in order to spare functioning in this attentional process.

Research has consistently demonstrated that sustained attention, or vigilance, is the earliest developing factor of attention (Rueda et al., 2004). Demands on the Sustain aspects of attention may not increase over time, as would be seen in the more executive aspects of attention. The skill level that a child has achieved early in childhood may not change over time; as a result, Age at Testing would not be related to (i.e., significantly predict) outcome on Sustain.

Shift. When examining the Shift factor of attention, Age at Stroke is a significant predictor of outcome, whether or not Age at Testing is controlled for in the model (Figures 3 and 4). The significant positive relationship found between Shift and Age at Stroke suggests that the older the child is at the time of his or her stroke, the better the child's performance will be on measures of Shift, regardless of his or her age at the time of testing. The findings suggest that the Shift factor may therefore be more vulnerable to early insult than later injury.

Age at Testing is also a significant predictor of Shift, whether or not Age at Stroke is controlled for in the model. This finding suggests that regardless of when a child's stroke occurs, they will tend to have better performance on measures of Shift the later they are tested in childhood or adolescence. The Shift factor of attention tends to be present early in infancy (around 6 to 9 months of age) but the ability to disengage from a particular stimulus slowly improves over time, tending not to be fully established until later in adolescence (Rueda et al., 2004), and therefore children's performance will improve on the tests of shifting attention as they get older and the skills become more solidified. Taken together, the findings would suggest that the poorest outcomes on measures of Shift are likely to occur for a child who has an earlier stroke and is tested early on in childhood, before Shift is expected to be fully developed.

In their review of the "Mirsky Model", Koziol et al. (2014) stated that Mirsky's Shift falls under the greater umbrella term of executive attention. As mentioned previously, cognitive developmental literature suggests that the more executive aspects of cognitive functioning (including executive attention) are established later in childhood. Specifically, conflict resolution and inhibition are later developing cognitive skills and are critical for performance on the WCST subtests, which make up Mirsky's Shift. In regards to Shift, the results of the current investigation support the theory of vulnerability, suggesting that early stroke will lead to greater impairment in a child's performance on measures of shifting attention. However, the findings contradict the idea that children tend to *grow into* their cognitive impairments. In fact, children in the present investigation demonstrated improvement in performance over time on the Shift measures, as executive factors of attention are expected to develop and better compensate.

Encode. When examining Encode, there is a significant relationship between Encode and Age at Stroke as the sole predictor of outcome (Figure 3). When Age at Testing is controlled for, however, this relationship no longer exists (Figure 4). This finding suggests that Age at Testing is somehow modifying the relationship between Age at Stroke and Encode. On the other hand, when Age at Testing is examined as a predictor variable, performance on Encode is not predicted by Age at Testing, whether or not Age at Stroke is controlled for (Figures 5 and 6). Taken together, these findings suggest that performance on factors of Encode may not be affected by stroke to the same extent that other factors of attention appear to be.

Research suggests that Encode is an attentional process mediated by cortical structures (Mirksy et al., 1991; Koziol et al., 2014), which tend to develop slowly throughout a child's life, and are not fully established in until later in adolescence (Anderson et al., 2001). Encode (a working memory process) does not appear to be influenced by the timing of a stroke in a consistent manner, such that early insult would impair the later development of a process (consistent with the early vulnerability theory), or that later injury would be associated with greater impairment of an established skill (consistent with the early plasticity theory). It is possible that, because Encode is a skill that slowly develops throughout childhood, there may not be a clear relationship between the timing of the injury or the timing of testing and outcome on measures of Encode. Levels of impairment, or resilience, may be relatively equivalent for this particular factor of attention across individuals with paediatric strokes.

Challenges and Further Considerations. Throughout the present investigation, there were challenges encountered that may have influenced the results of the study. One of the primary concerns with the statistical analyses was the large amount of missing data, coupled with a relatively small sample size. With only 196 participants who met the inclusion criteria in this investigation, the sample size was not large enough to account for the number of parameters to be estimated in a model with missing data. In fact, in the full latent variable model, which included both predictor variables and the four factors of attention, there were 50 parameters. According to Mueller and Hancock's (2010) rule of thumb, a sample size of 250 would have been necessary to accurately interpret the fit indices of the model. As a result, goodness-of-fit statistics were considered unreliable and could not be interpreted in the current study, for the full latent variable models.

The only options to decrease the number of parameters to be estimated in structural equation modeling are: 1) decreasing the amount of missing data; 2) increasing the sample size; or 3) reducing the number of parameters in the model. Given the clinical and retrospective nature of the current investigation, it was not possible to ensure that an identical test battery was administered to a large sample of children; therefore, the option of decreasing the number of parameters was initially considered. However, in order to preserve the clinical integrity of the models (i.e., accurately reproduce the original models and have at least two variables per factor in the model) it was determined that 50 parameters were necessary to represent the structural model. As a result, the power of the model was limited and fit indices of the full latent variable models were not considered.

In addition to the consideration of the number of parameters being estimated in the model, the relationship between Age at Stroke and the factors of attention should be interpreted with the caveat that the distribution of Age at Stroke was not normal in the current sample (see Appendix A). In fact, 38% of children in the sample had a stroke within the first year of life. This finding appears to be relatively consistent with the literature reporting that approximately 32% of paediatric AIS occur within the perinatal period (i.e., the first month of life; deVeber, 2000). The fact that such a large proportion of children had their strokes prior to the age of 1 year suggests that there is limited variance in the sample. The relationship between Age at Stroke and the factors of interest was likely affected by the limited variance. Future researchers are encouraged to examine age by categorical groups. For example, comparing children with strokes during the perinatal period to those in the early or late childhood (e.g., Westmacott et al., 2010) would more clearly demonstrate the relationship between Age at Stroke and outcome on each of the four factors of attention. A categorical analysis can be accomplished with a larger, more complete, sample than was available in the present investigation.

An additional limitation to the second goal of the investigation was the lack of data regarding attrition within the sample. A concern with using clinical data is that patients who fail to return for reassessment may not do so at random; there may be confounding variables, such as the severity of symptom presentation. Given the limited availability of data in an archival sample, it was not possible to access the rates of attrition for any particular child who participated in the study. In the stroke program at the Hospital for Sick Children, parents are encouraged to assess their children following the original stroke, and are provided the opportunity for reassessment throughout the child's life, until the age of 18 years, regardless of the severity of their clinical presentation. Children are therefore provided with repeated opportunity to determine their needs and make recommendations for supports. Given that all children are provided with identical opportunity to access the assessments, the investigation proceeds with the assumption that attrition does not significantly impact the sampling procedures.

Along a similar line, in their validation of the Paediatric Stroke Outcome Measure (PSOM; a study using the sample of children from the Paediatric Stroke Clinic at the Hospital for Sick Children), Kitchen et al. (2012) considered the possible limitation that not all children referred to the clinic consented to participate in the testing; there was concern of referral bias within the study. The researchers noted, however, that the sample of participants in question had a normal distribution of neuropsychological test performance, and consisted not only of a wide range of age groups but also a range in the severity of deficits. Kitchen and her colleagues noted that the normal distribution of the large sample decreased the likelihood of potential confounding from referral bias, which may be related to severity within the population. Based on this precedent, it was considered unlikely that the attrition rates of the sample in the current investigation were related to severity of clinical presentation.

Finally, the post-hoc analyses, comparing Age at Stroke and lesion location, provided the opportunity to further delineate the relationships between the predictor variables identified in the current investigation. The findings suggest that strokes localized to the subcortical regions tend to occur later in childhood (mean age of 6.55 years); therefore, factors of attention that are mediated by subcortical structures (e.g., Focus/Execute, Sustain) are less likely to be impacted during a child's early life. Given that Focus/Execute tends to develop gradually throughout childhood and peak later in adolescence, the skill may not be established at an early age, prior to the occurrence of the average subcortical stroke. Sustain, on the other hand, is one of the earliest established factors of attention, and has a considerable subcortical involvement. It is possible that the majority of strokes that affect brain regions that mediate Sustain occur later in childhood, after the skill has already been established. This line of reasoning is consistent with the findings of the current investigation, such that there was no linear relationship been Age at Stroke and Sustain.

In contrast to the subcortical lesions, the findings suggest that strokes localized to cortical regions tend to occur earlier in childhood (with a mean age of 2.11 years).

Factors of attention that are largely mediated by cortical structures (e.g., Encode, Shift) tend to have a slower development throughout childhood and adolescence, and therefore may be more plastic following earlier insult, prior to the establishment of the skill.

The post-hoc analyses reviewed here demonstrate that Age at Stroke is significantly associated with the location of the lesions, suggesting that certain cerebral structures are more susceptible to injury at different ages throughout development. Future researchers are encouraged to pursue this line of research by examining possible interactions between Age at Stroke, lesion location, and each of the four factors of attention identified in the current model, in order to provide a clearer picture of outcomes on measures of attention.

CHAPTER 6

Summary and Conclusions

In the present investigation, the first goal was to determine a model of attention that best represented a sample of children with AIS. A three-factor model based on Posner's theory of attention was compared to a four-factor model, representing Mirsky's theory of attention. Despite finding that both a three- and a four-factor model of attention had relatively similar fit indices and both represented a good fit with the sample, when theoretically-based psychometric properties, neuroanatomical correlates, and developmental factors were taken into consideration, the four-factor model was determined to be the most appropriate model of attention to represent the sample of children.

In the second goal of the investigation, predictors of attention were sought to be identified, with respect to the four-factor model of attention. Both Age at Stroke and Age at Testing were determined to be significant predictors of Focus/Execute and Shift, while Sustain and Encode were not significantly predicted by either Age at Stroke or Age at Testing. More specifically, performance on tests of Focus/Execute tend to become worse the older the child is at the time of his or her stroke (when controlling for age at the time of testing), as well as the older the child's age at testing in general. On the other hand, performance on tests of Shift tend to be worse the younger the child is at the time of his or her stroke as well as the younger the child's age at the time of testing.

Despite the predictions made by the vulnerability and plasticity theories of development, the findings of the current investigation suggest that it may be too simplistic to consider the young brain as *either* vulnerable to early impairment *or* plastic and thus better able to reorganize following damage. The results of the present study demonstrated that individual cognitive abilities may be differentially influenced by damage at varying points throughout development. The findings suggest that factors of attention that are established early in life (i.e., sustained attention or vigilance) may be relatively plastic, such that early insult does not necessarily lead to greater impairment than later damage. On the other hand, some skills that are not fully established until later in life (e.g., focusing and executive attention, shifting attention) may have critical periods during which disruption has disproportionately adverse effects.

For example, Focus/Execute and Shift, both considered executive aspects of attention, show different patterns of impairment throughout development. Focus/Execute tends to be more plastic earlier in life, showing relative resilience to earlier stroke, and demonstrating greater impairment as the child develops over time and the skill becomes more fully established. In contrast, Shift tends to be more vulnerable, showing greater impairment the earlier the stroke occurs in development and the younger the age at testing.

The Encode (or working memory) factor of attention tends to continue to develop slowly throughout childhood and adolescence and does not appear to have critical periods of development such that outcomes can be linearly predicted by age factors. In this particular aspect of attention, the level of impairment (or resilience) may be relatively stable across development, regardless of a child's age at the time of stroke or at the time of testing.

Despite the relatively simplistic arguments of the vulnerability vs. plasticity theories, researchers have demonstrated the complexities of contributing factors with respect to functional outcome. Throughout her research career, Kennard sought to explain the factors that influenced outcome following cerebral insult; she identified age at injury and lesion location as significant predictors (Dennis, 2010). Consistent with these findings, post-hoc analyses in the present investigation demonstrated that children with strokes localized to the subcortical regions tended to be significantly older at the time of stroke than children with strokes localized to cortical regions alone or with combined cortical/subcortical lesions.

Within the paediatric stroke literature, the argument has been made that not only do earlier strokes tend to be associated with greater cognitive impairment, but when the location of the lesion is taken into account, there are interactions between the Age at Stroke and the affected neuroanatomical regions. For example, Westmacott et al. (2010) demonstrated that lesion location modulates the effect of Age at Stroke on cognitive outcome. For those who acquired subcortical lesions, the children with perinatal stroke (i.e., stroke occurring within the first month of life) had the greatest vulnerability for impairment, while cortical lesions were associated with the greatest vulnerability in the early childhood stroke group (i.e., stroke occurring between 1 month to 5 years of age).

Furthermore, Westmacott et al. (2010) demonstrated that there appear to be critical periods of development that are most vulnerable to insult and that these periods vary depending upon the neuroanatomical regions in question. In fact, for cortical lesions, a U-shaped curve can be graphically represented to demonstrate the relationship between Age at Stroke and outcomes on the cognitive processes of interest; Westmacott and her colleagues demonstrated that perinatal and later childhood Age at Stroke were not associated with the same degree of impairment as strokes occurring during the critical *early childhood* period (1 month to 5 years old). Other studies have also demonstrated U-shaped relationships between age at lesion and severity of impairment using different age at stroke cutoffs, such that strokes occurring during early childhood (0- 5 years old) or later childhood (10-18 years old) were associated with greater impairment than those occurring during middle childhood (5 and 10 years old; see Murias et al., 2014 for a review).

In the present investigation, it was noted that certain attentional processes could be significantly predicted by the age of a child at the time of his or her stroke, as well as the age at testing (i.e., Focus/Execute, Shift); however, not all of the attentional processes demonstrated clear linear relationships (i.e., Sustain, Encode). Due to sample size limitations, it is beyond the scope of the present study to examine the type of relationship that may occur between individuals from different age categories and outcomes on the factors of attention. However, it is possible that a U-shaped curve would be noted in the present investigation as well, such that earlier and later injury would be related with better outcomes than injury occurring during the early to middle childhood years, or vice versa. Future researchers are encouraged to further examine the relationship between Age at Stroke and Age at Testing on the outcomes of the factors of attention, as the relationships between age and outcome may not be linear (particularly for factors such as Sustain and Encode).

Although the current findings clearly demonstrated that Age at Testing somehow modified the relationship between Age at Stroke and the outcomes on certain factors of attention, it is beyond the scope of this investigation to be able to speak to the mechanism by which Age at Testing alters this relationship. Mediating and moderating effects are typically small, and therefore require a large sample size in order to determine whether or not these processes are modifying the relationship between the predictor variables.

The findings of the current investigation highlight the importance of considering *attention* as a network of overlapping yet distinct processes, as opposed to a solitary cognitive ability. Based on the results of the present study, the development of attentional processes does not appear to be easily described as either vulnerable or plastic when considering early damage. In addition, children who acquire early cerebral insult may grow into their impairments over time, as the demands on the cognitive ability are increased; however, this snowball effect of increasing demands does not occur for all factors of attention. The development of attentional processes should, therefore, be taken into consideration given that individual factors are differentially affected by impairment over time.

In practice, clinicians are encouraged to assess a child's level of ability on all four factors of attention, as opposed to simply examining the most traditionally relied upon measures of attention. An understanding of a child's abilities on each of the four factors of attention will allow the clinician to: a) monitor the child's progress over time, as particular skills continue to develop and differentially demonstrate gains; b) assess for discrepancies among the factors of attention and target them individually through intervention strategies; and c) predict possible trajectories based on the known relationships between Age at Stroke and outcome on individual factors over time.

Although the four-factor model of attention is considered to be representative of the general population despite relying on data from a paediatric stroke sample, outcomes across these factors of attention are likely differentially influenced by the type of damage acquired to the brain. Future research should continue to investigate how age variables can be used to predict outcomes across factors of attention in different clinical populations, such as children with seizures or traumatic brain injuries, for example. Investigators are encouraged to continue to evaluate the four-factor model of attention using different clinical populations in an attempt to provide a broader understanding of the implications of age factors.

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Appendix A

Delis-Kaplan Executive Function System

The Delis-Kaplan Executive Function System (D-KEFS; Delis, Kaplan, & Kramer, 2001) is a standardized measure made up of nine subtests that assess executive function, which is a higher level cognitive ability that relies on basic cognitive skills, such as attention, language etc. Several studies have demonstrated that performance on the D-KEFS subtests is sensitive to frontal lobe lesions, frontal-lobe epilepsy, Fetal Alcohol Spectrum Disorder (FASD), and subcortical ischemic vascular disease in older adults (see Strauss et al., 2006 for a review).

Colour-Word Interference Test. The D-KEFS colour-word interference test is a variant of the Stroop procedure that can be used as a verbal measure of cognitive flexibility, as well as the ability to inhibit over learned responses and generate conflicting responses (Strauss et al., 2006). In *Condition 1*, children are asked to name patches of colour. In *Condition 2*, children read colour names, printed in black ink. In *Condition 3*, children name the ink colour in which the words are printed. In *Condition 4*, children switch between naming the ink colours and reading the words.

The first two conditions are measures of word and colour naming, and therefore require basic attention skills. The third condition is a measure of executive function in terms of cognitive inhibitions and maintaining a course of action despite intrusions and can also be considered a measure of speeded processing (Boone, Pontón, Gorsuch, González, & Miller, 1998). The fourth condition involves more complex executive functions, in terms of switching between rules. In the current study, only the third condition of the D-KEFS Stroop test (i.e., the interference task) will be relied on as a representation of the original Stroop test, in order to remain consistent with previous investigations of attention using the Stroop (e.g., Mirsky et al., 1991). In terms of reliability coefficients for the D-KEFS, the Colour-Word Interference subtest has adequate internal consistency and test-retest reliability (*r* = .70-.79).

Trail Making Test. The D-KEFS trail making test is a variant of Reitan and Wolfson's (1985) Trail Making Test (outlined below). In the two conditions of interest for the current investigation, children are asked to connect numbers in ascending order (*Condition 2*) and switch between connecting numbers and letters, in order (*Condition 4*). *Condition 2* is a measure of visual scanning and sequencing, while *Condition 4* is a measure of executive functioning that assesses flexibility of thinking (Homack, Lee, & Riccio, 2005). In terms of reliability coefficients for the D-KEFS, the Trail Making test has low internal consistency ($r \leq .59$) and marginal test-retest reliability (*r* = .60-.69).

Test of Everyday Attention for Children

The Test of Everyday Attention for Children (TEA-Ch) is a battery of nine subtests that measure different attentional processes in children aged 16 and under (Manly, Robertson, Anderson, & Nimmo-Smith, 1999). The three primary factors of attention assessed by this battery are: focused (selective) attention, sustained attention, and attention control/switching (Manly et al., 1999). In the current investigation, three of the nine subtests will be examined; the subtests are described below. Manly et al. (1999) reviewed a study of children with traumatic brain injury who demonstrated significant deficits in the three factors of attention (i.e., selective attention, sustained attention, and attentional control) on the TEA-Ch.

Sky Search. The *Sky Search* (SS) subtest of the TEA-Ch is a measure of selective or focused attention (Manly et al., 1999). Children are asked to circle the 20 identical pairs of spaceships among a set of distracters, as quickly as possible. When they are done, they are asked to check the box in the bottom right-hand corner to stop the time. To control for motor speed, the children are asked to circle all of the target pairs of spaceships, in an array without distracters. The SS *target* score is based on the number of pairs circled (i.e., how many of the 20 targets were identified). The SS *attention* score is adjusted for motor speed based on their performance on the second part of the test (Strauss et al., 2006). According to Manly et al. (2001), the test-retest reliability of the SS subtest is very high (r = .90).

Score!. The *Score!* task is a measure of auditory sustained attention (Manly et al., 1999). Children are asked to count the number of "beeps" they hear on a tape, until they hear the signal to provide the examiner with the total score. Targets are separated by long gaps, thus increasing the demands on the child's sustained attention (Strauss et al., 2006). According to Manly et al. (2001), the test-retest reliability of the Score! subtest is marginal (r = .64).

Sky Search Dual Task. The *Sky Search Dual Task* (SS DT) is a dual-task measure of sustained and divided attention (Manly et al., 1999). Children are asked to complete a version of the visual stimuli used in the Sky Search task, while also counting the number of "beeps" presented, as in the Score! task, to determine whether performance is significantly affected by the divided attention component. The task ends when the child has completed the visual search task. Time to completion is calculated along with the percentage of counting item identified correct (Strauss et al., 2006). According to Manly et al. (2001), the test-retest reliability of the SS DT subtest is high (*r* = .81).

Trail Making Test

The trail making test (Trails; Reitan & Wolfson, 1985) is designed to tap selective attention/visual search and the capacity to switch attention. Trails A is considered a measure of attention, while Trails B requires greater executive functioning, and is more reliant on shifting, sequencing, and perseveration (Mitrushina, Boone, Razani, & D'Elia, 2005). In this test, children are asked to draw lines connecting consecutive numbers (Trails A) or alternating numbers and letters (Trails B; Strauss et al., 2006). Both the scores from Reitan and Wolfon's (1985) Trail Making Test and the D-KEFS Trail Making Test subtests will make up the Trail Making Test (Trails) variables in the current investigation, using *z*-scores.

Strauss et al. (2006) review various studies examining the reliability and validity of the Trail Making Test. According to Strauss et al. (2006), the test-retest reliability varies depending on the age and population studied, but is generally adequate (i.e., *r* = .70-.79). For adults, test-retest reliability tends to be in the low range (*r* = .46 - .55) for Trails A and in the low to adequate range (*r* = .44 - .75) for Trails B. Test-retest reliability in a sample of children was low for Trails A (*r* = .41) and marginal for Trails B (*r* = .65).

Trails A and B appear to correlate moderately well with one another (*r* = .31-.60; Strauss et al., 2006). Evidence from a variety of investigations have demonstrated that the Trail Making Test correlates with other aspects related to attention (i.e., visual search, scanning, and speed), as well as other tests of attention (e.g., PASAT; Strauss et al., 2006). The trail making test has been shown to be sensitive to neurological impairment and traumatic brain injury, but is not as sensitive in cases of mild head injury (Strauss et al., 2006).

Wechsler Intelligence Scales

Either the Wechsler Adult Intelligence Scale (WAIS-R, WAIS-III, WAIS-IV) or the Wechsler Intelligence Scale for Children (WISC-III, WISC-IV) was administered to all participants. Due to the relatively limited occurrence of paediatric stroke, the current sample size was maximized by including children who have been assessed over the past 20 years; therefore, the participants have received different versions of the Wechsler Intelligence battery. This is common practice in larger neuropsychological studies and, given the thorough analyses involved in test development to ensure convergent validity (Williams, Weiss, & Rolfhus, 2003) it is considered an acceptable procedure (Westmacott et al., 2010). American norms were used for the Weschler Intelligence Scales.

Digit Span. The digit span subtest involves asking children to repeat strings of digits of increasing length, both forwards and backwards. For decades, the digit span subtest has been purported to measure a wide range of attention processes, including auditory short term/working memory, mental control, flexibility, immediate memory, phonological processing, information processing, span of attention (see Hale, Hoeppner, & Fiorello, 2002 for a review). Hale et al. (2002) found that both Digits Forward and Backward were predictive of attention, executive function and behavioural rating measures. In particular, the authors found that Digits Backward was predictive of attention and executive functions, but not the short term auditory memory processes, which are predicted by Digits Forward (Hale et al., 2002).

The reliability estimates for Digit Span on the WISC-III and WISC-IV are high (*r* = .85 and *r* = .87, respectively) and the correlation between the two versions of the subtest is adequate (*r* = .76; Williams, Weiss, & Rolfhus, 2003). The stability coefficient for the WISC-IV, corrected for the variability of the standardization sample is high (*r* = .83; Williams, Weiss, & Rolfhus, 2003). For the WAIS-IV (Strauss et al., 2006), the internal consistency estimate and reliability coefficient for Digit Span are both very high (*r* = .93 and *r* = .98, respectively). The test-retest coefficient, corrected for variability of the normative sample, is high (*r* = .83) for all ages, and adequate (*r* = .75) for individuals ages 16 through 29 years. For the WAIS-III (Strauss et al., 2006), test-retest reliability of Digit Span is high (*r* = .80-.89) and internal consistency is very high (*r* = .90+).

Coding. The Coding subtest is a measure of visuomotor coordination, motor and processing speed, as well as visual working memory. Children are asked to copy the symbols paired with either geometric shapes or numbers using a key, within a 120-second time interval (Strauss et al., 2006).

The reliability estimates for Coding on the WISC-III and WISC-IV are relatively high (*r* = .79 and *r* = .85, respectively) and the correlation between the two versions of the subtest is adequate (*r* = .77; Williams, Weiss, & Rolfhus, 2003). The stability coefficient for the WISC-IV, corrected for the variability of the standardization sample is very high (*r* = .92; Williams, Weiss, & Rolfhus, 2003). For the WAIS-IV (Strauss et al., 2006), the internal consistency estimate for Coding is high (*r* = .86). The test-retest coefficient, corrected for variability of the normative sample, is high (*r* = .86) for all ages, as well as for individuals ages 16 through 29 years (*r* = .85).

Letter-Number Sequencing. The letter-number sequencing subtest measures auditory short term/working memory and mental flexibility. Children are read a random sequence of numbers and letters and are asked to repeat them back to the examiner in ascending numerical and alphabetical order (Strauss et al., 2006).

For the WISC, Letter-Number Sequencing subtest estimates are only available for the 4^{th} edition (WISC-IV) when the subtest was introduced. The reliability estimate for Letter-Number Sequencing on the WISC-IV is very high (*r* = .90). The stability coefficient for the WISC-IV, corrected for the variability of the standardization sample is high (*r* = .83). For the WAIS-IV (Strauss et al., 2006), the internal consistency estimate and reliability coefficient for Letter-Number Sequencing are both high (*r* = .88 and *r* = .90, respectively). The test-retest coefficient, corrected for variability of the normative sample, is high (*r* = .80) for all ages, and for individuals ages 16 through 29 years (*r* = .83). For the WAIS-III (Strauss et al., 2006), test-retest reliability of Letter-Number Sequencing is adequate (*r* = .70-.79) and the internal consistency is high (*r* = .80-.89).

Wisconsin Card Sorting Test

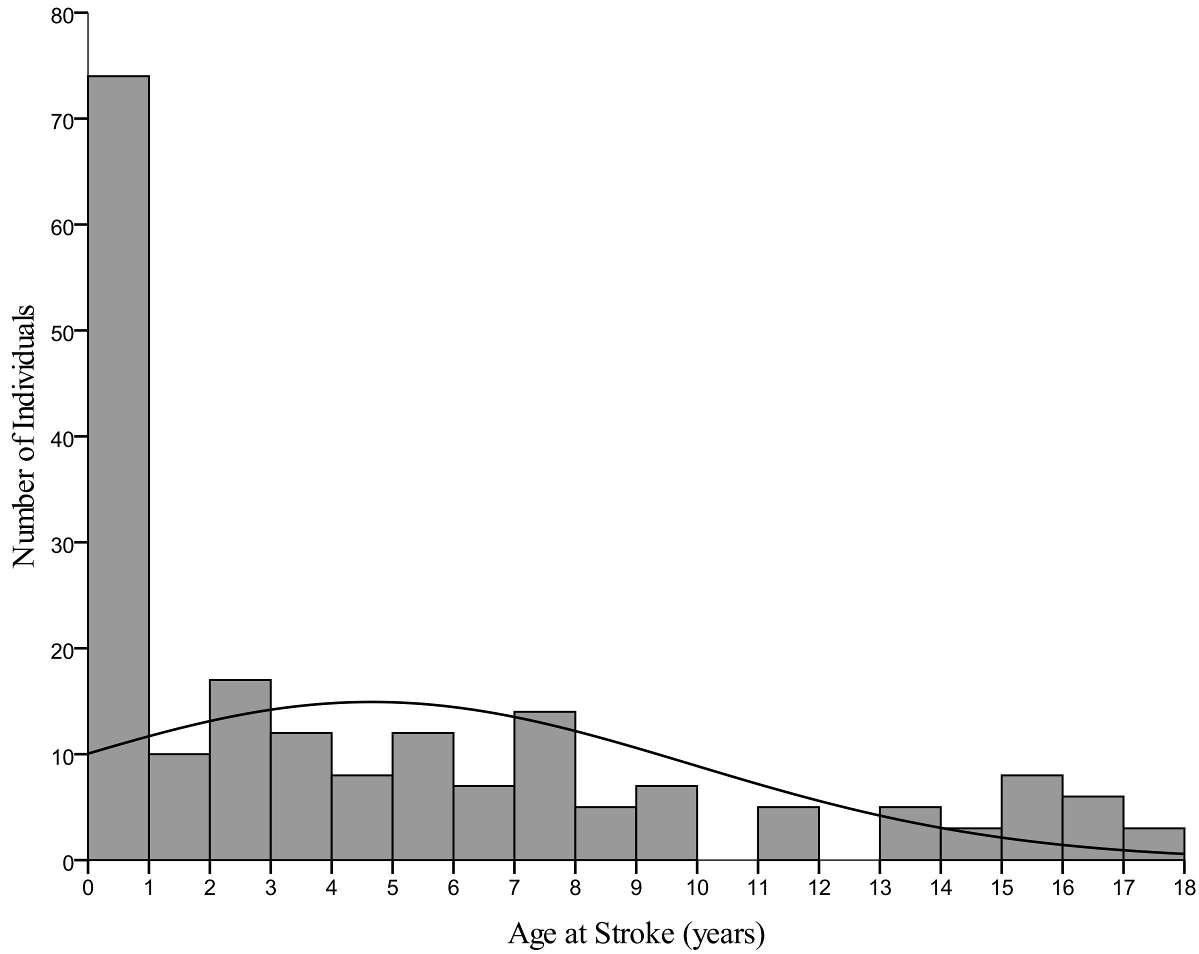
The Wisconsin Card Sorting Test (WCST; Grant & Berg, 1948) assesses abstraction and the ability to shift cognitive strategies in response to feedback. The test is a measure of executive function that requires strategic planning, searching, relying on feedback to shift cognitive set, and inhibition of impulsive behaviour (Strauss et al., 2006). Children are asked to place each response card below one of the four key cards, based on their own opinion of where it should go. The experimenter responds “right” or "wrong" depending on the given sorting rule, which switches from *colour*, to *form*, to *number*, without warning, after every 10 consecutive correct responses.

Scores can be derived based on a number of factors. The most common scores of interest include: 1) *number of categories* completed (raw scores); 2) number of *trials* to complete the first category (raw scores); 3) number of *errors* (*T* scores) and 4) *perseverative responses* (*T* scores) represent the number of items in which the child persists in responding to a stimulus characteristic that is incorrect; 5) *loss of set* (raw scores) occurs whenever a child makes an error after 5 or more correct consecutive responses. Consistent with previous investigations of attention models (e.g., Mirsky et al., 1991), the scores of interest in the current investigation included the number of errors (T-scores), number of perseverative errors (T-scores) and the number of categories achieved (raw scores).

From the WCST manual (Heaton et al., 1993), inter-rater agreement is reported to be high for nonperseverative errors (r = .75-.88) and very high for perseverative errors (r = .92-.97). Inter-rater consistency is very high for both nonperseverative and perseverative errors (r = .91 and r = .94, respectively). With a sample of children, inter-rater reliability coefficients ranged from r =.895 to r = 1.000. Heaton et al. (1993) reviewed several investigations demonstrating that the WCST is a valid measure of executive function in children and adolescent with neurological impairment, including attention deficit disorder, reading disability, seizure disorder, and traumatic brain injury.

Appendix B

The number of individuals who suffered strokes between the ages of 0 and 18 years old.



Appendix C

Breakdown of Age at Stroke variables (in years) across the tests of attention.

	Age at Stroke							
Tests of Attention	**Range**	**Minimum**	**Maximum**	**Mean**	**SD**	**Variance**	**Skewness**	**Kurtosis**
All tests	*17.59*	*0.00*	*17.59*	*4.66*	*5.22*	*27.30*	*1.04*	*-0.04*
Stroop	17.24	0.00	17.24	4.42	5.25	27.56	1.08	-0.07
Trails A	17.27	0.00	17.27	4.14	4.93	24.30	1.22	0.58
Trails B	17.27	0.00	17.27	4.33	5.03	25.33	1.19	0.46
TEA-Ch SS	15.90	0.00	15.90	3.30	3.89	15.17	1.39	1.44
TEA-Ch Score!	15.90	0.00	15.90	3.18	3.91	15.25	1.46	1.60
TEA-Ch SS DT	15.90	0.00	15.90	3.05	3.83	14.67	1.71	2.59
WCST Errors	17.27	0.00	17.27	5.01	5.17	26.71	0.94	-0.15
WCST Perseverative	17.27	0.00	17.27	4.98	5.18	26.85	0.96	-0.14
WCST Categories	17.59	0.00	17.59	5.34	5.48	30.04	0.86	-0.47
Digit Span	17.59	0.00	17.59	4.82	5.21	27.11	0.98	-0.15
Coding	17.27	0.00	17.27	4.42	4.85	23.53	1.03	0.10
Letter Number Sequencing	17.59	0.00	17.59	3.95	4.94	24.42	1.38	0.95

[1]Stroop: Stroop Inhibition test; Trails A: Trail Making Test A; Trails B: Trail Making Test B; TEA-Ch: Test of Everyday Attention for Children; TEA-Ch SS: Sky Search Attention; SS DT: Sky Search Dual Task; WCST: Wisconsin Card Sorting Test; Errors: Number of Errors; Perseverative: Number of Perseverative Errors; Categories: Number of Categories Achieved.
[2] Age represented in years.

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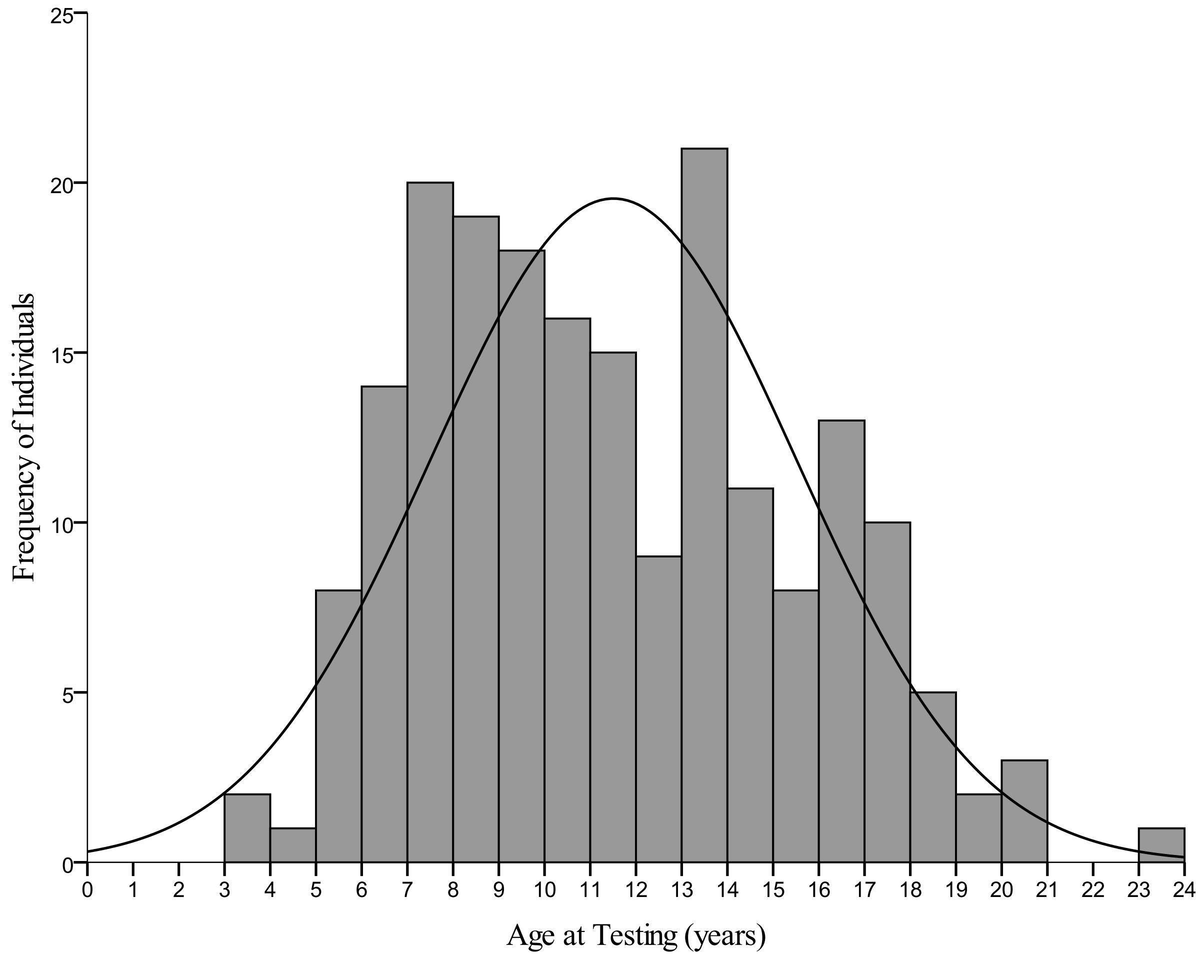
Appendix D

The number of individuals who were tested between the ages of 4 and 24 years old.



Appendix E

Breakdown of Age at Testing variables (in years) across tests of attention.

	Age at Testing							
Tests of Attention	**Range**	**Minimum**	**Maximum**	**Mean**	**SD**	**Variance**	**Skewness**	**Kurtosis**
All tests	*19.84*	*3.42*	*23.26*	*11.51*	*3.99*	*15.95*	*0.35*	*-0.58*
Stroop	14.82	8.44	23.26	13.36	3.41	11.60	0.61	-0.19
Trails A	14.68	6.03	20.70	12.02	3.58	12.82	0.35	-0.69
Trails B	14.52	6.18	20.70	12.15	3.49	12.18	0.40	-0.57
TEA-Ch SS	12.15	6.18	18.33	10.91	3.03	9.20	0.40	-0.71
TEA-Ch Score!	12.15	6.18	18.33	10.84	2.96	8.73	0.41	-0.60
TEA-Ch SS DT	12.15	6.18	18.33	10.60	2.93	8.58	0.59	-0.16
WCST Errors	16.38	6.88	23.26	12.87	3.46	11.97	0.43	-0.21
WCST Perseverative	16.38	6.88	23.26	12.84	3.46	11.99	0.45	-0.18
WCST Categories	16.38	6.88	23.26	13.12	3.47	12.06	0.31	-0.35
Digit Span	14.55	6.03	20.58	11.75	3.66	13.38	0.40	-0.82
Coding	16.38	4.20	20.58	11.40	3.54	12.50	0.41	-0.66
Letter Number Sequencing	14.55	6.03	20.58	11.69	3.63	13.19	0.40	-0.76

[1]Stroop: Stroop Inhibition test; Trails A: Trail Making Test A; Trails B: Trail Making Test B; TEA-Ch: Test of Everyday Attention for Children; TEA-Ch SS: Sky Search Attention; SS DT: Sky Search Dual Task; WCST: Wisconsin Card Sorting Test; Errors: Number of Errors; Perseverative: Number of Perseverative Errors; Categories: Number of Categories Achieved.
[2] Age represented in years.

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Appendix F

Breakdown of Time since Stroke variables (in years) across tests of attention.

	Time Since Stroke							
Tests of Attention	**Range**	**Minimum**	**Maximum**	**Mean**	**SD**	**Variance**	**Skewness**	**Kurtosis**
All tests	*17.44*	*0.00*	*17.44*	*6.85*	*4.10*	*16.77*	*0.27*	*-0.52*
Stroop	17.43	0.01	17.44	8.94	3.84	14.74	-0.30	-0.03
Trails A	17.44	0.00	17.44	7.89	4.05	16.43	0.00	-0.47
Trails B	17.44	0.00	17.44	7.82	4.17	17.37	0.01	-0.53
TEA-Ch SS	16.74	0.01	16.75	7.60	3.72	13.81	0.08	-0.34
TEA-Ch Score!	15.81	0.01	15.82	7.66	3.62	13.09	-0.07	-0.47
TEA-Ch SS DT	14.47	0.20	14.66	7.55	3.53	12.43	-0.13	-0.51
WCST Errors	17.44	0.00	17.44	7.85	4.10	16.83	-0.02	-0.43
WCST Perseverative	17.44	0.00	17.44	7.86	4.12	16.99	-0.02	-0.45
WCST Categories	17.44	0.00	17.44	7.78	4.31	18.54	-0.02	-0.58
Digit Span	17.43	0.01	17.44	6.93	4.13	17.05	0.23	-0.52
Coding	16.74	0.01	16.75	6.97	3.99	15.92	0.20	-0.54
Letter Number Sequencing	17.43	0.01	17.44	7.74	3.89	15.17	0.04	-0.31

[1]Stroop: Stroop Inhibition test; Trails A: Trail Making Test A; Trails B: Trail Making Test B; TEA-Ch: Test of Everyday Attention for Children; TEA-Ch SS: Sky Search Attention; SS DT: Sky Search Dual Task; WCST: Wisconsin Card Sorting Test; Errors: Number of Errors; Perseverative: Number of Perseverative Errors; Categories: Number of Categories Achieved.
[2] Age represented in years.

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Appendix G

Descriptive statistics for the tests of attention.

						Descriptive Statistics				
Tests of Attention	**N**	**% Missing[2]**	**Range**	**Minimum**	**Maximum**	**Mean**	**SD**	**Variance**	**Skewness**	**Kurtosis**
Stroop	80	59.2	12.00	1.00	13.00	7.93	3.47	12.04	-0.52	-0.85
Trails A	141	28.1	6.27	-4.00	2.27	-0.44	1.38	1.90	-1.15	1.07
Trails B	125	36.2	6.39	-4.00	2.39	-0.37	1.57	2.48	-0.91	0.04
TEA-Ch SS	98	50.0	15.00	1.00	16.00	8.50	3.49	12.19	0.10	-0.33
TEA-Ch Score!	99	49.5	15.00	0.00	15.00	7.60	3.46	11.96	0.10	-0.67
TEA-Ch SS DT	76	61.2	19.00	0.00	19.00	5.39	4.16	17.28	0.74	0.48
WCST Errors	109	44.4	61.00	27.00	88.00	50.19	11.87	140.93	0.22	-0.39
WCST Perseverative	108	44.9	62.00	20.00	82.00	50.84	11.39	129.65	0.05	0.41
WCST Categories	113	42.3	6.00	1.00	7.00	4.93	1.55	2.39	-1.17	0.08
Digit Span	166	15.3	16.00	1.00	17.00	8.52	3.27	10.69	-0.01	-0.20
Coding	161	17.9	16.00	1.00	17.00	7.32	3.36	11.27	0.29	-0.08
Letter-Number Sequencing	129	34.2	14.00	1.00	15.00	8.66	3.29	10.80	-0.52	-0.25

[1]Stroop: Stroop Inhibition test; Trails A: Trail Making Test A; Trails B: Trail Making Test B; TEA-Ch: Test of Everyday Attention for Children; TEA-Ch SS: Sky Search Attention; SS DT: Sky Search Dual Task; WCST: Wisconsin Card Sorting Test; Errors: Number of Errors; Perseverative: Number of Perseverative Errors; Categories: Number of Categories Achieved.

[2]Percentage of individuals who were not administered the test of attention

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Appendix H

Factor matrix of Mirsky's four factors of attention determined by Confirmatory Factor Analysis including both the Adult and Child batteries (Mirsky, 1991).

Focus/Execute	Sustain	Shift	Encode
Digit Symbol Substitution[a]	CPT Hits[ab]	WCST Categories[ab]	Digit Span[ab]
Stroop (Word, Colour, Inhibition)[a]	CPT Commissions[ab]	WCST Correct[ab]	Arithmetic[ab]
Trails A[a]	CPT RT[ab]	WCST Errors[a]	
Trails B[a]			
Cancellation[a]			
Cancellation Omissions[b]			
Cancellation Completion Time[b]			
Coding[b]			

[a] Adult battery
[b] Child battery

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