Effects of traumatic brain injury on the attention system of children

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EFFECTS OF TRAUMATIC BRAIN INJURY ON THE
ATTENTION SYSTEM OF CHILDREN

by

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Bachelor of Arts
University of Nevada Las Vegas
2002

Master of Arts
University of Nevada Las Vegas
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A dissertation submitted in partial fulfillment
of the requirements for the

Doctor of Philosophy in Psychology Degree
Department of Psychology
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ABSTRACT

Effects of Traumatic Brain Injury on the Attention System of Children

by

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Mirsky et al. (1991) proposed a four factor structure of attention (Shift, Focus, Encode, and Sustain) that found strong support across various clinical and non-clinical samples (see Mirsky & Duncan, 2004). Using a differing theoretical model Spikman et al. (1999) found that traumatic brain injury (TBI) changed the measured structure of attention. The purpose of the study was to assess if the structure of attention maintained in children who had sustained a TBI using the Mirsky model of attention. For the study 151 children between the ages of 8.9 and 18.4 years (mean 12.9, sd 2.6) suffering from traumatic brain injury (TBI) and 50 normal controls were evaluated. Results supported the four-factor Mirsky model of attention. Factor scores were subsequently created and used to predict the severity of brain injury. The shift and focus factors...
significantly predicted brain injury. The findings may assist determining what functions are most connected to severity of brain damage and could be used to assist those recovering from brain injury.
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CHAPTER 1

INTRODUCTION

Traumatic brain injury (TBI) is a principal cause of disability among children in the United States (Centers for Disease Control and Prevention, 2007; National Information Center for Children and Youth with Disabilities, 2007). The effects of TBI are pervasive, with impairments affecting children’s cognitive, behavioral, academic, and emotional functioning (Dennis, Guger, Roncadin, Barnes, & Schachar, 2001; Max, Lansing, Koele, Castillo, Bokura, & Schachar, 2004; Wassenberg, Max, & Lindgren, 2004; Roberts, & Furuseth, 1997; Lowther & Mayfield, 2004; McIntire et al., 2006; Allen, Knatz, & Mayfield, 2006). It has been proposed that attentional deficits are among the most severe and frequently reported impairments of childhood TBI in both the acute and chronic phases of injury (Dennis, Guger, Roncadin, Barnes, & Schachar, 2001; Hooper, Alexander, & Moore, 2004; Lehnung, Leplow, & Ekroll, 2003; Max, Lansing, Koele, Castillo, Bokura, & Schachar, 2004; Wassenberg, Max, & Lindgren, 2004; Catoppa, Anderson, & Morse, 2007; Levin et al., 2007). The resulting deficient attentional-inhibitory controls seen in children with TBI affect academic, adaptive, social, and psychological functioning (Levin, Hanten, Zhang, Swank, & Hunter, 2004; Anderson, Anderson, & Anderson, 2006; Levin et al., 2007). It thereby becomes
vital to understand these post-trauma attentional deficits for parents, teachers, and service providers working with these children.

For clinical professionals who evaluate TBI it is common to obtain various measures of attention. While global attention problems resulting from TBI in adults have been well established (Harmsen, Geurts, & Fasotti, 2004; Azouvi, Couillet, & Leclercq, 2004; O'Keeffe, Dockree, & Robertson, 2004), literature assessing attentional deficits related to pediatric TBI has mainly come about over the last decade. The research has consistently shown deficits across a variety of attentional tasks, although some variability exists from one study to the next (Anderson, Fenwick, Manly, and Robertson, 1998; Chan & Lai, 2006; Ewing-Cobbs et al., 1998; Fenwick & Anderson, 1999; Levin et al., 2004; Ponsford & Kinsella; 1992). However, in many of these studies attention is conceptualized as a unitary neurocognitive construct, even though it is becoming increasingly apparent that there are a number of component processes that must be intact in order for the attentional system to function optimally.

Zubin (1975) theorized three separate components of the attention processing system, which he described as focus, sustain, and shift. These components work in unison to create what is commonly referred to as attention. The focus component allows for the selection of relevant stimuli from the environment, and further to ignore distracters while making appropriate responses. The sustain component allows a person to maintain focus and alertness over a long period of time while retaining the ability to respond or inhibit as needed. The shift component is the ability to change attentional focus flexibly.
and efficiently from one stimulus to another as the situation demands. Mirsky (1987, Mirsky et al. 1991) further elaborated on Zubin’s work by proposing a four factor structure of attention, which included Zubin’s original three components, but also proposed an additional “encode” component. This component represented a brief retention of information while performing various cognitive operations, linking attended stimulus input to the proper output system.

These multicomponent theories of attention have been supported primarily by factor analytic work, in which neuropsychological tests thought to assess the various components are subjected to exploratory or confirmatory analyses. The results of these studies are largely consistent across neurological, psychiatric, and healthy controls of various ages (Allen et al., 1997; De Jong, 1991; Goldstein, Johnson, & Minshew, 2001; Shum, McFarland, & Bain, 1990, 1994). However some variability is also present. For example, Pogge, Stokes, and Harvey (1994) validated Mirsky’s four-factor model in a sample of 278 adolescent psychiatric patients using confirmatory factor analysis. In contrast, Spikman and colleagues utilized a differing theoretical construct and found a two factor structure of attention (memory-driven action and stimulus-driven reaction) through exploratory analyses in a group of 60 healthy adult subjects, but also found a qualitatively different structure in an adult group of 60 people with TBI. Spikman et al. (2001) suggested that these differences may be due to a number of causes including (a) differences in tests attributed to attentional processes, (b) factors represented by one measure (mono-operation bias), and (c) sample group differences.
Establishing the factor structure of attention is important for both practical and theoretical reasons, which are discussed in the following sections. The potential for variability as found with Spikman et al. (2001) between TBI and non-brain injured populations can only be compounded with regard to neurocognitive development of attentional abilities in children. Dennis (1989) suggested that neurodevelopmentally, children have consolidated fewer cognitive and behavioral skills than adults, with a strong positive trend between age and acquired abilities. The earlier the age at the time of the brain insult the fewer established neurocognitive skills. Therefore, Dennis suggested that when chronic deficits in attention result, future impairments can emerge due to information processing and skill insufficiency, resulting in increasing discrepancies with peers over time. This form of developmental neurocognitive impairment can be conceived of as 'growing into a cognitive deficit' (Anderson et al., 2000). Deficient attention significantly affects the ability to process and learn information in everyday activities, particularly in educational settings (Lehnung, Leplow, & Ekroll, 2003). Attentional deficits contribute to a reduced capacity for new learning, slowed information processing, impaired organizational functions, and deficits in intellectual development and academic achievement (Lezak, Howieson, & Loring, 2004). Thus, as suggested by Anderson et al. (2000) attention deficits resulting from TBI can cause profound difficulties related to the expansion of learning in children.

Based on these considerations, the current study has two main purposes. The first is to determine the applicability of the three factor attention model
proposed by Zubin (1975), and the four factor model proposed by Mirsky (1987), to children using confirmatory factor analysis in a TBI sample to compare with earlier findings in normative samples (Mirsky et al., 1991). The second purpose is to identify those components of the attention system that are most susceptible to the effects of TBI in children and adolescents through group differences (Severe TBI, Moderate-Mild TBI, and Normal Control). Differential susceptibility is anticipated given the fact that some components of the attention system are more globally distributed throughout the brain (Mirsky et al., 1999). Also, it has been found that external force to the head results in characteristic patterns of cerebral damage to the anterior and ventral surfaces of the frontal and temporal lobes (Wilde et al., 2005). Mirsky et al., (1991, 1995) posited that these cerebral areas directly affect the ability to shift, sustain, and focus attention. This study shall utilize the Zubin and Mirsky models of attention for structural stability subsequent to pediatric TBI.
CHAPTER 2

LITERATURE REVIEW

In the following section, literature relevant to the current proposal is reviewed. These sections include: 1) defining attention, 2) models of attention and associated neural structures, 3) traumatic brain injury, and 4) attentional system following traumatic brain injury.

Defining Attention

William James (1890) provided this oft used definition of attention, "It is the taking possession in the mind, in clear and vivid form, of one out of several simultaneous possible objects or trains of thought. Focalization, concentration of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others" (p. 416). While a number of competing definitions of attention have been proposed, attention continues to be thought of as a focus of mental activity on a selection of necessary information (van Zomeren & Brouwer, 1994). This definition implies direction, intensity, and selection as its properties. A common metaphor of attention is that of a spotlight, in which the beam of light being aimed at an area constitutes the selection of information and the intensity of the light as well as the beam area represents the breadth and detail of what will be perceived. This conceptualization of attention works well for
the visual system but abstractly can be applied to all sensory inputs. In the following sections brief descriptions and evaluations of three general models will be discussed including: 1) Broadbent’s filter model, 2) Treisman’s attenuation model, and 3) late-selection models.

Broadbent’s Filter Model

David Broadbent’s (1958) filter model described the information processing system beginning with messages flowing into the sensory store, which is believed to have an unlimited capacity, but can only hold information for a short period of time. To be processed, this information must be transferred to the Filter. The Filter then distinguishes the attended message based on physical characteristics of the information (e.g., a speaker’s intonation, pitch, verbal cues, and speed of speaking), and all other input is filtered out. This information then moves from the filter to the Detector, where it is processed at more advanced and complex levels. For example, meaning is assigned to the incoming perceptual information in the Detector. From the Detector, information is then sent to the memory system. A term used for several models including Broadbent’s model is a *bottleneck* theory, indicating that only a limited amount of information can be processed, much like a bottleneck restricts the flow of liquid passing through it. Another term for this model is an *early-selection* model because information is filtered before it can be analyzed.

Treisman’s Attenuation Model

Treisman (1964) found that when told to attend to information presented to one ear auditory information was still being processed in the unattended ear. This suggests that information is processed prior to what Broadbent had
suggested in at least some cases. Treisman's (1964a, 1964b) attenuation model
suggested that all information entered the initial stage called the Attenuator
where it is evaluated based on: i) Physical Characteristics (e.g., pitch and tone),
ii) Language (e.g., syllables or word groupings), and iii) Meaning (e.g., cogent
phrases for basic identification). In this model, both the attended and unattended
information is processed at some level. However, the attended message moves
on to the next stage of processing whereas the unattended information is
processed at diminished strength. Information is then processed by the
Dictionary Unit (semantic analysis) which contains words with varying levels of
activation thresholds. For the purposes of this discussion, this model can be
termed an intermediate-selection model based on the extended selection
process. This model better accounts for implicit absorption of information often
seen in learning and memory. However, other researchers claim this model does
not account for the great deal of information processing that can be
accomplished via unattended channels (Deutsch & Deutsch, 1963).

Treisman and Gelade (1980) also proposed Feature-Integration Theory.
This theory suggests that when we look at a scene we sometimes take in the
distribution of a whole scene or we may focus attention onto specific features.
However, these two types of visual information processing are on a continuum.
Treisman and Gelade suggest that people are most often in between the two
forms of input reception. This theory has provided a crucial framework for
understanding visual attention, however as new research continues to come forth
the theory has been continually modified and subsequently has become more complex (Palmer, 1999).

**Late-selection Model and Capacity Theories**

Based on the apparent limitations of the Attenuation model Deutsch and Deutsch (1963) posited that information processing comes later than either Broadbent’s or Treisman’s models. In their Late-selection Model all data received is fully processed, but the significance and meaning of the input affects how the information will be responded to. This model suggests the use of a great deal of resources, which seems implausible. However, it may be credible depending upon the cognitive demands, or task load, that the person is facing (Kahaneman, 1973; Lavie, 1995; Schneider & Shriffrin, 1977). Attentive demands are dependant on cognitive resources. When cognitive demand is high, requiring a greater level of resources, then earlier selective attention is used. Lower loads allow for later and more in depth processing of larger amounts input. Park, Moscovitch, and Robertson (1999) investigated the effects of severe TBI in a study requiring attention on simultaneous tasks, or what is referred to as divided attention. The results indicated deficits in divided attention when the tasks require controlled processing involving working memory, but not when the tasks could be carried out relatively automatically. This would suggest that there is a limitation in cognitive load for this group.

In summary, these varying theories provide basic understanding of the current attentional models from a purely cognitive perspective. The framework of all of these models contains input, selection, and response. The direction, intensity, and selection of mental activity provide a broad definition of attention.
However, different components of attention have been found in research utilizing clinical populations with varying forms of brain dysfunction. This research has attempted to link attentional components with specific brain regions using neuropsychological testing procedures (Allen et al. 1997; Mirsky, 1987; Posner & Peterson, 1990; van Zomeren & Brouwer, 2004; Zubin, 1975). In the proceeding sections attentional models are reviewed that have linked brain behavior relationships. Both the neurological theories of attention and the neuropsychological elements of attention will be discussed.

Integrated Models of Attention and Associated Neural Structures

As described by Posner and Peterson (1990), the human brain has a network of anatomical structures and pathways that are associated with the constructs we attribute to attention. The processes underlying the construct of attention are not found solely in one structure or part of the central nervous system. Models of the neural substrates of attention generally include cortical regions (frontal, prefrontal, and parietal) as well as subcortical structures (limbic system, thalamus, hypothalamus, reticular formation, and basal ganglia) (Cohen 1993; Luria, 1973; Mesulam, 1981 & 1985; Mirsky, 1987 & 1996; Posner & Peterson, 1990; Stuss & Benson, 1984 & 1986; van Zomeren & Brouwer, 1994). These systems are not independent, but interact with each other through extensive projections and pathways connecting the different areas. Focal damage to these structures and connections results in dysfunction of specific components of the attentional system.
Mirsky model

Zubin (1975) examined the difficulties of assessing attention in patients with schizophrenia. Through this analysis he described how the attention construct can be separated into smaller components. As previously mentioned, the three separate components of attentional processing he described were focus, sustain, and shift. These components are defined as the ability to focus upon and select information from all potential stimuli, the ability to sustain focus over time ignoring irrelevant information, and the ability to shift attention from one stimulus to another in a functional manner. Zubin proposed that these components combine to produce what is perceived as the general construct of attention. In his research it was found that patients with Schizophrenia were particularly impaired in the sustain and shifting components, which provided preliminary evidence for the dissociable nature of the components, as well as their unique sensitivities to dysfunction of specific brain regions.

Based on Zubin’s work, Mirsky (1987, Mirsky et al. 1991) performed a factor analysis of numerous attention measures in a sample of 203 adult neuropsychiatric patients and 435 elementary school children. Mirsky’s findings confirmed Zubin’s three components (focus, sustain, & shift), but discovered an additional ‘encode’ factor. This model substituted the previously conceived diffuse and global concept of attention with a new factor analyzed system consisting of four components including focus, sustain, shift, and encode. Based on these findings, Mirsky and colleagues (Mirsky et al. 1991, 1999) described the four factors of attention and their associations with neuroanatomical areas.
The first area in Mirsky’s model is *sustain*, which is also referred to as vigilance. Vigilance is defined as the ability to maintain focus and alertness over a long period of time while responding rapidly to target stimuli and inhibiting responses to distracter and other stimuli. Based on the early theories of the attention system (Mesulam, 1981; Stuss & Benson, 1984, 1986) Mirsky suggested that the reticular activating system was critical to the sustain component as it responded to sensory input through increasing overall alertness or arousal. The reticular formation lies at the core of the brain stem in all vertebrate species. Projecting from the reticular formation is the excitatory ascending reticular activating system, which exerts an excitatory influence directly on the thalamus, and subsequently hypothalamus and non-specifically on general brain structures. However, this system is to an extent limited to general wakefulness. For example, a person can be asleep while stimulus information is still being received.

Mirsky (1989) also suggested that the reticular formation is essential for the maintenance of arousal and the basis for sustaining attention. Arousal refers to a sudden increase in alertness. This function appears to be affected by two reciprocal systems from the prefrontal cortex that activate the limbic system, particularly the amygdala (Mirsky, 1996; Posner, 2004; Pribram & McGuinness, 1975; Ricco et al. 2001; van Zomeren & Brouwer, 1994). The amygdala’s involvement may also explain the modulation of emotions during periods of arousal. Pribram and McGuinness (1975) suggest that the hippocampus plays an important role in distinguishing between new and old stimulus information. This
arousal process is essential for attention to new or changing stimuli. Thus, Mirsky et al., (1991, 1995, 1999) specifically associated the sustain component of attention with rostral midbrain structures, including the mesopontine reticular formation, and midline and reticular thalamic nuclei (see figure 1).

Figure 1

Neuroanatomical areas of the brain associated to components of attention

Semischematic representation of the proposed brain attention system, with tentative attributions of functional specialization to distinct brain regions. Adapted from Mirsky et al. (1991).
The ability to sustain attention, or vigilance, is most commonly assessed using the Continuous Performance Test (CPT) (e.g., the Connors' Continuous Performance Test; Conners, 2000) or a variant of this test, which assesses the capacity to maintain a regular, predictable response to task stimuli over time. In one variant of this task, a person responds through the press of a button to any letter on the computer screen except the target letter. Percent correct is often used as an indicator of performance on the CPT. An established feature of this factor is that it deteriorates over time (Parasuraman et al., 1987). Mirsky and colleagues also purport that CPT performance is adversely affected by damage to the prefrontal cortex.

The second component of Mirsky's model, focus, is defined as the ability to select target information from a broad range of stimuli received and respond accordingly. Restated this is the concerted effort to concentrate attentional resources on specific stimuli, identify relevant information, and perform motor responses in the presence of distracters. Mirsky and colleagues were unable to separate focus from rapid response, therefore they sometimes refer to this factor as focus/execute. This factor is tested by Coding (Wechsler, 1981), Stroop Test (Stroop, 1935), Trail Making Test Parts A and B (Reitan, 1958), and letter cancellation tests. The focus element is often what has been construed as attention and has been the source of tremendous research to analyze its processes, such as the level at which selection takes place, visual aspects of selection and eye movements, automatic selection, and auditory detection and selection (see Mirsky et al., 1991 for a review). Neurologically, Mirsky and
colleagues found support for this construct in that symptoms of neglect or lack of focus often resulted from damage to the parietal lobes as well as the cingulate gyrus, thalamus, and corpus colossum. Mirsky (1987, Mirsky et al. 1991) further refined the cerebral basis of the focus component stating that it is associated with the superior temporal cortex, inferior parietal cortex, and aspects of the corpus striatum.

Mirsky's third factor, shift, is defined as the ability to change attentional focus flexibly and efficiently from one stimulus to another as the situation demands. Shifting ability has been examined by using the perseveration score from Wisconsin Card Sorting Test (Heaton, Chelune, Talley, Kay, & Curtiss, 1993). The ability to shift attention is an integral part of daily life, as a person progresses from one task to another encountering a great of unexpected environmental stimuli. Mirsky et al., (1991) suggests that the capacity to shift attention requires the executive function of the prefrontal cortex combined with the anterior cingulate gyrus.

The fourth factor, encode, is defined as brief retention of information while performing various cognitive operations, including sequential registration, recall, and mental manipulation of numerical information. It is the aspect of attention that links attended stimulus input to the proper output system. The encode construct proposed by Mirsky shows substantial overlap with working memory (Baddeley, 1996) and from a practical stand point could be considered the same. Encode has been assessed using the Wechsler Intelligence scale Digit Span and Arithmetic subtests, but almost any test that validly assesses working memory...
could be used to measure the encode component. Encoding information is suggested by Mirsky et al., (1991) to also be associated with the hippocampus and amygdala.

Current research suggests that the basal ganglia, which are a network of subcortical nuclei surrounding the thalamus, are a gating system that relays information to specific areas of the cortex through the thalamus making it essential in the selection of information to be attended to (Goldman-Rakic, 1988; Hassler, 1978; Mirsky et al., 1991, 1999; Pribram & McGuinness, 1975; van Zomeren & Brouwer, 1994; Voeller, 1991). The basal ganglia, especially the striatum (caudate and putamen), are also believed to synchronize attentional processes in conjunction with the frontal and parietal areas (Damasio, Damasio, & Chang Chui, 1980; Goldman-Rakic, 1988; Riccio, Reynolds, Lowe, & Moore, 2002). In addition, the basal ganglia have also been implicated in selective output via the motor control system. Based on this information Selemon and Goldman-Rakic (1990) have suggested that the striatum plays a primary role in the attentional system.

To summarize the neural processes of Mirsky’s model, he proposed that the reticular formation is important for maintaining arousal, which in turn supports the general function of the attentional system. From the reticular formation the thalamus is the relay station for projections between frontal, parietal and cortical regions. Specifically the prefrontal cortex is suggested to be involved in directing and organizing. The parietal cortex is involved in selective and spatial attention. Different from prior theorists on this topic Mirsky included the temporal lobes in
his model, which were postulated to integrate sensory information. In this model the limbic system directs emotional and motivational aspects of the attention process. Finally, the basal ganglia work as a gating system of information to the frontal cortex. This model proposes numerous projections and neural pathways interconnecting this system allowing it to work as a whole.

Mirsky et al. (1999) provided a 4 part summary of their model stating the following: (a) Attention is a multifaceted system involving focus/execute, sustain, stabilize, shift, and encode that can be evaluated through neuropsychological measures constituting an "Attention Battery". (b) The factors of attention have corresponding, although interrelated, brain structures that form an organized system. (c) When damage or dysfunction occurs to the brain regions involved in the attentional system specific deficits related to this system will be observed. (d) Based on the theoretical description by Mirsky (1987, Mirsky et al. 1991, Mirsky et al. 1999) and others (Cohen 1993; Luria, 1966; Mesulam, 1981, 1985; Posner & Peterson, 1990; Reitan & Wolfson, 1993; Stuss & Benson, 1984, 1986; van Zomeren & Brouwer, 1994) of an interdependent attentional system, some structures may function for others in the event of dysfunction or damage.

The factorial validity of this Mirsky’s attention model has been supported by various other researchers. For example Allen et al. (1997) examined the factor structure of patients diagnosed with schizophrenia in both medicated and medication free using principle components analysis. The factor structure was stable in medicated and unmedicated conditions and was consistent with the
Mirsky model. Therefore Allen and colleagues concluded that, Mirsky's 4-factor model is valid for this population.

In a sample of 103 children and adults with autism and 103 control subjects Goldstein, Johnson, and Minshew (2001) evaluated the attention components based on the Mirsky model. They concluded that significantly poorer performance was found for the focus and shift factors, but not the sustain and encode factors. However, they utilized tests of basic motor function as measures of covariance which reduced significance across many measures requiring psychomotor speed. They concluded that children with high functioning autism may have deficits in psychomotor speed and high demand cognitive tasks.

Pogge, Stokes, and Harvey (1994) evaluated the attentional functioning of 278 adolescent psychiatric inpatients, with a mean age of 14.7 (2.8) years (53% female) using Digit Symbol Coding, Digit Span, and Arithmetic from the Wechsler tests, the Continuous Performance Test, the Trail Making Test parts A and B, and the Wisconsin Card Sorting Test. Confirmatory factor analysis was used to examine Mirsky’s (1987) 4 factor model and a variation of the Mirsky model where 2 factors are collapsed into one. Results supported the 4 factor model.

However, Shum, McFarland, and Bain (1990) evaluated 8 tests of attention in 170 university student and community normal controls, as well as in 37 patients with closed head injuries. Principle component factor analysis with Varimax rotation indicated three factors including visuomotor scanning, sustained selective processing, and visual/auditory spanning. Patients with severe TBI in the acute phase of their illness were impaired on the visuomotor scanning and
visual/auditory spanning components, whereas patients with severe TBI in the chronic phase were impaired on only the visuomotor scanning component. The authors suggest differential effects of TBI on the attentional system. These results are inconsistent with the Mirsky model, although a variety of different tests were used that may evaluate somewhat different constructs of attention.

**Mesulam's Model**

Mesulam's (1981) view of an integrated attentional system suggests that the reticular and the limbic systems as well as the frontal and posterior parietal cortex are involved in attention. In his view the frontal cortex has a reciprocal influence on the reticular system via the thalamus. Mesulam suggests that the frontal lobes are involved in "fixating" or selective attention to the target as well as for other functions (e.g., scanning, reaching). Cohen elaborated on this suggesting that the orbital prefrontal cortex modifies or directs the arousal received from the limbic system and hypothalamus (Cohen, 1993). The posterior parietal cortex is incorporated in this theory as an internal sensory map. Stuss and Benson (1984, 1986) gave additional emphasis to the frontal-thalamic gating system, which they suggest affects selective attention, while the afferent and efferent thalamic projections to the reticular system affect the stability or variability in levels of alertness.

Mesulam suggested that the thalamus and hypothalamus are prominent subcortical areas involved in the attention system. As with other researchers Mesulam suggested that the thalamus is the relay station connecting various structures in the attentional system, particularly between the frontal cortexes and

*Posner and Petersen Model*

Posner and Petersen (1990) have proposed the anterior, posterior, and vigilance networks as three interrelated neural networks within the brain. Their work is derived from numerous studies with macaque monkeys, normal human controls, neural imaging, and brain-injured patients (Fan & Posner, 2004; Fan et al., 2002; Fernandez-Duque & Posner, 2001; Petersen et al., 1989; Posner, 1988, 2004; Posner & Petersen, 1990). In their research they found the following three elements are required for shifting attention: (a) disengage, (b) move, and (c) engage. This research led to the current model of highly interconnected anterior, posterior, vigilance networks.

The first proposed and least clearly defined network is the vigilance (alerting) system. The vigilance system works at achieving and maintaining a state of high sensitivity to incoming stimuli. The alerting system has been loosely
associated with the reticular activating system (RAS) and thalamus and interconnections to the frontal and parietal cortex (Posner, 2004).

The posterior (orienting) network is formed by the following structures: posterior parietal lobe, the lateral pulvinar nucleus of the thalamus, and the superior colliculus. The posterior network is responsible for automatic or involuntary orientation to locations and the selection of information from sensory input (Petersen et al., 1989). The parietal lobe disengages attention from a current target until it is refocused by subcortical structures to a new target. Posner (1988) found that in humans, localized injuries to any of these three areas in the posterior network diminished the ability to shift visual attention from one target to another target. However, damage to the posterior parietal lobe decreased the ability to shift attention from a target on the same side as the injury to a target located contralateral to the injury. This type of impairment in shifting attention is termed hemi-neglect. When the pulvinar nucleus of the thalamus is damaged, problems occur maintaining focus to targets located contralateral to the damage. Finally, damage to the superior colliculus has been found to be related to a slowed response to new stimuli (Posner, 1988).

The anterior (executive) network includes the anterior cingulate, the midline frontal areas, and the supplementary motor areas. It is involved in the detection of sensory and semantic events and awareness of input (Goldman-Rakic, 1988). Further, the anterior network is suggested to be related to conscious and focused attention. Posner and Petersen's (1990) vigilance network is related to alertness and the ability to sustain attention. Anatomically
this system involves aspects of the frontal and parietal cerebral hemispheres and
the norepinephrine neurotransmitter system. This concept of the anterior and
posterior attention systems creates a clear dichotomy from which to research and
assess.

*van Zomeren and Brouwer Model*

An additional and prominent structural model of attention initially described
by Davies, Jones, and Taylor (1984), and elaborated on by van Zomeren and
Brouwer (1994) contains the following 4 main elements: focused, divided,
sustained, and supervisory attentional control. Table 1 presents their model. The
most basic element of attention is alertness (van Zomeren & Brouwer, 1994), or
the state of being receptive to potential stimuli and the availability to respond to
such. Focused attention is described as converging mental resources on one
piece or type of information to the exclusion of others. Divided attention
constitutes sharing mental resources for the intake and processing of
information. Both focused and divided attentional factors are considered aspects
of the selection process or selectivity. With regard to the level of attentional
intensity on incoming stimuli basic alertness is required, but most importantly
sustained attention. Sustained attention is defined as holding mental resources
on a particular task over periods of time waiting for variations or changes in
stimuli requiring responses. Supervisory attentional control organizes both the
selection and intensity of attention through inhibitory or excitatory modulation of
the mental resources being directed (see Table 1). This basic structure of
attention provides a practical utilitarian definition of the attention system for researchers and clinicians alike.

Table 1

Model of Attention van Zomeren and Brouwer

<table>
<thead>
<tr>
<th>Selectivity</th>
<th>Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focused Attention</td>
<td>Alertness</td>
</tr>
<tr>
<td>Divided Attention</td>
<td>Sustained Attention</td>
</tr>
</tbody>
</table>

Supervisory Attentional Control

Supervisory Attentional Control can modulate both selectivity and intensity. Adapted from van Zomeren and Brouwer (1994)

The van Zomeren and Brouwer (1994) model bears many similarities to the Zubin and Mirsky model in that they both have common focus and sustain elements that are in theory defined in very similar ways. Mirsky’s encode factor and supervisory attentional control both share a common concept of manipulation of information. Further, both of there definitions are commonly used to describe aspects of working memory. However, theoretically Mirsky’s shift component and van Zomeren and Brouwer’s divide component are very different. Divided attention postulates the view that multiple things can be attended to at
once while shifting attention espouses the belief of moving quickly from one
stimulus to the next. The model proposed by van Zomeren and Brouwer also
subsumes divided and focused attention into a selectivity factor. Therefore while
these two models share a variety of elements in common they are also
conceptually different in some respects. Work by Riccio, Reynolds, and Lowe
(2001) evaluated many of the attentional theories. They summarize the
components of attention including (a) arousal/alertness based on motor intention
and initiation, (b) selective attention made of focused attention
(inhibiting/filtering), divided attention, and encoding, (c) sustaining attention and
concentration (vigilance), and (d) shifting of attention. The structure proposed by
Riccio, Reynolds, and Lowe appears to coalesce aspects of both Mirsky model
and the van Zomeren and Brouwer model.

As previously mentioned, in a study by Spikman, Kiers, and Deelman,
(2001) the factor structure of attention was explored in adults with TBI and a
normal control comparison group. In this study it was expected that the factor
structure discussed by van Zomeren and Brouwer (1994; i.e., focused, divided,
sustained, and supervisory control attention) would be found. An exploratory
factor analysis with Varimax rotation was implemented. Results indicated the
presence of two factors Memory-driven Action and Stimulus-driven Reaction in
the control group (N = 60). This was unexpected by the authors who then
proceeded to see if this same structure could be identified in the TBI sample (N =
60). Among the patient sample with closed head injuries (CHI) the author’s
report a qualitative difference was found, however there appeared to be an
altogether different structure between the two samples. The authors propose that
the lack of factorial support for van Zomeren and Brouwer’s attention theories are
due to a shift from automatic to controlled processing of information. In reviewing
the findings of Spikman, Kiers, and Deelman (2001) it appears that the measures
implemented in their study evaluated very similar constructs of attention resulting
in the consolidated factor structure found.

While the Davies (1984) and van Zomeren and Brouwer (1994) theory of
attention is practical and useful in many ways, it has not shown the needed
factorial support thus far. However, despite these criticisms of the study by
Spikman, Kiers, and Deelman, (2001) it is of importance to this present study
because it demonstrated that the factor structure of attention differed between
the normative and TBI sample, suggesting that the need to confirm a pediatric
TBI attention structure is still pertinent.

In conclusion, Mirsky’s model, Mesulam’s model, Posner and Petersen’
model, and van Zomeren and Brouwer’s model all maintain general overlapping
constructs based on interconnected attentional components associated generally
with frontal, parietal, and subcortical regions of the cerebral cortex and the RAS
(see table 2). As previously discussed van Zomeren and Brouwer’s model and
Mirsky’s model conceptually have many common constructs. However,
psychometrically the Mirsky model has been the best supported. Mirsky’s model
has also been associated with very specific brain structures (Mirsky et al. 1991,
1999, Mirsky & Duncan, 2002) and therefore provides the best model to test.
The following sections will provide a broad overview of traumatic brain injury to assist in understanding how TBI can affect the attentional system.

Table 2

<table>
<thead>
<tr>
<th>Attentional Models</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mirsky (1987, Mirsky et al. 1991)</strong></td>
<td>Sustain</td>
</tr>
<tr>
<td><strong>Zubin (1975)</strong></td>
<td>Focus</td>
</tr>
<tr>
<td></td>
<td>Shift</td>
</tr>
<tr>
<td></td>
<td>Encode</td>
</tr>
<tr>
<td><strong>Mesulam (1981)</strong></td>
<td>Selective</td>
</tr>
<tr>
<td>Stuss and Benson (1984, 1986)</td>
<td>Alertness</td>
</tr>
<tr>
<td>Heilman et al. (1985)</td>
<td>Visual-spatial</td>
</tr>
<tr>
<td>Cohen (1993)</td>
<td></td>
</tr>
<tr>
<td><strong>Posner and Peterson (1990)</strong></td>
<td>Anterior (Executive)</td>
</tr>
<tr>
<td>Luria (1966)</td>
<td>Posterior (Orienting)</td>
</tr>
<tr>
<td>Pribram and McGuinness (1975)</td>
<td>Vigilance (Alerting)</td>
</tr>
<tr>
<td><strong>van Zomeren &amp; Brouwer (1994)</strong></td>
<td>Focused</td>
</tr>
<tr>
<td>Goldman-Rakic (1988)</td>
<td>Divided</td>
</tr>
<tr>
<td>Davies, Jones, and Taylor (1984)</td>
<td>Sustained</td>
</tr>
<tr>
<td>Riccio, Reynolds &amp; Lowe (2001)</td>
<td>Supervisory attentional control</td>
</tr>
</tbody>
</table>

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Traumatic Brain Injury

Hannay, Howieson, Loring, Fischer, and Lezak, (2004) prefaced a recent chapter on traumatic brain injury with the following verse,

_Humpty Dumpty sat on the wall._
_Humpty Dumpty had a great fall,_
_And all the king's horses and all the king's men_
_Couldn't put Humpty together again._

_Mother Goose_

TBI is a primary cause of neurological injury in the United States. The Centers for Disease Control and Prevention (CDC, 2004) estimate that each year 1.4 million people in the United States sustain a TBI, of which approximately 50,000 to 55,000 die. It is further estimated that 80,000 to 90,000 people will suffer a long-term or lifelong disability due to TBI (CDC, 2004). The leading causes of TBI are falls, motor vehicle accidents, and assaults (including child abuse). Motor vehicle accidents are the major cause of TBI in people under 75 years of age. For people 75 years and older falls cause the majority of TBI cases. These statistics provide information on the magnitude and relevancy of research in this area.

Head injuries are typically caused by a severe blow to the head or a sudden and forceful acceleration/deceleration that consequently damages the central nervous system and causes some form of an alteration in the level of consciousness (Larrabee, 2004) and/or persisting neurobehavioral deficit. Smith,
Barth, Diamond, & Giuliano (1998) explain that a comprehensive description of the presumed mechanisms underlying TBI include injury mechanism or how damage was sustained to the neural tissue (i.e., shear strain, compressive, tensile, penetrating), neurocognitive severity (i.e., mild, moderate, severe), type of neuropathology (i.e., diffuse, focal, hypoxic-ischemic, edema), primary versus secondary events, age, premorbid status (i.e., education, level of adjustment), and other medical and psychosocial factors. The following discussion elaborates on the classification of TBI based on neurocognitive severity. Additional discussion of injury mechanisms and types of neuropathy will be discussed in subsequent sections.

**Classification of Traumatic Brain Injury**

Classification of head trauma assists in evaluating, understanding and treating those that suffer from TBI. The most immediate classification of TBI is in regard to skull fractures. In closed head injuries (CHI) the skull integrity is maintained, but in penetrating, or open, head injuries (PHI) the skull integrity is fractured or damaged. There are two major subtypes of PHI: a) depressed fracture(s) of the skull and b) fracture(s) of the skull resulting in direct contact with cerebral tissue. These three categories of head trauma generally relate to greater levels of cerebral damage starting with the first (CHI) as typically having the least (barring no extenuating internal pressure such as a hematoma) and progressing to the last (PHI with cerebral tissue contact) as experiencing the most severe damage.

Bigler and Clement (1997) suggest that currently there is no common consensus on guidelines for determining the severity of brain damage. However
the available systems typically combine some common features including alterations in consciousness, length of coma, presence of persisting neurological signs, and/or cognitive dysfunction. One such system has been proposed by Jenette and Teasdale (1981), Becker, Grossman, McLaurin, and Caveness (1979), and Coxe and Grubb (1978) and suggests the following 4 major levels of neurobehavioral deficits due to trauma:

1) **Mild Brain Injury:** In mild TBI there is a brief alteration in the level of consciousness defined by Larrabee (2004) as, “a loss of consciousness (typically < 30 minutes) and/or circumscribed confusion and disorientation/post-traumatic amnesia” (for a period not exceeding 60 minutes). Mild TBI’s often constitute what is called a ‘concussion’, which is characterized by difficulties with headache, confusion, lightheadedness, dizziness, blurred vision or tired eyes, ringing in the ears, bad taste in the mouth, fatigue or lethargy, a change in sleep patterns, behavioral or mood changes, and trouble with memory, concentration, attention, or thinking (Bigler & Clement, 1997). Sometimes these problems arise several days to weeks after the head trauma in what is known as post-concussion syndrome (PCS). The symptoms of PCS in mild TBI generally continue for several weeks before subsiding. Greater amounts of attention is being paid to mild TBI due to newer findings suggesting that neurobehavioral problems arising from the trauma can persist longer than previously thought (Reitan & Wolfson, 1993; Hannay, 2004).
2) **Moderate Brain Injury:** Symptoms of moderate TBI will have all the same symptoms of Mild-TBI, but in this state there is an alteration in the level of consciousness that lasts longer than an hour or the person experiences focal neurological deficits. Moderate TBI may also include a headache that progresses in intensity and/or continues with no sign of relief, dilation of one or both pupils of the eyes, persistent vomiting or nausea, convulsions or seizures, an inability to awaken from sleep, slurred speech, weakness or numbness in the arms or legs, loss of coordination, or increasing levels of confusion. Greater length of PCS symptoms. Inside the first 24 hours of the injury approximately 25-30 percent of patients experiencing brain contusions or hematomas and about 45-60 percent of patients with penetrating head injuries will develop seizures. These seizures typically cease within a week. The person can also experience Posttraumatic Amnesia (PTA: impaired memory) for up to 24 hours.

3) **Severe Brain Injury:** In this range the person experiencing TBI can experience all of the previously described symptoms to a greater extent, but may also experiences an abrupt loss of receptive comprehension and lucid expression. This can often extend to the point that the person is comatose. A coma is generally defined as: 1) not opening eyes, 2) not obeying commands, and 3) not uttering understandable words. Motor and sensory impairment is common in this state that is likely a result of a brain contusion (bruising of the brain) and shearing damage (shear strain: refers to the pulling apart of axons and disruption of cell bodies as one layer of
neuronal material slides over another) to the white matter. Recovery can vary, but is often limited.

4) Profound (Very Severe) Brain Injury: In this state the person becomes unconscious and unresponsive immediately or shortly after the insult. This commonly results in death, or in the case of those that survive, there is such profound CNS damage that the person will likely be hospitalized for life often in a persistent vegetative state.

Additional symptoms experienced by children can include significant changes in socialization at school, reduction eating/nursing up to and including no intake of food, and persistent crying or irritability.

A number of scales have also been developed to assist in classifying severity of brain injury. Probably the most popular is the Glasgow Coma Scale (GCS) developed by Teasdale and Jennet (1974). It is commonly used for assessing the severity of head trauma while the person is still in the acute posttraumatic state. GCS scores range between 3 and 15, with 3 suggesting severe impairment, and 15 being considered a baseline functional state. It is composed of three areas: Best Eye Response (Score 1-4), Best Verbal Response (Score 1-5), Best Motor Response (Score 1-6) (see Table 3). The GCS's scaling system provides objectivity, reproducibility, and simplicity. When the GCS is properly used, the degree of inter-rater reliability is high. Subsequently, a change in the GCS from one assessment to the next is not only reliable, but further indicates a significant change in level of consciousness. Neurobehavioral deficit severity is generally categorized by GCS scores into mild
(13-15), moderate (9-12), and severe (3-8), with scores of 8 or less being generally indicative of a comatose state (Teasdale & Jennett, 1974; Jennett & Teasdale, 1981; Lezak, Howieson, & Loring, 2004).

Some investigators have also utilized posttraumatic amnesia (PTA) to assess the severity of injury. PTA has been found to be well correlated with GCS scores (Levin, Benton, & Grossman, 1982). If PTA estimates are considered to begin at the point of injury it has been found that PTA will typically last four times the length of coma (Brooks, 1989). However, problems related to utilizing PTA as a determinate of severity create greater problems in practical application. For example, some researchers consider PTA to begin once the person is conscious (Bigler & Clement, 1997), while others initiate PTA estimates from the point of injury (Brooks, 1989). Other difficulties lie in determining when PTA has subsided and subjective reports from the person experiencing PTA. Jennett and Teasdale (1981) proposed the following scale for estimating the severity of injury utilizing PTA (see Table 4). Additionally, medical professionals typically pay close attention to the length of time a person experiences a loss of consciousness (LOC), where longer levels of LOC tend to experience more negative outcomes. The use of PTA, LOC, and GCS classification methods provide only gross, acute, and simple estimates of brain injury severity.

Table 4.

Estimates of Severity of Injury Based on PTA Duration

<table>
<thead>
<tr>
<th>PTA Duration</th>
<th>Severity</th>
</tr>
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</table>

32
Another way of evaluating the severity of brain damage is through neuroimaging and neurorecording technologies. Neuroimaging and neurorecording provide a way to evaluate the structural effects of the neural damage. Some of the more prominent forms are computerized tomography (CT) scans, magnetic resonance imaging (MRI), electroencephalogram (EEG), computer aided tomography (CAT), positive emission tomography (PET), and single photon emission computed tomography (SPECT). However, these methods are limited to evaluating structural and processing abnormalities and dysfunction. The existence or pervasiveness of neurobehavioral dysfunction cannot always be detected or associated with these techniques (Reitan & Wolfson, 1993; Hannay, 2004).

A precise evaluation of the neurocognitive effects of TBI is important for understanding the limitations and prognosis of individuals who are affected. To evaluate the broad spectrum of damage to the brain that can affect all cognitive,
emotional, sensory, and motor areas Reitan and Wolfson (1993) proposed a system of measurement. This system is based on evaluating *interindividual differences* (what levels of functioning are significantly below what is expected in the normal population) and *intraindividual differences* (patterns or signs of performance indicative of impairment) for determination of neuropsychological impairment. There are two general subsections within each of these two areas. Within interindividual differences there is the Level of Performance (LOP; scores low enough to be considered suggestive of impairment) and Pathognomonic Signs (PS; errors on tasks that are not typically missed by people in the normal population). In the intraindividual realm there is Pattern of Performance (POP; specific strengths and weaknesses that are uncharacteristic of typical neural functioning) and Right-Left Differences (R-L D; Dramatic differences in level of performance between measures typically indicative right hemisphere versus left hemisphere functioning). By assessing these four areas across essential regions of neuropsychological function Reitan and Wolfson suggest that predictions can be made concerning preexisting conditions, recovery trends, and outcome of traumatic brain injured patients with some degree of certainty through the use of the Halstead-Reitan Neuropsychological Test Battery (HRNB, Reitan, 1969).

The HRNB is composed of a variety of neuropsychological tests that evaluate the broad functioning of the person being tested. The specific tests from the HRNB that have been found to be most sensitive to impairment are the Category Test, the Tactual Performance Test – Localization, and the Trail Making Test – part B. From the Wechsler scales, commonly included in
administration of the HRNB, Digit Symbol Coding has been found to be the most sensitive of those scores (Reitan & Wolfson, 1993). Also derived from the HRNB is the Halstead Impairment Index (Halstead, 1947) consisting of 7 scores from tests and subtests in the HRNB and provides a score of general impairment. Similar to the Halstead Impairment Index is the Average Impairment Rating (Russell, Neuringer, Goldstein, 1970), which is a more extensive summary index of cognitive ability based on the tests from the Wechsler Scales and the HRNB. Reitan and Wolfson (1993) discuss the ability of both of these indices to discriminate between people with or without cerebral damage. However, they further describe the more extensive General Neuropsychological Deficit Scale (GNDS, Reitan & Wolfson, 1988), which provides a ranking of overall neuropsychological functioning as compared to the general population based on all the scores derived from the HRNB. The GNDS assesses a person’s level of adaptive ability, problem solving skills, and integrative skills utilizing both interindividual and intraindividual differences to attain a final score.

This section has briefly described the major ways of classifying the severity of brain damage in TBI based on open versus closed head injuries, immediate levels of conscious behavior, neuroimaging techniques, and through neuropsychological testing. However, other important aspects of brain injury are the mechanisms involved and the neurobehavioral sequelae resulting from TBI. The following sections will discuss these areas in greater detail.
Mechanisms of Brain Injury in TBI

There are both primary mechanisms (acute affects of the brain insult) and secondary mechanisms (subsequent problems related to the insult) that are responsible for cerebral damage in TBI (see Table 5). According to Ommaya and Gennarelli (1974), head injuries occur when the head suddenly moves in a direction with a dramatic acceleration/deceleration. Or restated, the skull is thrown forward, but the brain tends to lag behind because of inertia (or resistance), this causes the brain to 'slosh' around within the cerebral spinal fluid impacting against the skull on one interior surface then recoiling against the opposite side. Because the head pivots at the neck when the head is suddenly thrown forward (as in whiplash), the maximum effect of the inertia is between the cerebral cortex and the skull. The brain stem is the most proximal to the neck and thereby experiences the least movement and effects of inertia. However, as the size of the force is increased the deeper the radiating forces of travel. Ommaya and Gennarelli suggest that as the affects of this force descend into subcortical regions it results in greater severity of symptoms. Should these forces be large enough to emit deep into the brain stem and the reticular activating system the harm to this region can affect arousal and incur unconsciousness or death.

Damage can also occur as the brain impacts against the skull resulting in contusions or lacerations (Hannay et. al., 2004). Bruising of the neural tissue is referred to as a contusion. A coup contusion results from direct impact with the skull (see Figure 2, part A). A countercoup contusion results form the recoil of
the brain to the opposite side of the skull (see Figure 2, part B). As with all
bruises to bodily tissue, there is local swelling in the area. Because of the
enclosed skull cavity the brain has no space to swell. This causes additional
pressure to be placed on the brain as it pushes up against the skull walls. This
swelling causes an interruption of brain communication and normal functioning.
To a greater degree, severe contusions and the symptomatic swelling create
vascular insufficiency resulting in encephalomalacia (softening of the brain
tissue).
<table>
<thead>
<tr>
<th>TYPE OF MECHANISM</th>
<th>Primary</th>
<th>Secondary</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Focal</strong></td>
<td>Laceration</td>
<td>Hematoma</td>
</tr>
<tr>
<td></td>
<td>Contusion</td>
<td>Hygroma</td>
</tr>
<tr>
<td></td>
<td>Depressed Skull Fracture</td>
<td>Localized Edema</td>
</tr>
<tr>
<td></td>
<td>Cavitation from PHI</td>
<td>Focal Hypoxia-Ischemia</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Herniation</td>
</tr>
<tr>
<td><strong>Diffuse</strong></td>
<td>Acceleration/deceleration</td>
<td>Increased ICP</td>
</tr>
<tr>
<td></td>
<td>and rotation producing</td>
<td>Hydrocephalus</td>
</tr>
<tr>
<td></td>
<td>diffuse axonal injury</td>
<td>Generalized Edema</td>
</tr>
<tr>
<td></td>
<td>And hemorrhage</td>
<td>Diffuse Hypoxia-Ischemia</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Neurochemical changes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Herniation</td>
</tr>
</tbody>
</table>

Adapted from Smith, Barth, Diamond, & Giuliano (1998)

Lacerations or cutting and tearing of the neuronal tissue are primary focal damages to specific areas of the brain commonly conceptualized as being part of a penetrating head injury (PHI). Lacerations also result in dysfunction to the associated neural area (Hannay et. al., 2004). Less visibly, head injuries often cause the brain to impact against the rigid boney prominences on the anterior basal plate of the skull causing tearing or twisting of the structures and blood vessels of the brain (Hannay et. al., 2004) resulting in lacerations to the anterior and ventral surfaces of the frontal and temporal lobes (Wilde et al., 2005). This
characteristic pattern of cerebral damage often found in TBI may be associated with the aspects of the attentional system found in the frontal and temporal lobes.

Figure 2
Illustrating Coup and Countercoup

1) Showing the brain impact (A) and recoil (B).

One primary mechanism that was initially overlooked is the diffuse or widespread shearing and stretching of neuronal white matter fibers within the CNS (the friction of a layer of brain material sliding over another layer), which is called shear strain. The shear strain of neurons has been found to be some of
the most influential effects of brain injury (Levin, Benton, & Grossman, 1982) resulting in *diffuse axonal injury* (DAI). DAI is the tearing or breaking of axons and the disruption of cellular bodies. A strong swift external force to the head can cause acceleration/deceleration and rotation of the brain inside of the skull resulting in DAI. DAI most notably can affect arousal, attention, mood disturbance, and behavioral changes occurring in both CHI and PHI (Bigler & Clement, 1997). All of the major models of attention discussed previously describe the projections and communication pathways that form the system. DAI most directly disrupts these pathways throughout the brain.

Intracranial hemorrhages can also occur from cranial trauma, and are defined as bleeding within the intracranial cavity, including bleeding in the brain and within the cranial epidural, subdural, and subarachnoid spaces. Hemorrhages can cause hematomas, which are usually a mass of clotted blood that can cause rapid neurological deterioration. The following is a brief description of various subtypes of hemorrhages and hematomas (Bavetta & Benjamin, 2002; Reed & Welsh, 2002; Laplaca, Cullen, & McLoughlin, 2005).

1) **Intracerebral hemorrhages** occur with injury to larger deeper cerebral vessels with extensive cortical contusion affecting the cerebral tissue.

2) **Intraventricular hemorrhages** occur when there is bleeding within the ventricles, resulting from exceptionally severe TBI, typically with subsequent mortality.

3) **Subarachnoid hemorrhages** occur due to lacerations of the superficial microvessels in the subarachnoid space between the pia and arachnoid
membranes. Traumatic subarachnoid hemorrhages can create hydrocephalus when blood clotting obstructs the arachnoid villi or the third or fourth ventricle.

4) Epidural hematomas result from laceration of the dural arteries or veins, and often come about as a tear in the middle meningeal artery, sometimes by bone fragments.

5) Subdural hematomas occur below the inner layer of the dura but external to the brain and arachnoid membrane and is rapidly clotting blood. Subdural hematomas occur in severe TBI's with injuries to the cortical veins or pia artery. The associated mortality rate can be as high as 80%.

Contusions, intracranial hemorrhages, and edema (excessive accumulation of fluid in neural tissue spaces, which causes swelling) can produce increased intracranial pressure (ICP). The dangers involved with ICP are the potential for ischemia (the interruption in cerebral blood flow reducing the movement of glucose, oxygen, and waste removal). Elevated levels of ischemia can produce infarction (necrosis or death of cells in a tissue). This results in dysfunction within seconds and will lead to permanent damage within minutes (Bigler & Clement, 1997). The subsequent damage can be experienced across any system of the CNS.

It is important to note that prominent secondary mechanisms in the form of posttraumatic degenerative changes are often found in the weeks following a traumatic brain injury. The development of seizures, hydrocephalus, and neurotransmitter pathway changes may also occur (Smith et. al. 1998; Hannay

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et. al., 2004). Degenerative changes will produce neural atrophy leading to reduction in brain matter and increase in the size the ventricles (Bigler & Clement, 1997; Smith et. al. 1998; Hannay et. al., 2004). Bigler, Kurth, Blatter, and Abildskov (1993) found that 15 subjects with moderate to severe brain injuries showed normal ventricle-to-brain ratios under CT scans on the day of the injury, but at a six week post-injury scan there was a significant increase in ventricle-to-brain ratios. This loss neural tissue due to head trauma can lead to numerous forms of neurobehavioral problems.

**Neurobehavioral Sequelae**

Post-concussive symptoms typically are experienced as headaches, dizziness, fatigue, irritability, memory weaknesses, attentional problems, blurred vision, vertigo, etc. Symptoms are generally experienced beyond the acute phase of injury with moderate to severe TBI, but are more immediate with mild head injury. In mild TBI these symptoms generally abate with time. Long and Haban (1986) found that there was an interaction between neurological damage and situational stress as individuals attempted to perform pre-trauma activities and tasks. Assessing post-concussive symptoms can provide beneficial information regarding the recovery and enduring effects of the injury on the individual.

Emotional struggles and personality changes are common following TBI (Larrabee, 2004). MMPI scale elevations with TBI populations have been found on scales 2 (Depression), 8 (Schizophrenia), 1 (Hypochondriasis), 3 (Hysteria), and 7 (Psychasthenia; Bigler & Clements, 1997). While subsequent emotional
problems related to difficulties from the TBI are to be expected, it is interesting to note that on the MMPI Harris-Lingo subscales mental dullness and physical problems demonstrated the most significant raises in elevations (Gass & Russell, 1991). This suggests that there are physical and cognitive difficulties elevating some scales as well as emotional issues and stress related problems. Personality change is a distinct possibility as well.

Cognitive disruptions are common longer term effects of TBI. The most common deficits are reduction in processing speed and attentional capacity as these processes require greater global CNS abilities. Other areas of concern are retrograde amnesia (loss of long-term memories for events prior to trauma) and anterograde amnesia (difficulty creating new long-term memories beyond the event). In these cases memory impairment that can be debilitating or substantially distressing well beyond that of typical post-concussive symptoms. Learning, flexible thinking, logic and reasoning skills, and concentration can all be affected and should be properly assessed (Smith et. al. 1998).

Evaluating Traumatic Brain Injury
Numerous areas of neurocognitive function can be adversely affected by TBI (Spreen & Strauss, 1998; Lezak, Howieson, & Loring, 2004) such as intelligence, academic achievement, language, visual-spatial, learning, attention/concentration, memory, planning and organization (sometimes referred to as executive function), and sensory and motor function. A thorough neuropsychological evaluation should assess these specific areas to provide the clinician with a global understanding of the person and the specific deficits they may be facing. All of these areas are important to assess because of the
complexity of excitatory and activating processes involved in brain function. Particularly relevant to this study is evaluating the attentional system.

Attention and concentration can be measured with numerous neuropsychological tests. One of the best used of these is the Trail Making Test, where a person must draw a line from beginning to end following an organized sequence. From the Wechsler intelligence scales Arithmetic, involving attention, concentration, and numerical reasoning, Digit Symbol Coding and Symbol Search, involving visual motor co-ordination, speed, and concentration, and Digit Span, which involves short term auditory memory and concentration. Also, vigilance tests such as the Continuous Performance Test that require the individual to keep alert to target stimuli in a monotonous task provide information on the ability to sustain attention. These various tests evaluate different aspects of attention and are not equivalent.

Closely akin to attentional measures are tests of planning, learning, and organization, sometimes referred to as executive function. Executive function is best evaluated by tests such as the Wisconsin Card Sorting Test (WCST) and Halstead Category Test. These tests evaluate the ability to conceptualize and adapt to information. For the WCST, the subject is required to categorize the cards presented to them based upon color, shape, or number. The person taking the test must learn how to categorize the cards based on feedback from the examiner, and the categories change throughout the test. In the Category Test the person taking the test must determine what number between 1 and 4 various symbolic pictures suggest. The Category Test is divided into seven subtests.
where the idea or principle that assists in solving the question changes for each new subtest. The Stroop Test is also a good measure for evaluating executive function. It requires a person to continually shift their perceptual set and suppress habitual responses. These three tests provide information on a person's ability to think abstractly and inhibit irrelevant or distracting information.

Summary

Traumatic brain injury can cause extensive damage to the cerebral cortex and underlying areas. While this damage can be associated with an array of neurocognitive deficits, of particular interest in this study is its effects on the attentional system. In TBI a characteristic pattern of damage to the anterior and ventral surfaces of the frontal and temporal lobes. It is theorized that this damage can result in attentional deficits (Schachar, Levin, & Max, 2004; Spikman, Deelman, & van Zomeren, 2000). Lezak (1995) described how the impairment of attentional abilities can diminish general cognitive functioning and productivity due to the resulting inattentiveness and faulty concentration. TBI can result in persistent attention problems years after the brain trauma (Robin, Max, & Stierwalt, 1999; Schachar, Levin, & Max, 2004; Spikman, Deelman, & van Zomeren, 2000). In the proceeding section numerous studies involving the assessment of attention subsequent to TBI.

Attentional System Following Traumatic Brain Injury

Attentional-inhibitory problems subsequent to traumatic brain events are frequent (Ponsford & Kinsella, 1992; Spikman, van Zomeren, & Deelman, 1996;
Dennis, Guger, Roncadin, Barnes, & Schachar, 2001; Max, Lansing, Koele, Castillo, Bokura, & Schachar, 2004; Wassenberg, Max, & Lindgren, 2004; Lowther & Mayfield, 2004). The heterogeneity of pediatric brain injury is a clear difficulty encountered by any study on the matter. Differences in severity, age since injury, depth and length of coma, impact region, age, premorbid factors, and socio-environmental factors all affect each individual greatly. Also, TBI generally causes diffuse brain damage, due to factors such as edema, diffuse axonal injury, and hemorrhaging. These events will often result in the interruption, disconnection, or adverse influence of the structure and connecting pathways of the attentional system (Trexler & Zappala, 1988). The neuropsychological manifestations are less specific in TBI than in disorders characterized by more focal pathology (e.g., strokes) and so TBI can cause a dysregulation of the whole system, resulting in multiple neurobehavioral disturbances. Traumatic brain injury results in a wide array of deficits of the attentional system that generally relate to the severity of the TBI. This linear path can progress from a passing state of disorientation to a persistent coma (Lezak, Howieson, & Loring, 2004; Mirsky et al. 1991; Posner & Peterson, 1990; Stuss & Benson, 1984 & 1986; van Zomeren & Brouwer, 1994). The severity of brain injury to deep subcortical areas is associated with the length of coma, and indirectly the general damage to brain structures that may influence the type of attentional disorders manifested (Jennett & Teasdale, 1981; Levin, 1985; Mirsky et al., 1991 & 1999; Teasdale & Jennett, 1974; Trexler & Zappala, 1988; van Zomeren & Brouwer, 1994). However, even mild TBI can result in attention...
impairments (Reitan & Wolfson, 1993), which may be due to damage of the connecting pathways of the attentional system.

In one of the early studies on the attention system following TBI Trexler and Zappala (1988) evaluated the recovery of attention and the determinants of variability of attentional functioning after a traumatic brain insult. The sample consisted of 70 TBI subjects ranging in age from 16 to 62 years with a mean of 32 (sd=10) and an average 12.6 years of education. The sample was divided into the acute group (n = 20) that was 2-18 weeks postinjury, the subacute group (n = 21) that was 19-52 weeks postinjury, and the chronic group (n = 23) that was 53 to 520 weeks postinjury. The only significant differences between the groups were for time since injury and length of coma, and no meaningful differences were found on measures of attentional functions. The authors found that when the sample was classified based on clinical-neuropathological syndromes that significant differences regarding attentional deficits were found. This was not true using typical severity indicators (e.g., depth and length of coma or cognitive disorientation). Therefore the authors suggest that qualitative aspects of the subjects' pathology may be more important for determining the nature of the attentional problems. Although, Ponsford and Kinsella (1992) evaluated attentional deficits in 88 severely traumatically head-injured people who were 16 to 45 years old and an age matched orthopedic rehabilitation group of 59 people. Three studies provided no evidence for the presence of deficits of focused, sustained, or supervisory attentional control. Yet evidence for a deficit in speed of information processing was readily found.
In contrast, Spikman and colleagues (Spikman, van Zomeren, & Deelman, 1996; Spikman, Timmerman, van Zomeren, & Deelman, 1999; Spikman, Deelman, & van Zomeren, 2000; Spikman, Kiers, & Deelman, 2001) have done several studies evaluating the attentional process subsequent to TBI. The first major paper Spikman, van Zomeren, and Deelman (1996) compared the performance of 60 closed-head-injured patients between the ages 15 to 58 years. The TBI patients were assessed on a series of tests addressing focused, divided, and sustained attention, and supervisory attentional control to the performance of a matched group of 60 healthy controls. While the TBI group as a whole performed worse on an array of attention tasks among the severity subgroups. The authors found little evidence of subgroup differences on attention, but did find an overall slowing of speeded task abilities. Subsequently, Spikman, Timmerman, van Zomeren, and Deelman (1999) evaluated recovery of attention utilizing the same TBI group 1 year or more after TBI. Results indicate that group deficits across attention measures still remained, but that the scores indicated recovery over time. As previously mentioned Spikman, Kiers, and Deelman, (2001) explored the factor structure of adults with TBI and a normal control comparison group resulted in a unique 2 factor structure among both samples, although structures were found for each group. Similar findings were purported by Chan (2002) who evaluated persistent attention problems in 92 TBI patients compared with 86 normal controls basing the analyses on the van Zomeren and Brouwer (1994) model. Results indicated that TBI patients with
persistent cognitive complaints demonstrated clear deficits in attentional functioning and changes in attentional structure.

Dockree, Kelly, and Roche (2004) investigated sustained attention in 10 TBI patients and 10 age and gender matched controls. TBI patients were selected based on common disruptions to fronto-parietal connections in traumatic brain events. Currently sustained attentional abilities are theorized to be modulated by the fronto-parietal circuits that are often compromised following TBI. Sustained attention was examined through a no-go type task where the participant withheld a key press to an infrequent no-go target embedded within a predictable sequence of numbers. Results were analyzed through response times and EEG. Results indicated that TBI patients made significantly more errors than controls. Further, through analysis of the EEG and RT intervals, the TBI group demonstrated impaired ability at enhancing sustained attention as the upcoming no-go trial approached. This supported the author's assumption that errors are a result of a transient drift in controlled processing.

Whyte, Grieb-Neff, Gantz, and Polansky (2006) sought to evaluate commission errors on a continuous performance task with patients who had TBI scores below 12 on the Glasgow Coma Scale. The task used was the sustained attention to response task (SART). Participants received the test every day for six weeks following stabilization from TBI (N = 26; mean age 36) or two weeks in the control group (N = 35; mean age 37). Results indicate that TBI patients were not differentiated on errors of commission.
In a study by Azouvi, Couillet, and Leclercq (2004) dual-task performance was assessed in 43 patients at the subacute or chronic phase post TBI. The patients were all assessed as being in the severe stages of TBI. The results of this study indicate that divided attention deficit in patients with TBI is associated to a reduction in available cognitive processing resources. However, a deficit related to strategic processes in attentional allocation and switching was not supported. The authors suggest that the higher level of subjective mental effort may explain why TBI patients frequently complain of mental fatigue.

These adult TBI studies provide a basis for the expected general effects the injury may result in. Smith, Barth, Diamond, and Giuliano (1998), provided an expected trajectory of general cognitive recovery subsequent to moderate and severe TBI (see Figure 3). As shown below the greatest improvement typically occurs within the first 3 to 6 months often designated as the acute phase. Whereas beyond the 6 month mark, referred to as the chronic phase, there is a substantial tapering off that occurs. By 24 months the majority of improvement has occurred. While attentional deficits can show similar recovery the major attentional systems are located in areas most likely to receive the brunt of the damage in a traumatic head injury event (Hannay et al., 2004; Posner & Peterson, 1990; van Zomeren & Brouwer, 1994; van Heugten et al., 2006). Research has found sizable attentional deficits several years following a TBI (Ponsford & Kinsella, 1992; Trexler & Zappala, 1988). To complicate this problem further, models for neurocognitive recovery of children following TBI have not been established, likely due to the developmental factors involved.
Developmental Effects on the Assessment of Attention

Children differ dramatically from adults due to the rapid neurocognitive development they experience. Attentional development has only recently been studied and will require greater research to establish its general progression. Korkman, Kemp, and Kirk (2001) studied the development general neurocognitive function in children ages 5 to 12. They found a general acceleration of acquired function in the 5 to 8 year old range with a slowing in the
9 to 12 year old group. Pascualvaca, Anthony, and Arnold (1997) found that girls performed significantly better on attention tasks and that higher verbal intelligence was associated with elevated performance on attentional tasks. To evaluate deficiencies in development Mirsky, Pascualvaca, Duncan, and French (1999) applied their neuropsychological model of attention (encoding, focusing, sustaining, and shifting attention) in children with attention deficit hyperactivity disorder (ADHD). The results indicated that in ADHD several areas of the attentional system are impaired in children diagnosed with ADHD. The authors tentatively feel at this time that the deficiencies in attention found in ADHD are probably not best ascribed to learning disorders, but may very well be related to immaturity of brain development. In a heterogeneous clinical sample of children Price, Joschko, and Kerns (2003) found that attention and adaptive functioning are correlated even when controlling for intelligence. The authors suggest that a child's attentional development is essential to their ability daily life functioning.

In a large sample of 435 children followed from the ages of 8 to 13 years of age Rebok, Smith, Pascualvaca, Mirsky, Anthony, and Kellam (1997) examined changes in attention based on the Mirsky four factor model. This was done across three samples with reductions in sample size on each ensuing sample (435, 289, and 269). Results indicate that Sustained attention as measured by the Continuous Performance Task showed marked improvements across the three samples. However, general improvements were seen across all factors of attention (sustain, focus, shift, and encode), with greater overall improvement from 8 to 10 years than 10 to 13 years. The authors suggest that
neuroanatomical development in children corresponds to greater attentional achievement, with greater progress found in younger ages.

Klenberg, Korkman, and Lahti-Nuuttila (2001) evaluated the changes in performance of attention and executive functioning by assessing 400 children (50% female) between the ages of 3 to 12 years. The participants completed 2 tasks of motoric inhibition, 4 tasks of attention, and 4 tasks of executive function utilizing the NEPSY, a Developmental Neuropsychological Assessment (Korkman, Kirk, & Kemp, 1997). The results indicated significant relationships among gender and development in Phonemic Fluency subtest, the Visual Attention subtest and the Auditory Response Set subtest of the NEPSY. Significant relationships were also found among parental education and development in Semantic Fluency, Phonemic Fluency, and Visual Search. It was also found that inhibitory function develops prior to more complex attentional systems.

This research was supported by Klimkeit, Mattingley, and Sheppard (2004) where they utilized a novel task with 40 children from age 7 to 12 years of age. The task involved reaching quickly towards a target while having to sporadically ignore a distractor. The results indicated that between the ages of 8 and 10 the greatest advances in vigilance, set-shifting, response inhibition, selective attention, and impulsive responding were made. However, it was found that performance tapered off between 10 and 12 years of age. The authors suggested that these findings of attentional functioning improvement correspond...
with developmental expansion of frontal brain functions between 7 and 10 years of age.

Developmentally it appears that in pediatric samples there is an accelerated trajectory of growth in attention that slows with age as attentional skills are consolidating. The research does not suggest that certain skills do not exist at younger ages, but that they are in a continuous state of improvement and refinement. Therefore, while younger children may perform more poorly than older children this is within a developmental continuum. The following section will review pediatric TBI so as to better understand the interaction between attentional development and the neurocognitive deficits of TBI.

Attention in Pediatric TBI

Attention deficits are a common consequence of traumatic brain injury in childhood. While attention problems are commonly reported following pediatric TBI (Hooper, Alexander, & Moore, 2004), the literature regarding this problem is relatively recent and not fully developed at this time. A number of clinical tests have been developed to assess various aspects of attention, but the factor structure of attention in pediatric TBI has not been examined. As previously discussed, current theories of the attentional system suggest an interdependent group of components in connection with certain brain structures (Goldman-Rakic, 1988; Mirsky et al., 1991; van Zomeren & Brouwer, 1994), however developmental factors such as maturation and plasticity involved with these structures is still undetermined. A limited number of studies have reported on attentional outcomes following childhood TBI, and have provided largely
inconsistent results. The proceeding discussion shall determine the problem and discuss relevant findings with regard to attention and pediatric TBI.

In establishing the problem Hooper, Alexander, and Moore (2004) investigated pediatric TBI from the reported perspective of the primary caregiver(s). Their sample consisted of 681 children who had sustained a TBI ranging in age from infancy to 18 years. The sample was composed of 83% mild, 5% moderate and 12% severe TBI. While the sample clearly has limitations with regard to severity and age range, the caregiver responses at 10 months after the TBI indicated that attentional problems and low tolerance for frustration were equivalent to headaches as the most pervasive problem reported.

Evidence for preinjury attentional deficits may confound the problem, where it is suggested that attentional problems place children at a higher risk for developing TBI. However, research by Schachar, Levin, and Max (2004) suggest that TBI in children leads to secondary attention deficit hyperactive disorder (SADHD) even after taking preinjury disturbance into account. Further, Max et. al. (2004), found research demonstrating postinjury rates of SADHD, sometimes referred to as “hyperkinetic” disorder, ranging from 8 to 53 percent. The broad range of percentages appears to be related to the differing samples and study design. However, a child may still have acquired an attentional deficit as compared to pre-morbid functioning (Konrad et. al., 2000, Dennis et. al., 2001).

In research by Anderson, Fenwick, and Manly (1998) residual deficits in attention following TBI in children was examined using the four attentional...
domains of sustained, focused, and divided attention, and response inhibition. The sample consisted of a clinical group that had obtained a moderate or severe TBI and a normal control group. Their specific hypothesis was to investigate whether attentional deficits after TBI are global, or if specific components of attention are affected. Results indicated deficits in sustained and divided attention, and response inhibition, but no significant deficit in focused attention for TBI.

Ewing-Cobbs, Prasad, and Fletcher (1998) utilized Mirsky's (1991) multidimensional framework to evaluate the attentional system in a pediatric sample with mild-moderate and severe TBI. Attentional processes were measured in 91 pediatric (34 mild-moderate and 57 severe) TBI cases, aged 4 months to 15 years at the time of injury, but 5 to 8 years post TBI. Severity was evaluated using the Glasgow Coma Scale with modifications for children 5 and under (see Table 2), and CT scans. Data was analyzed using ANOVA's. Results indicate that children with severe TBI performed more poorly than children with mild-moderate TBI on tests comprising the focus and shift factors. Interestingly, younger children scored below older children regardless of injury severity on the Digit Span subtest and continuous performance test. The authors concluded that younger children are particularly vulnerable to attention related deficits and increasingly so with greater injury severity. While this study provides excellent information regarding children with TBI as compared to normal controls it did not establish the factor structure in the TBI sample to verify the stability of the structure proposed by Mirsky. Based on the findings of Spikman, Keers, and
Deelman (2001) and Chan (2002), it is possible that this structure may not hold true.

Robin, Max, and Stierwalt (1999) examined sustained attention in 64 children and adolescents 49 of whom had suffered a TBI 2 years prior and 15 were orthopedic controls. Results indicated that greater TBI severity resulted in greater vigilance (sustain) decrements. Catroppa and Anderson (1999) also examined sustained attention in a group of 76 children with TBI. The WISC-III and Continuous Performance Test were used to evaluate the children. Reaction time did not significantly differentiate the TBI severity groups. Catroppa and Anderson found that children with severe TBI showed significant deficits with regards to sustained attention. The authors conclude from this study that during the acute stages of TBI attentional impairments are not global in children.

Fenwick and Anderson (1999) explored attentional deficits experienced by children suffering from TBI. This was done by evaluating established aspects of TBI. The specific areas investigated were sustained, focused, and divided attention, attentional shift, and response inhibition among a sample of 18 children with TBI (between the ages 8 and 14 years) and 18 non-injured matched controls. The results indicate that children who have sustained moderate-to-severe TBI exhibiting significant deficits on sustain, focus, and response inhibition.

Konrad, Gauggel, and Manz (2000 b) performed another study using mostly the sample as a prior study (Konrad, Gauggel, & Manz, 2000 a) but deriving different results based on variations in tests included and composition of
the TBI sample. Again the study assessed differences between pediatric TBI and ADHD on response inhibition processes. In this sample 27 children with TBI, 31 children with developmental ADHD, and 26 matched controls between the ages of 8-12 years. The results showed that the ADHD group displayed deficits in stop processes, and that the TBI group had deficits in both stop and go processes. The authors further concluded that TBI patients showed an overall slowing in information processing.

Konrad, Gauggel, and Manz (2000 a) investigated response inhibition deficits in children with ADHD and TBI with regards to motivational factors. The use of the stop signal task was implemented with and without reward contingencies for successful inhibition. Ninety-four children between the ages of 8 and 12 from three groups (31 children with ADHD, 37 with TBI, and 26 normal controls) formed the participant group. The results indicate that learning effects were found among all three of the groups. However, reward contingencies elicited different responses among the groups. When the ADHD group was provided reward contingencies performance improved to the level of the normal controls. The TBI group showed less improvement with reward contingencies. The authors conclude that this provides evidence suggesting motivational explanation playing a significant role with inhibitory deficits in ADHD, and a primary response inhibition deficit related to structural brain damage in children with TBI. The authors conclude that improved neuroimaging and testing of both ADHD and TBI groups are required to validate these results.
Dennis, Guger, and Roncadin (2001) evaluated 105 children and adolescents with closed head injuries (CHI) evaluating both attentional-inhibitory control (vigilance, selective attention, response modulation) and social variables. These results were compared with parent ratings of attention and behavioral regulation as well as age at CHI, time since CHI, CHI injury severity, and frontal lobe injury moderated by CHI severity. Divisions were made based on frontal lobe injury. The authors described the attentional results as 'imperfectly correlated' meaning that while some modest relationships were found between behavioral attention ratings and neuropsychological tests of attention they were less than would be expected. In predicting attentional-inhibitory control, age at injury and time since injury were found to be the most predictive of outcome. The authors conclude that cognitive outcome after childhood CHI appears to be associated to age at injury, time since injury, and biological features of the injury.

In a study by Vriezen and Pigott (2000) sensitivity of attention measures were evaluated with children experiencing mild (N = 14) or moderate/severe (N = 13) brain injury. The measures used were the Continuous Performance Test, the Trail Making Test, and Digit Span. Results indicated no evidence of attention problems in children with mild brain injury evaluated on average 4 months post injury. Children with moderate/severe injuries did demonstrate poor performance on the Continuous Performance Test, but not Digit Span or Trail Making. However, these results may be limited by small sample size, where heterogeneity of the sample could not be separated.
Catroppa and Anderson (2003) examined sustained attention using a modification of the Continuous Performance Test at 24 months post TBI in 69 children between the ages of 8 to 12 years. The authors did not find significant differences among the TBI groups on two of the conditions (i.e., a measure of simple reaction time, and a CPT version where the interstimulus interval was lengthened). In the third most complex condition requiring speed, accuracy, and decision making a significant difference was found between the mild and severe TBI groups. The authors suggest that these findings demonstrate a weakness in complex tasks that primary care providers should be concerned with.

Another study by Max, Lansing, and Koele (2004), they were specifically interested in attention deficit hyperactivity disorder in children and adolescents subsequent to TBI. The author’s preliminary goal in this article was to obtain psychiatric, family, cognitive, and neuroimaging data to evaluate ADHD that develops after traumatic brain injury (TBI), or what is commonly termed secondary-ADHD (SADHD). The participants were combined from 2 non-overlapping samples previously collected that consisted of 118 children following either TBI or orthopedic injury. No significant differences were found between various groups based on ethnicity, gender, socioeconomic status, or age at injury or assessment. Preinjury ADHD was excluded from both TBI and orthopedic samples. The authors found that SADHD occurred in 13 of 34 eligible subjects with severe TBI but resolved in 4 of 13 of these subjects. SADHD also occurred in 1 of 8 eligible moderate TBI subjects, and 3 of 39 of eligible mild TBI cases. Interestingly, SADHD was found in 1 of 20 of eligible participants with orthopedic
injury without any brain injury. The results found suggested that SADHD was significantly associated with TBI severity. The authors suggest that while severity is an influential aspect of obtaining SADHD other environmental influences may also play a significant role.

Max et al. (2005a & 2005b) put forth two additional studies evaluating predictive factors of secondary attention-deficit/hyperactive disorder (SADHD). The study followed a deteriorating sample of 143 subjects between the ages of 5-14 without preinjury ADHD. Psychiatric interviewing, preinjury variables, and measures of adaptive functioning were assessed. The first study evaluated predictive factors of diagnosed SADHD at 6 months post injury. Results showed that 18 out of 115 subjects (16%) were diagnosed with SADHD. Independently orbitofrontal gyrus lesions (p = .005) and socioeconomic status (p = .041) predicted SADHD. In the second paper 12 month and 24 month post injury evaluations were assessed. With a diminishing sample set SADHD occurred in 15 out of 103 subjects (15%) at the 12 month evaluation and 17 of 82 subjects (21%) at the 24 month evaluation. Interestingly in SADHD was not predicted by lesion location or severity of injury. However preinjury psychosocial adversity was a significant independent predictor. Further investigation with an attentional battery subscribing to a specified model of attention would further strengthen these findings.

Slomine et al. (2005) also evaluated SADHD, but looked at persisting ADHD (PADHD) meaning premorbid ADHD that persisted after TBI. Subjects with TBI and no PADHD or SADHD were also evaluated. Neuropsychological
evaluations one year post injury revealed that a diagnosis of SADHD was related
to problems with attention, executive function, and memory skills. No conclusive
differences were found between SADHD and PADHD.

Schachar, Levin, and Max (2004) examined the effect of closed head
injury (CHI) on the development of symptoms of secondary attention deficit
hyperactivity disorder (SADHD), emotional disturbance, and impaired response
inhibition with 119 children. Time since injury varied from 2.1 to 15 years.
Response inhibition was measured with the stop-signal task. Of note, a greater
proportion of the severe CHI group scores from the stop-signal task were
excluded for invalid responses. Results indicated that the combination of severe
CHI and a high level of SADHD predicted poor response inhibition. The authors
propose that CHI in children leads to attention deficits even after taking preinjury
behavior disturbances into account. Further, the authors found that inadequate
response inhibition is generally only experienced in this group when severe CHI
and high levels of SADHD symptoms are experienced.

In a study by Levin, Hanten, and Zhang (2004), inhibition was assessed
on 12 children suffering from chronic effects (post 1 year) of severe TBI and 15
control children. The subjects underwent a flanker task (pressing a button
corresponding to the direction of an arrow at different inter-stimulus intervals with
intermittent inhibition stimuli) where the TBI group performed less accurately than
controls under interference and go-no-go conditions, but not neutral for
facilitation conditions. Further, the authors found that response latency was
related to age and task condition, but not to group.
The purpose of a study by Wassenberg, Max, and Lindgren (2004) was to examine sustained attention using the Pediatric Assessment of Cognitive Efficiency (PACE: A new version of the continuous performance task) in regards to childhood traumatic brain injury (TBI) severity and family psychosocial variables (double hazard hypothesis). Forty-two children age 6-14 years with TBI participated in 4 assessments over a 2 year study to evaluate sustained attention. Specific attention was paid to parceling out errors of omission (considered a measure of inattention) and errors of commission (considered a measure of impulsiveness). Results suggested that severity of injury was predictive of impulsiveness. Further, inattention and impulsiveness assessed in the acute stages of TBI were predictive of later development of secondary attention-deficit/hyperactivity disorder.

In research by Catroppa and Anderson (2005), the recovery pattern of attentional skills and their interaction with ongoing development was evaluated. Seventy-one children between the ages of 8 to 12 years with TBI participated in the study. Attentional abilities were assessed over a two year period. The results found that severe TBI generally performed the poorest, but showed most recovery over time with variations concerning the attentional component being assessed. The deficits were most evident on more complex and timed tasks. The authors conclude that recovery is evident, but that deficits do persist beyond 24 months. However, while sufficient time lapses were established (6 months or greater) the authors did not account for practice effects across multiple
presentations. The use of a control group would have allowed them to account and potentially correct for this weakness.

Anderson and Catroppa (2005) examined disruptions in executive function among 69 children who had sustained a TBI. The sample was evaluated among four proposed interrelated components: 1) attentional control planning, 2) goal setting and problem solving, 3) cognitive flexibility, and 4) abstract reasoning. The authors focus regarding this matter was on the possible recovery trajectories in the years subsequent to TBI. Digit Span which was used to assess attentional control showed improvement for all groups across time, although this may be due to practice effects. Severity of injury showed no overall effect. With regard to Trails B no effect of severity or time was found. However, the authors did find that the greater the severity of the brain injury the more poorly subjects generally performed in the acute stage of post-injury across several measures. Further, these findings found that the severe TBI group showed the greatest amount of recovery in 24 months, but still had the greatest decrement of scores.

In a study by Anderson, Anderson, and Anderson (2006) developmental and acquired attentional impairments were evaluated using the continuous performance test (CPT). Four specific groups with conditions impacting the CNS were compared: a) attention deficit-hyperactivity disorder (ADHD: N = 27); b) moderate traumatic brain injury (TBI: N = 41); c) acute lymphoblastic leukemia (N = 31); and d) insulin-dependent diabetes mellitus (N = 39). A healthy control group (N = 46) was also used. The findings indicated the most severe global impairments were found with ADHD patients. However, TBI patients (moderate to
severe) displayed detectable attention difficulties in the areas of selective and sustained attention. The author's had been seeking a disorder-specific profile though this was not found. This study was limited though do to the model of attention that is assumed from various sources as apposed to being an established and derived theory. Further the paucity of the sample sizes for the four groups was very limited allowing for individual differences to account for some of the instability. Thus a future study rectifying these two problems could allow for more significant findings.

In a study by Catroppa, Anderson, Morse, Haritou, and Rosenfeld (2007) 54 children ranging from 2 to 7 years at the onset of a TBI were evaluated five-years post-TBI. A control sample (N = 16) was also used. The authors formed a model of attention derived from numerous sources: sustained attention, shifting attention, divided attention, and processing speed. The unfortunate results were variable an overall inconclusive. The overall general depression of attentional function was indicated, but not with regards to specific areas of function. Catroppa and colleges assert as previously (Anderson et al., 2000) that TBI can affect the expansion of learning in a child. That the disruption of forming neural circuitry can have permanent affects on the cognitive development. These conclusions are well founded from their previous research, but may be overstated for the current paper.

In meta-analytic work by Mathias and Wheaton (2007) utilized stringent inclusion and exclusion criteria to evaluate research pertaining to attention following severe TBI. The review evaluated articles from 1980 to 2005 and found
41 articles meeting the determined criteria. Findings suggested that substantial significant deficits were seen across measures of information-processing speed, attention span, focused/selective attention, sustained attention, and supervisory attentional control. Another important finding from this study was the lack of significance for the related variables of age, education, and post-injury interval. However, while a strict selection criterion was required to obtain validity many quality studies that examined attention were not able to be used.

The research on attentional deficits subsequent to TBI in children and adolescents is still sparse. It has been found that the attentional system in children is in a state of development and refinement that appears to advance rapidly, but progressively tapers off with aging (Klimkeit, Mattingley, & Sheppard, 2004; Korkman, Kemp, & Kirk, 2001; Mirsky et al., 1999). In pediatric TBI the majority of the research describes general deficits in the ability to sustain, shift, and focus attention that has been found both acute and chronic cases (Dennis et al., 2001; Hooper, Alexander, & Moore, 2004; Max et al., 2004; Murray, Shum, & McFarland, 1992; Wassenberg, Max, & Lindgren, 2004). However, the findings are not entirely consistent with regard to deficits experienced or defining the factors of attention, suggesting the need for greater clarification in the literature.

**Summary**

The previous literature review provides a broad explanation of the attentional system, traumatic brain injury, and relevant information concerning affects on the attentional system subsequent to trauma in children and
adolescents. This information discusses the neurocognitive structure of attention and how this can be impaired through traumatic brain injury. Specific to pediatric brain injury attentional deficit findings have not been consistent due to research on diverse theories, concepts, and measures of various constructs of attention. However, impaired functioning in the ability to focus, sustain and shift attention has been most commonly found. These deficits in attention can be severely complicated by the lack of neural consolidation in development.

To date the pediatric neuropsychological literature has not addressed the factor structure of attention in traumatic brain injury. While the structure of attention has been found in children (Mirsky et al. 1999), research in adult populations found differences in the factor structure of attention between a TBI and normative sample (Spikman, 2001). These findings suggested that important qualitative differences between these groups can be found. However, Spikman and colleagues were evaluating attention using a different model and tests designed to evaluate different constructs of attention. Based on a review of the literature it appears that the Mirsky model of attention is the most well researched model of attention. Therefore, this study seeks to evaluate the structure of attention utilizing the Mirsky model with suffering from traumatic brain injury. This study seeks to clarify how children with TBI differ on attentional tasks when compared to their non clinical peers.
Hypotheses

Based on the review of the literature, the following two hypotheses were evaluated. The first hypothesis addresses the absence of a rigorous investigation of the factorial structure of attention in children with TBI. Based on the previous work of Mirsky and colleagues (Mirsky 1987; Mirsky et al., 1991; Mirsky et al., 1999) with children and adults with ADHD and normal comparison samples, it is hypothesized that attention in Pediatric TBI will consist of four separate but related neurocognitive components, including focus, sustain, encode and shift abilities. Confirmatory factor analysis (CFA) is be used to evaluate the appropriateness of Mirsky's four factor model in children and adolescents with TBI.

Based on the four-factor structure the second hypothesis evaluates the relation of the four factors to brain injury through analysis of variance where TBI severity is the dependent variable. TBI severity will be broken into three separate groups. One group has a Glasgow Coma Scale (GCS) score of 3-8, which is considered to be in the severe range for the GCS. The next group is the Moderate to Mild group on the GCS, which ranges from 9-15. The final group is the neurocognitively normal control group. A confirmatory factor analysis of this group is not required as it has already been done by Mirsky et al. (1999), this sample will be used for making comparisons only. A priori predictions proposed a significant overall model with the best strongest associations to brain injury being the Shift and Focus (Dennis et al., 2001; Hooper, Alexander, & Moore, 2004;
Max et al., 2004; Murray, Shum, & McFarland, 1992; Wassenberg, Max, & Lindgren, 2004).
METHODS

Participants

The sample is comprised of 201 children and adolescents between the ages of 7 and 17 years of age. Of these, 151 will have experienced a traumatic brain injury and make up the TBI group, while the remaining 50 will have no history of neurological disorder, traumatic brain injury, learning disability, or attention deficit disorder, and make up the neurocognitively normal comparison sample. Through repeated one-way ANOVAs no significant differences were found between the TBI sample and the normative sample on gender, ethnicity, age, or handedness.

For the TBI sample, the data consisted of 151 children that were all referred to Our Children’s House at Baylor in Dallas, Texas for a neuropsychological assessment after having experienced a traumatic brain injury (TBI). When evaluated, the children were between the ages of 8.9 and 18.4 years old (mean = 12.9, $sd = 2.6$), and 58.3 percent were boys. The majority of participants were Caucasian (37.7%), then African American (11.3%), Hispanic-Latino (9.9%), and “other” (2.0%). In the TBI sample 83.4% right handed. The mean Glasgow Coma Scale scores ranged from 3 to 15 (mean = 7.28, $sd = 3.0$)
and the time since onset of injury ranged from 3 to 32 months (mean = 8.05, sd = 4.5).

The 50 children in the normal comparison sample were obtained from the community and had no history of a psychiatric disorder that would inhibit their result. The children in the normative sample were between the ages of 8.9 and 16.3 years old (mean = 12.5, sd = 2.2), and 44.0 percent were boys. The majority of participants were Caucasian (78.0%), then Hispanic-Latino (16.0%), African American (6.0%). In normative sample 90% were right handed.

Measures

A variety of tests have been used to assess the components of attention, and the measures for the current investigation were selected based on prior studies, as well as the underlying abilities that are assessed by each test that aligned with the Mirsky model of attention (Mirsky et al., 1991). Table 6 presents the attention components and the tests that will be used to assess each component. Each test is described in the following sections.
### Table 6
Tests associated with each attentional component

<table>
<thead>
<tr>
<th>Attention Component</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focus</td>
<td>Trailmaking Test Parts A and B</td>
</tr>
<tr>
<td>Sustain</td>
<td>Continuous Performance Test</td>
</tr>
<tr>
<td>Encode</td>
<td>Wechsler Digit Span and Arithmetic</td>
</tr>
<tr>
<td>Shift</td>
<td>Wechsler Digit Symbol/Coding and Symbol Search</td>
</tr>
</tbody>
</table>

**Focus**: The focus component will be assessed using the Trail Making Test (TMT; Army Individual Test Battery, 1944; Reitan, 1958). Although the TMT was originally developed well over 60 years ago, it continues to be one of the most widely used neuropsychological tests in clinical practice (Rabin, Barr, & Burton, 2005). The TMT consists of two parts, A and B, which require individuals to draw lines between consecutively number circles in part A, and between alternating consecutively circled numbers and letters in part B. Part A requires attention, visual searching, and motor coordination and speed. Part B requires the same abilities as part A, but in addition requires manipulation of two sets of information. The general reported reliability coefficient is .80 and above, although it ranges from .60's to .90's (Lezak, Howieson, & Loring, 2004). The test validity in interpreting potential neurological or attentional problems has been well...
supported (Spreen & Strauss, 1998). The Trail Making Test, particularly part B, has been commonly used to assess the focus factor in prior research of attention structure and particularly to validate Mirsky’s model (Allen et al. 1997, Mirsky et al. 1991, 1999; Mirsky, 1987; Pogge, Stokes, & Harvey, 1994; Shum, McFarland, & Bain, 1990; Spikman, Kiers, & Deelman, 2001). Using normative data from a review by Spreen and Strauss (1998) raw scores will be converted to normed T-scores by age.

**Sustain:** The sustain component will be assessed using the *Conner’s Continuous Performance Test* (Conners, 2000) and is administered as a measure of sustained attention and vigilance. In this computer-based task, participants are required to respond by pressing the spacebar each time a letter appears on the screen, with the exception of letter X. Measures of performance examined in the current investigation include: Variability (consistency of response speed and is considered a measure of inattention) and Standard Error by Block (response reaction across the administration of the test and is considered a measure of vigilance). These variables were selected because they have been previously shown to assess the sustain factor in normal and clinical populations. Normative data for the CPT was collected from six states within the United States for the Conners’ CPT, with 520 normative subjects and 238 clinical subjects. The reliability coefficient is .89 and has been proven in numerous studies to be an excellent measure for detecting attention problems in children (Lezak, Howieson, & Loring, 2004). The CPT has been commonly used to assess the sustain factor in previous studies of attention and particularly to validate Miršky’s model (Allen...

**Encode:** *Wechsler Intelligence Scales* (Wechsler, 1991, 1997) are made of various subtests that together provide information about a child’s (aged 6–16 years) intellectual abilities and reasoning skills in four primary areas including Verbal Comprehension, Perceptual Organization, Freedom from Distractibility/Working Memory, and Processing Speed. The Wechsler scales produce age-based standard scores with a mean of 100 (sd = 15) on the indices. Each of these four areas is made up of two or more subtests. The Full Scale intelligence score is derived from all four of these index scores, index scores will be used to assess overall qualities of the sample. Kaufman and Lichtenberger (2000) found generally high split-half reliability coefficients across all age groups for both subtests and indices ranging from .69 to .95.

The subtests from the Wechsler scales used to measure the Encode factor will be Arithmetic (involving attention, concentration, and numerical reasoning), and Digit Span (involves short term auditory memory and concentration). These subtests of the Wechsler scales are reported in age corrected scaled scores with a mean of 10 (sd = 3). These subtests have been commonly used to assess the encode factor in previous studies of attention and particularly to validate Mirsky’s model (Allen et al. 1997, Mirsky et al. 1991, 1999; Mirsky, 1987; Pogge, Stokes, & Harvey, 1994). For analysis and the creation of factor scores Wechsler normed scaled scores were converted to T-scores.
**Shift:** Digit Symbol Coding and Symbol Search (involving visual motor coordination, speed, concentration, and mental flexibility) of the Wechsler scales are used for this factor. These subtests of the Wechsler scales also result in scaled scores with a mean of 10 ($sd = 3$). Digit Symbol Coding, sometimes referred to as Digit Symbol or Coding, requires a person to find a particular number that matches to a particular symbol for several continuous rows of 10 randomly aligned symbols. This is a timed task that requires a person to constantly shift from the required answer for one symbol to the next. Digit Symbol Coding has been commonly used to evaluate various attentional factors even within the Mirsky model (Ewing-Cobbs, Prasad, & Fletcher, 1998; Pogge, Stokes, & Harvey, 1994; Shum, McFarland, & Bain, 1990). However, it should be noted that Coding requires cognitive flexibility defined as the ability to shift freely from one concept to another or change a course of action or thought according to the demands of the situation (Lezak, 1983; Logan & Cowan, 1984; Walsh, 1978). Requiring similar abilities Symbol Search necessitates a person to look among four selection designs for one of two example designs. If either one of the two example designs is the same as any of the four selection designs then the person marks a box marked ‘Yes’. If neither of the two example designs are found in the four selection designs then the person marks ‘No’. This is done repeatedly with different sets during a timed test. This requires the ability to shift from one response set to the next in a rapid manner. Therefore the cognitive flexibility needed for these tests appear to best represent Mirsky’s (1987)
definition of shift, interpreted as the ability to change attentional focus flexibly and efficiently from one stimulus to another as the situation demands.

Additional Measure: Glasgow Coma Scale (GCS, Teasdale & Jennet, 1974) is used in the acute stages after a traumatic head injury. The GCS is scored between 3 and 15, 3 being the worst, and 15 the best. It is composed of three parameters: Best Eye Response, Best Verbal Response, and Best Motor Response. A GCS score of 13 or higher correlates with a mild brain injury, a score of 9 to 12 is a moderate injury, and a GCS less than 8 is considered a severe brain injury (see Table 3).

Procedures

Participants in the normal control group (NC) were obtained through advertising and word of mouth. In the NC group, each participant’s legal guardian received information about the study by telephone. If the legal guardian was still interested in having their child participate in the study then oral consent was obtained to participate in the phone screening. Once consent was obtained, the legal guardian completed a brief phone interview to obtain demographic information and to screen for prior head trauma, attentional problems, learning disorders, developmental disorders, DSM-IV psychological disorders and any physical limitations that might affect eligibility criteria. All of the participants met the eligibility requirements for participation. The phone interviews were conducted by trained psychology graduate students.
At the appointment, prior to completing the study procedures, informed consent for the neuropsychological portion of the study was obtained from the legal guardian, and assent was obtained from the child. Following a review of informed consent and presentation of instructions, participants were administered the relevant tests. Tests were administered individually in a quiet room at the child's home with the guardian near by. The participants in the NC group were administered the Trail Making Test A and B (Reitan, 1958), the Conners' Continuous Performance Test II (Version 5.0; Conners, 2000), and selected subtests from the Wechsler scales (Wechsler, 1991, 1997) to evaluate attention (Digit Span, Arithmetic, Digit Symbol-Coding, Symbol Search, Matrix Reasoning) and to estimate their intelligence score (Vocabulary, Similarities, Matrix Reasoning, Block Design; see Randolph, Mohr, & Chase, 1993). Doctoral students trained to reliably administer the tests accomplished the administration. The test administration was approximately 50 to 60 minutes. Breaks were given as needed and positive reinforcement techniques were used to maintain effort level. Before leaving, participants and their legal guardian were debriefed regarding the purpose of the study and provided the opportunity to ask any questions regarding the experience.

No identifying information was on test materials to protect the anonymity and confidentiality of participants. Instead, test materials were given a four-digit code. The master list of contact information for each code was kept in a locked cabinet by the primary investigator. The participants received financial compensation by way of a movie ticket.
The traumatic brain injury group was drawn from a large archival database of children and adolescents suffering from traumatic brain injury. The cases were selected from a large clinical database that had been collected over the past five years at Our Children's House at Baylor. Brain injury was confirmed independent of the neuropsychological test data, using medical examination and diagnostic methods that were appropriate for each case. Each child was referred for a neuropsychological evaluation by their physician, an educator, or a community mental health provider due to behavioral or cognitive disturbances that were thought to be related to the traumatic brain injury. All participants were assessed in a rehabilitation setting. At the time of evaluation, all participants were medically stable and capable of cooperating with testing procedures. Each participant was administered a comprehensive neuropsychological and behavioral evaluation.

All data was devoid of identifying information to protect the anonymity and confidentiality of the patient. Neuropsychologists will be instructed to carefully remove the identifying information and apply a unique ID number to each of the four cases prior to sending the data to the principal investigator. However, certain demographic information was used, including age, gender, ethnicity, years of education, SES, and geographical region when available. Some clinical information was also used, such as diagnosis, type of injury, date of injury, and date of assessment.

Premorbid intelligence estimates were made utilizing “hold” tests as suggested by Axelrod, Vanderploeg, and Schinka (1999). In this method tests
that are typically resistant to the negative cognitive effects of brain injury are used to estimate prior intelligence. In children the Information and Vocabulary subtests of the Wechsler scales were be used to estimate premorbid intelligence.

The sample size of 151 is a minimum number that would allow us to test the study hypotheses. No compensation was provided to the actual TBI participants as their data was archival.

Analyses

Data Entry and Screening

Data will be entered twice into separate Microsoft Excel spreadsheets, and the Excel program was used to compare the two spreadsheets for discrepancies, i.e., data entry errors. After any inconsistencies were identified and corrected, the data was then imported into either Lisrel version 8.8, or SPSS version 12.0, for analyses.

Descriptive statistics were calculated for the dependent variables to detect out-of-range values (frequency counts) and non-normal distributions (skewness and kurtosis). Furthermore, box plots were used to visualize the data and check for outliers, which are defined here as scores 2 standard deviations above or below the sample mean. Six outliers for the Trail Making Test Part A and eight outliers for Part B were identified causing positively skewed distributions of these test scores as indicated a skewness of 1.4 and a kurtosis of 1.3. The outliers (Part A: 153, 183, 306, 203, 113, 189; Part B: 225, 315, 325, Incomplete, 225, Incomplete, 270, 334) were retained but their influence was minimized by reducing them to the next highest value (Trails A beginning at 73, Trails B...
beginning at 177) in the distribution of scores (Tabachnick & Fidell, 1989). While other methods could be used, such as transforming individual variables, the proposed approach has a number of advantages, including retaining real data in a way that maintains the ranking of scores but allows for a more normally distributed data set such that the significance of the results is not merely due to the outliers in the population.

All attentional tests were converted to normed T-scores (CPT scores are given as T-scores, Wechsler scores were converted from normed scaled scores to T-scores, normative data for making T-scores for children and adult versions of Trail making test was obtained from a review by Spreen & Strauss, 1998). This was done to make create less variance in data analysis and for the creation of factor scores.

Evaluation of Main Hypotheses

Evaluation of Hypothesis 1

Confirmatory factor analysis (CFA) was used on the TBI sample \((N = 151)\) to evaluate Hypothesis 1, which is concerned with the structure of attention in the normal control and TBI groups. CFA was utilized to compare various proposed models for the underlying latent structure of attention. The goal of CFA was to discover theoretical constructs that underlie a set of observed variables by examining the correlations among the observed variables. It is utilized when evidence derived theoretically or empirically suggests that specific latent variables explain the relations between the observed variables. CFA allows for the testing of a hypothesized statistical model against the actual set of data. The
goodness-of-fit between the hypothesized model and the actual data set is evaluated using a number of statistics. Some of the more widely used measures include the chi-square ($\chi^2$) statistic, the goodness-of-fit index (GFI), and the adjusted goodness-of-fit index (AGFI), the comparative fit index (CFI), the root mean square error residual index (RMSR), and the root mean squared error of approximation (RMSEA). The $\chi^2$ statistic is used to evaluate the fit between the hypothesized statistical model and the unrestricted actual data set, however $\chi^2$ is unduly affected by sample size (Kline, 1998). The GFI and AGFI provide estimates of the relative amount of variance and covariance jointly explained by the model. The CFI compares the existing model fit with a null model to determine the percentage of 'lack of fit' that can be accounted for. The GFI, AGFI, and CFI have ranges of 0.00 to 1.00. Values on these indices greater than 0.90 indicate an adequate model fit, but values of 0.95 and greater indicate a good model fit (Kelloway, 1998; Kline, 1998; Maruyama, 1998). The RMSR and RMSEA indices describe the discrepancy between the observed correlations and the model-reproduced correlations, values greater than 0.05 typically indicate a poor fit (Byrne, 1989). These indices provide the information necessary to evaluate the overall model fit of competing models.

Using Lisrel (Jöreskog & Sörbom, 2003) to perform the CFA four factor structures will be tested on the TBI and normative samples separately. These models are presented in Table 7. The first model specifies that all tests will load on a single factor. This model assumes that attention is a unitary construct, rather than a multicomponent system. The second model is based on the
original work of Zubin (1975) and proposed three factors, sustain, shift, and focus. Where it is assumed that Digit-Symbol Coding and Symbol Search will load together on Zubin’s shift factor. Next, Arithmetic, Digit Span, and the Trail Making Test (Part A & B) will all load together on the focus factor. Finally, the measure of Commissions and Detectability will load together on the sustain factor. The third model will be based on Mirsky and colleagues (1991) model but missing the shift factor (focus, sustain, and encode), since Digit-Symbol Coding had been previously viewed as an aspect of the focus factor by Mirsky and colleagues it as well as Symbol Search were combined with the Trail Making Test (Part A & B) to form the focus factor. While Arithmetic and Digit Span combine to form the encode factor in the model and the CPT subtest form the sustain factor. This leaves out the shift factor from the model. We desired to compare this three-factor model to the version of Mirsky’s four-factor model used in this paper. The final model will be the complete 4-factor model proposed by Mirsky (shift, focus, sustain, and encode). In this model the Digit Span and Symbol Search form the shift factor, Arithmetic and Digit Span form the encode factor, the Trail Making Test (Part A & B) form the focus factor, and the CPT subtests form the sustain factor.

**Evaluation of Hypothesis 2**

Using the confirmed factor structure subtest scores were transformed into T-scores (see data entry and screening) and averaging the T-scores for each factor created factor scores. Of the 151 subjects with traumatic brain injuries 99 of these participants had Glasgow Coma Scale scores (GCS; Teasdale & Jennet,
1974). Using the GCS cutoff scores for estimating severity of injury (score of 3 to 8 = severe, 9 to 12 = moderate, & 13 to 15 = mild see Table 3) the sample was divided into two groups severe ($N = 67$) and mild/moderate ($N = 32$). Additionally, the normative sample ($N = 50$) was used for comparison. This was done to evaluate the effects of brain injury severity on the four factors (sustain, shift, encode, focus). MANOVA was used to evaluate each factor across three brain injury subgroups (Severe, Moderate/Mild, and Normative Controls). Post hoc analyses were then used to detect differences between the TBI and normative samples regarding attentional performance across the different factors.
<table>
<thead>
<tr>
<th>Variables</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wechsler subtests</strong></td>
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</tr>
<tr>
<td>Digit Symbol</td>
<td>1-Unitary</td>
<td>1-Shift</td>
<td>1-Focus</td>
<td>1-Shift</td>
</tr>
<tr>
<td>Symbol Search</td>
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<td>1-Shift</td>
<td>1-Focus</td>
<td>1-Shift</td>
</tr>
<tr>
<td>Arithmetic</td>
<td>1-Unitary</td>
<td>2-Focus</td>
<td>2-Encode</td>
<td>2-Encode</td>
</tr>
<tr>
<td>Digit Span</td>
<td>1-Unitary</td>
<td>2-Focus</td>
<td>2-Encode</td>
<td>2-Encode</td>
</tr>
<tr>
<td><strong>Trail Making Test</strong></td>
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<td></td>
</tr>
<tr>
<td>Trails A</td>
<td>1-Unitary</td>
<td>2-Focus</td>
<td>1-Focus</td>
<td>3-Focus</td>
</tr>
<tr>
<td>Trails B</td>
<td>1-Unitary</td>
<td>2-Focus</td>
<td>1-Focus</td>
<td>3-Focus</td>
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<tr>
<td><strong>CPT-II</strong></td>
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<tr>
<td>Commissions</td>
<td>1-Unitary</td>
<td>3-Sustain</td>
<td>3-Sustain</td>
<td>4-Sustain</td>
</tr>
<tr>
<td>Detectability</td>
<td>1-Unitary</td>
<td>3-Sustain</td>
<td>3-Sustain</td>
<td>4-Sustain</td>
</tr>
</tbody>
</table>

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CHAPTER 4

RESULTS

The descriptive statistics of the attentional tests for all participants is presented in Table 8. The correlations among attentional tests with normed T-scores (under analyses see data entry and screening) for the TBI sample are presented in Table 9. Continuous Performance Test (CPT) scores showed consistently low correlations with the other test scores. The goodness-of-fit indices for the CFAs are presented in Table 9. Looking at Table 10, the four-factor model provided the best fit of the data when compared to the two other three-factor models, and the null and one-factor models. The \( \chi^2 \) for \( M_4 \) was not significant \( (p = .26) \) and the other goodness-of-fit indices were excellent, with the exception of the AGFI, which is in acceptable range (Bentler & Bonett, 1980). By comparison, the \( \chi^2 \) for the next best fitting model, \( M_{32} \), was significant \( (p = .0006) \) and the goodness of fit indices were lower. The CFI and GFI were acceptable, however the AGFI score was below the cutoff of .90 (Bentler & Bonett, 1980). Further, the RMR and RMSEA were in the acceptable range (Bentler & Bonett, 1980). Table 10 contains the \( \chi^2 \) differences and normed fit indexes (NFI) that provide estimates of incremental improvement in model fit. The \( \chi^2 \) differences indicate that the one-, three-, and four-factor models provided...
significant improvement in fit over the null model. Additionally, $M_4$ (see Figure 4, 5, 6, & 7) showed a better fit to the data than either the $M_{3Z}$ or $M_{3M}$ models or the one-factor model. While confirmatory factor analysis was not run on the normal controls the pattern of correlations showed a similar pattern of results (see table 11). Table 11 shows the maximum-likelihood solution for $M_4$. The attentional tests had excellent loadings on their respective factors. In the brain injured sample, the correlation between factors shown in Table 11 was moderately high amongst all the factors except Sustain. The sustain factor did not correlate with any of the other factors except shift ($r = .305$, $p < 0.05$). For the Encode, Shift, and Focus factors the moderately elevated correlations show relative expected overlap between the three factors.
Table 8

Descriptive statistics for attentional test and IQ scores

<table>
<thead>
<tr>
<th>Test</th>
<th>BI</th>
<th>NC</th>
<th>F</th>
<th>p &lt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR</td>
<td>42.68 (15.16)</td>
<td>53.52 (11.92)</td>
<td>21.10</td>
<td>0.001</td>
</tr>
<tr>
<td>DS</td>
<td>41.82 (14.57)</td>
<td>52.51 (15.46)</td>
<td>19.58</td>
<td>0.001</td>
</tr>
<tr>
<td>DC</td>
<td>32.25 (17.26)</td>
<td>55.70 (11.20)</td>
<td>80.85</td>
<td>0.001</td>
</tr>
<tr>
<td>SS</td>
<td>36.39 (18.04)</td>
<td>58.93 (10.41)</td>
<td>69.98</td>
<td>0.001</td>
</tr>
<tr>
<td>TA</td>
<td>31.10 (18.17)</td>
<td>50.42 (7.56)</td>
<td>40.61</td>
<td>0.001</td>
</tr>
<tr>
<td>TB</td>
<td>31.97 (21.07)</td>
<td>56.50 (8.36)</td>
<td>51.92</td>
<td>0.001</td>
</tr>
<tr>
<td>CV</td>
<td>44.30 (8.06)</td>
<td>56.05 (10.64)</td>
<td>51.15</td>
<td>0.001</td>
</tr>
<tr>
<td>CB</td>
<td>47.87 (8.28)</td>
<td>52.79 (9.94)</td>
<td>9.94</td>
<td>0.01</td>
</tr>
<tr>
<td>VCI</td>
<td>88.78 (12.46)</td>
<td>105.08 (9.09)</td>
<td>65.74</td>
<td>0.001</td>
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<tr>
<td>POI</td>
<td>85.24 (16.23)</td>
<td>104.40 (10.37)</td>
<td>56.92</td>
<td>0.001</td>
</tr>
<tr>
<td>FSIQ</td>
<td>84.92 (13.63)</td>
<td>106.90 (9.55)</td>
<td>100.52</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Note. BI = Brian Injury, NC = Normal Controls, AR = Arithmetic, DS = Digit Span, DC = Digit Symbol/Coding, SS = Symbol Search, TA = Trail Making Test part A, TB = Trail Making Test part B, CV = Continuous Performance Test-Variability, CD = Continuous Performance Test-Error Block Change, VCI = Verbal Comprehension Index, POI = Perceptual Organization Index, and FSIQ = Full Scale Intelligence Quotient.
Table 9

Pearson $r$ correlations between tests of attention

<table>
<thead>
<tr>
<th>Test</th>
<th>Sample</th>
<th>AR</th>
<th>DS</th>
<th>DC</th>
<th>SS</th>
<th>TA</th>
<th>TB</th>
<th>CV</th>
<th>CB</th>
</tr>
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<tbody>
<tr>
<td>AR</td>
<td>BI</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NC</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DS</td>
<td>BI</td>
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</table>


* $p < .01$

** $p < .001$
Table 10

Goodness of Fit Indices for one-, three-, and four-factor models

<table>
<thead>
<tr>
<th>Model</th>
<th>$\chi^2$</th>
<th>Df</th>
<th>$\chi^2/df$</th>
<th>GFI</th>
<th>AGFI</th>
<th>CFI</th>
<th>RMR</th>
<th>RMSEA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) $M_1$</td>
<td>108.49**</td>
<td>20</td>
<td>5.42</td>
<td>0.86</td>
<td>0.75</td>
<td>0.83</td>
<td>0.100</td>
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<td>2) $M_{3z}$</td>
<td>42.01**</td>
<td>17</td>
<td>2.47</td>
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<td>0.95</td>
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<td>3) $M_{3M}$</td>
<td>44.56**</td>
<td>17</td>
<td>2.62</td>
<td>0.93</td>
<td>0.86</td>
<td>0.95</td>
<td>0.053</td>
<td>0.10</td>
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<tr>
<td>4) $M_4$</td>
<td>16.04</td>
<td>14</td>
<td>1.15</td>
<td>0.97</td>
<td>0.93</td>
<td>1.00</td>
<td>0.030</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Note. $M_1$ = one-factor model; $M_{3z}$ = three-factor model based on Zubin’s proposed attention structure; $M_{3M}$ = three-factor model based on Mirsky’s proposed structure without the shift component. $M_4$ = four-factor model based on Mirsky’s structure. GFI = Goodness of Fit Index; AGFI = Adjusted GFI; CFI = Comparative Fit Index; RMR = Standardized Root Mean-Square Residual; RMSEA = Root Mean-Square Error of Approximation. Independence model $\chi^2 = 573.19$, df = 28, N = 151, $p < .0001$.

*p < .001
Table 11
Model Comparisons

<table>
<thead>
<tr>
<th>Comparison</th>
<th>$\chi^2$ difference</th>
<th>df</th>
<th>AIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M_n - M_1$</td>
<td>446.39*</td>
<td>8</td>
<td>129.33</td>
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<tr>
<td>$M_n - M_{3Z}$</td>
<td>512.87*</td>
<td>11</td>
<td>82.93</td>
</tr>
<tr>
<td>$M_n - M_{3M}$</td>
<td>510.32*</td>
<td>11</td>
<td>81.67</td>
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<tr>
<td>$M_n - M_4$</td>
<td>538.84*</td>
<td>14</td>
<td>59.77</td>
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<tr>
<td>$M_1 - M_{3Z}$</td>
<td>66.48*</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>$M_1 - M_{3M}$</td>
<td>63.93*</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>$M_1 - M_4$</td>
<td>92.45*</td>
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<td>-</td>
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<td>$M_4 - M_{3Z}$</td>
<td>25.97*</td>
<td>3</td>
<td>-</td>
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</table>

Note. $\text{AIC} = \text{Akaike Information Criterion}$, $M_1 = \text{one-factor model}$; $M_{3Z} = \text{three-factor model based on Zubin's proposed attention structure}$; $M_{3M} = \text{three-factor model based on Mirsky's proposed structure without the shift component}$. $M_4 = \text{four-factor model based on Mirsky's structure}$. Independence model for the AIC is 570.88 with 28 degrees of freedom.

* $\chi^2$ difference significant $p < .001$
Figure 4

Four-factor model for Confirmatory Factor Analysis

<table>
<thead>
<tr>
<th>Factor Corr</th>
<th>Factors</th>
<th>Test Corr</th>
<th>Tests</th>
<th>Error</th>
<th>Loadings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shift</td>
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<td></td>
<td>Symbol Search</td>
<td>E</td>
<td>0.84</td>
</tr>
<tr>
<td>Encode</td>
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<td>.86</td>
<td>Arithmetic</td>
<td>E</td>
<td>0.73</td>
</tr>
<tr>
<td></td>
<td>.54</td>
<td>.85</td>
<td>Digit Span</td>
<td>E</td>
<td>0.65</td>
</tr>
<tr>
<td>Focus</td>
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<td>.22</td>
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<td>E</td>
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<tr>
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<td>Trails part B</td>
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<td>Sustain</td>
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<td>Variability</td>
<td>E</td>
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<tr>
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<td>.88</td>
<td>.88</td>
<td>Block Change Err</td>
<td>E</td>
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</table>

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Figure 5

Unitary model of attention

<table>
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<th>Factors</th>
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<th>Tests</th>
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Figure 6

Three factor Zubin Model

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<th>Tests</th>
<th>Error</th>
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<td>Trails part B</td>
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Figure 7

Three factor Mirsky model

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<th>Factors</th>
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<th>Tests</th>
<th>Error</th>
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Table 12

Factor and Intelligence Score Correlations

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<th>Factor</th>
<th>Sample</th>
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<th>Encode</th>
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<td>0.617*</td>
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<td>BI</td>
<td>0.290*</td>
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<td>0.067</td>
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</table>

Note: VCI = Verbal Comprehension Index, POI = Perceptual Organization Index, FSIQ = Full Scale Intelligence Quotient.

*p < .05

Table 13 shows the performance of each of the three groups on all four factors and Wechsler intelligence scores with Univariate F test results for group comparisons to evaluate significant differences across groups. MANOVA comparing the attention factor scores between the brain injury groups indicated a
significant overall effect for group \( (F = 9.75, df = 2,148, p < .001) \). Examination of the \( F \) test results indicated there was no significant difference for the sustain component, however all other comparisons were significant. As seen in Table 13 intelligence scores for TBI groups are clearly suppressed when compared to the normal control sample. Figure 8 show the differences between the normal control and brain injury groups across the four factors. Further, post hoc analyses using Sheffe showed a significant difference for normal controls verses mild/moderate or severe brain injured participants for all four factors (see Table 13). However, the shift factor showed significant decline across all three groups with the normal control group performing better than the mild/moderate brain injury group, who in turn performed better than the severe brain injury group. Both the focus and encode factors showed significant differences between normal controls and brain injured groups, but not between the brain injured groups. As can be seen from the Figure, the Focus factor tended to be most sensitive to the presence of brain injury, as the brain injury groups performed the worst on this factor, regardless of severity of brain injury.

To examine the unique contributions of each attentional factor (sustain, shift, encode, focus) upon brain injury a simultaneous multiple regression was conducted using both the traumatic brain injury (TBI) sample. Of the 151 TBI subjects 99 of them had Glasgow Coma Scale scores (GCS; Teasdale & Jennett, 1974) severe. For the Multiple Regression the model analysis was significant \( F (4, 148) = 27.153, p < .001 \) \( R^2 = .43 \). There was no main effect for either sustain or encode. However, both the focus \( t(148) = -0.166, p = .042, \beta = -.05 \) and shift
\( t(148) = -4.804, p < .001, \beta = .01 \) were significant predictors, such that greater severity of GCS scores was directly related to lower factor scores.

Correlations of the four factor scores to intelligence scores are presented in Table 12. Strong correlations were seen across the focus, sustain, and shift factors, however no correlation was significant for the sustain factor. While the Wechsler tests used in the shift and encode factor are separately used in formulating the full-scale intelligence score the correlation amongst those factors and the focus factor suggest a strong relationship. Brain injury onset, or time since injury, was also correlated with the factors to assess any relationship between recovery and performance. Results indicate that there was no significant relationship at all for any of the factors.
Table 13

Group comparison by brain injury severity

<table>
<thead>
<tr>
<th>Factor/IQ</th>
<th>Severe M (SD)</th>
<th>Mild/Mod M (SD)</th>
<th>Controls M (SD)</th>
<th>df = 2, 148</th>
<th>p</th>
<th>Scheffe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sustain</td>
<td>45.3 (9.8)</td>
<td>45.6 (9.7)</td>
<td>53.9 (7.5)</td>
<td>31.871</td>
<td>0.001</td>
<td>N&gt;M, S</td>
</tr>
<tr>
<td>Encode</td>
<td>41.9 (11.1)</td>
<td>42.1 (10.1)</td>
<td>53.0 (10.8)</td>
<td>9.149</td>
<td>0.001</td>
<td>N&gt;M, S</td>
</tr>
<tr>
<td>Shift</td>
<td>33.1 (14.9)</td>
<td>42.6 (15.0)</td>
<td>57.3 (9.6)</td>
<td>32.479</td>
<td>0.001</td>
<td>N&gt;M&gt;S</td>
</tr>
<tr>
<td>Focus</td>
<td>21.6 (25.3)</td>
<td>27.4 (18.1)</td>
<td>53.5 (6.6)</td>
<td>26.86</td>
<td>0.001</td>
<td>N&gt;M, S</td>
</tr>
<tr>
<td>VCI</td>
<td>86.8 (12.0)</td>
<td>88.3 (11.9)</td>
<td>105.1 (9.1)</td>
<td>43.179</td>
<td>0.001</td>
<td>N&gt;M, S</td>
</tr>
<tr>
<td>POI</td>
<td>84.1 (13.7)</td>
<td>86.77 (17.2)</td>
<td>104.4 (10.4)</td>
<td>34.556</td>
<td>0.001</td>
<td>N&gt;M, S</td>
</tr>
<tr>
<td>FSIQ</td>
<td>82.9 (11.6)</td>
<td>86.6 (13.6)</td>
<td>106.9 (9.6)</td>
<td>67.315</td>
<td>0.001</td>
<td>N&gt;M, S</td>
</tr>
</tbody>
</table>

Performance across three groups on attentional factors and intelligence scores

Note: From the Wechsler Scales: VCI = Verbal Comprehension Index, POI = Perceptual Organization Index, FSIQ = Full Scale Intelligence Quotient.
Figure 8

Mean differences among 4 factors across brain injury severity

- Control
- Mild/Mod
- Severe

Factor Scores

Sustain  Encode  Shift  Focus

T-scores

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CHAPTER 5

DISCUSSION

Support for a four-factor model of attention in pediatric traumatic brain injury (TBI) similar to that proposed by Mirsky et al. (1991) was found in the present sample. These findings suggest that while brain injury can significantly impair attention, the structure of attention proposed by Mirsky and colleagues is present in these brain-injured children. In the current brain injury sample the structure of attentional processes is consistent with that identified in children and adults with clinical disorders (Allen et al., 1997; Mirsky, Pascualvaca, & Duncan, 1999; Goldstein, Johnson, & Minshew, 2001) as well as in non-clinical samples (Rebok et al., 1997; Mirsky et al. 1991). Therefore, the present results not only provide additional theoretical support for the validity of Mirsky's four-factor model of attention that includes focus, sustain, shift, and encode components, but also suggests that this model may be useful for understanding attentional function and dysfunction in children with traumatic brain injury.

With regard to other models of attention in childhood brain injury, results have been less consistent than those found here for Mirsky's model. For example, Spikman et al. (2001) reported instability of attentional constructs in brain-injured samples when examining a model of attention proposed by van
Zomeren and Brouwer (1994). That model included four interrelated factors of focused attention, divided attention, alertness, and sustained attention (see Table 1). To evaluate this model Spikman and colleagues used a measure of auditory attention (Paced Auditory Learning Test: Gronwall and Sampson, 1974), as well as the Stroop Color Word Test (Stroop, 1935), and the Trail Making Test (Reitan, 1958), as well as modified versions of the Rey Auditory Verbal Learning Test (Rey, 1958; Lezak, 1983) and the Wisconsin Card Sorting Test (Berg, 1948), and two reaction time tests (van Zomeren, 1981). Thus, Spikman et al. (2001) used substantively different tests to evaluate a model of attention that also substantially varied from the one examined in the current study. As a result, it is not possible to determine whether the differences Spikman found between the factor structures in normative versus brain injured groups was related to 1) methodological considerations (e.g., tests used to evaluate the model) 2) reflects a more basic problem with the theoretical conceptualization of the model of attention they were investigating, or 3) some combination of methodological and theoretical considerations. While the current results and those of Spikman et al. cannot be directly compared, at least two points are worth mentioning. First, the tests we used to investigate attention in the current brain injured and normative samples are widely used in clinical and research settings but more importantly have established reliability and validity. The established psychometric properties of the tests used were a strength of the current study in comparison to others that have investigated the structure of attention in brain-injured children. Second, it is important to note that the structure of attention proposed by Mirsky et al. (1991)
has garnered strong support in numerous studies (see Duncan & Mirsky, 2004; Mirsky & Duncan, 2004 for review) in addition to the current study. These studies have used a variety of measures that were selected a priori because they measured the constructs originally identified by Mirsky. For example, in the current study, not only did the population differ markedly from that sample originally examined by Mirsky, but there was also variation in the measures used to assess the four components of attention. Most notably, the Digit Symbol and Symbol Search subtests were used to assess the attention Shift factor, rather than the Wisconsin Card Sorting Test, which was used by Mirsky. Despite these differences in population and measures, the four factors of attention emerged as predicted. Thus, the structure of attention proposed by Mirsky and colleagues continues to be consistent across various samples, ages, and disorders. And, while direct comparisons with other models can not be made based on the current results, it may be that Mirsky’s emphasis on the association between his proposed attentional constructs and the underlying brain structures that are thought to regulate their function, may account for the robustness of the findings with regard to his four factor model.

With regard to this latter point, it is clear that attention can be separated into a number of distinct but interrelated component processes. Additionally, it has been demonstrated that sensory modality (e.g., auditory vs. visual) may further influence attentional processing (see Shum, McFarland, and Bain, 1990) such that an individual may exhibit deficits on attentional measures that are presented visually, but perform adequately on similar tests that are presented in
an auditory modality. Despite difference attributed to modality, one might expect that in an adequate model of attention, the core components of the attention processing system would be identifiable regardless of presentation modality, so that while variable patterns of performance might be present across its component processes, the components themselves would emerge when the latent structure of attention was examined using techniques such as CFA. Apparently, this is the case for Mirsky's theory, as the components of attention examined here have also been identified in other clinical and nonclinical populations and have been identified using a variety of different tests.

Given the stability of the factor structure proposed by Mirsky and its presence in the current sample, it was also of interest to understand how childhood TBI might effect these four components of attention particularly as it relates to what is known about the nature of brain injury resulting from TBI and those neuanatomical regions and circuits that are most vulnerable to insult. Using the confirmed factor structure to create factor scores allowed for examination of these issues. By using Glasgow Coma Scale scores (Teasdale & Jennett, 1974) the TBI sample was divided into two groups based on severity of injury, a severe traumatic brain injury group and a moderate/mild injury group. These two groups were compared to each other and to the normal controls in order to evaluate the impact of brain injury on the four attention factors, as well as to determine the relative sensitivity of each factor to the severity of brain injury. Consistent with previous research (Catroppa, Anderson, & Morse, 2007; Dennis et al., 2001; Hooper, Alexander, & Moore, 2004; Max et al., 2004; Murray, Shum,
McFarland, 1992; Wassenberg, Max, & Lindgren, 2004, Whyte, Grieb-Neff, Gantz, & Polansky, 2006) the focus and shift factors were both sensitive to the presence of brain injury and significantly differentiated the brain injury groups from the normal controls. When examining the differences between the groups on each factor through post hoc analyses, the shift factor was the only factor to show a consistent decline with brain injury severity (see Figure 5) in which the severe brain injury group performed significantly worse than the mild/moderate brain injury group, who performed worse than the normal control group. In contrast to the clear incremental decline on the shift factor associated with severity of injury, both of the brain injury groups performed poorly on the focus factor, but did not differ from each other. Interestingly, while not sensitive to the severity of brain injury, the focus factor was the most sensitive of the factors to the presence of brain injury, which is clearly seen by examining the absolute value of the t scores for each factor. For the shift factor the mild/moderate and severe brain injury groups attained t scores of 42.58 and 33.06 respectively, while for the focus factor comparable scores were 27.44 and 21.60. Thus, while a significant difference between the brain injury groups was not present for the focus factor, it was by far the most sensitive of the factors to the presence of injury. The contrasting pattern of results when comparing the shift and focus factors suggests that some components of the attention processing system are susceptible to the severity of injury so that greater destruction of brain tissue results in an associated linear decline in ability (e.g., shift). Other abilities, such as focus, have what might be characterized as an "all or none" property, in which
brain injury causes severe impairment regardless of the severity of injury. From a distributed processing perspective, it might be expected that those abilities that exhibit a linear decline associated with brain injury severity (shift) would be regulated by more globally distributed neural circuits so that damage to a specific brain region would be less likely to affect functioning, with decline present with more generalized and severe injury. On the other hand, those abilities that exhibit an "all or none" property may be more specifically localized to a particular brain region so that even a mild injury, if it were to affect that brain region, would cause a severe impairment in functioning (e.g., focus). While not directly examined in the current investigation, the difference in pattern of performance across the various factors does support the differential involvement in brain circuits regulating attention processes, as well as the varying susceptibility of these brain regions the neuropathology associated with traumatic brain injury. Finally, while much is often made of significant differences between groups, the nonsignificant difference between the groups for the sustain factor is also of great interest. The current results suggest that this ability is resilient in the presence of brain injury even in cases where injury has been severe.

From a clinical perspective, the results provide insights into the types of cognitive deficits that might be expected following traumatic brain injury in children and which would be important to consider when planning treatment. As previously mentioned, the resilience of the sustain factor to injury is quite remarkable and from a clinical standpoint one would not expect that the failures in attention would result from impairment in this cognitive ability. On the other
hand, the substantially impairment identified on the focus factor regardless of injury severity suggest that this attentional domain should be the “focus” of assessment and intervention even in cases with relatively mild injury. More specifically, in cases of mild injury, one should not overlook the possibility that significant impairment of the ability to focus attention may be present despite otherwise preserved abilities in other cognitive domains. In this sense, impairment in the ability to focus attention may be a rate limiting factor in the successful adjustment and functioning of children who have sustained traumatic brain injury and so should be considered as a target for behavioral interventions (cognitive rehabilitation) that aim to remediate or compensate for impaired ability to focus attention.

Care should be used when interpreting these results first of all because the TBI sample had 151 participants. Typically, a sample of more than 200 participants is required for a rigorous evaluation via confirmatory factor analysis. Further, traumatic brain injury (TBI) samples are inherently heterogeneous (e.g., impact point, force, focal versus diffuse damage, intraindividual protective factors, etc.). Developmental factors of pediatric samples must also be considered due to the rapid neurocognitive development they experience (Korkman, Kemp, & Kirk, 2001; Klenberg, Korkman, & Lahti-Nuuttila, 2001; Pascualvaca, Anthony, & Arnold, 1997). It is hoped that additional testing with more homogenous groupings (e.g., age, TBI severity, and gender) would allow for increased validity and application. A further point of study would be to assess age cohorts of normal and TBI pediatric groups to evaluate Dennis’ (1989)
suggestion regarding the neurodevelopment of cognitive and behavioral skills. This would allow for the consideration of the theory of age related neural establishment of attentional skills versus the progressive development of these skills over time. This could assist in evaluating the assertion of 'growing into a cognitive deficit' suggested by Anderson et al. (2000) speaking to the destruction of neural circuits in children prior to their establishment. Consequently it is important that these findings be reconfirmed in additional samples to ensure the salience of the findings. Despite these considerations, the current well characterized sample of children with TBI is one of the largest studied to date, and the consistency of the current findings with regard to factor structure and anticipated patterns of performance on the attention factors suggests that the findings here would generalize to the broader population of children with traumatic brain injury.

In relation to the procedure of this experiment, the specific tests used to evaluate the Mirsky model differed to some extent from those proposed by Mirsky et al. (1991). Most notably, the Wechsler scales of Digit-Symbol Coding and Symbol Search (Wechsler, 1991, 1997) were utilized in the current study to assess the shift component. These tests were chosen in order to evaluate children's ability to shift attention in an adaptive and flexible way from one target stimulus to the next in order to complete a given task. While both of these tasks clearly require the ability to shift attention, they also require processing speed. The Digit-Symbol Coding (DS) was used to evaluate focused attention in the attention battery for children (Mirsky & Duncan, 2004), but for the current study...
when combined with Symbol Search (SS) it was hypothesized that these two tests would better evaluate the 'Shift' component of the model. This was confirmed by the CFA, which clearly demonstrated that the four-factor model separating out DS and SS on their own factor provided better fit than the three-factor model in which they were specified to load with Trail Making part A and B for the focus factor. Thus, while the current tests varied to some degree from those used by Mirsky, the findings are consistent with his and support the robust nature of the four-factor model of attention. However, because the normal control sample was too small to perform analyses it remains to be seen whether the factor structure identified in our TBI sample would also be present in normals, given the variation in test selection used as compared to other studies of normal populations. While CFA could not be performed the correlation matrices of the normal children showed a similar pattern of results to that of the brain injured group suggesting a common result would likely have ensued if the sample was large enough.

The present findings are encouraging for the area of brain injury. Determining what functions are most connected to severity of brain damage could lead to future assistance for those suffering from brain injury. It is further hoped that in other neurocognitive areas the use of substantiated factor scores could assist in establishing specified patterns of attentional deficits for various disorders (see Mirsky et al., 1999, Duncan & Mirsky, 2004). With the strong support for the Mirsky (1987) four-factor model of attention (shift, focus, sustain, and encode), additional research with this model should continue. This is
important as attention is fundamental to basic perception, processing, and consciousness (Cohen & Schooler, 1997; Gray, 2004), hence understanding the neuroncognitive dynamics of attention is imperative to all facets of life. From a developmental standpoint, deficient attention significantly affects the ability to process and learn information in everyday activities, particularly in educational settings (Lehnung, Leplow, & Ekroll, 2003). Understanding the established structure of attention becomes particularly important during development as it relates to basic learning and structuring of cognitive processes. Specifically, the present findings have an impact on understanding pediatric brain injury and attention by from both theoretical and clinical perspective, providing greater support for the validity of Mirsky’s (1987) model of attention and also providing information on the impact that traumatic brain injury has on attentional processes which can provide direction to clinicians who provide treatment and rehabilitative services to these children.
APPENDIX A

INFORMED CONSENT (Parent)
Department of Psychology

TITLE OF STUDY: **Attention in Children**

INVESTIGATOR(S): **Brandon Park & Dr. Daniel Allen**

CONTACT PHONE NUMBER: **707 538-4082**

**Purpose of the Study**
Your child is invited to participate in a research study. The tests that your child will complete today provide information about the range of average attention, concentration, and memory abilities in normal children and adolescents. The purpose of this research is to try to understand the function of attention among children and adolescents.

**Participants**
Your child is being asked to participate in the study because he/she is between 9 and 17 years of age, and has average or better vision (with or without glasses/contacts), and English is understood fluently.

**Procedures**
If your child participates in this study, your child will be asked to complete various timed and un-timed tests assessing attention, memory and problem solving. The tests will take approximately one and a half hours (1.5) to complete. The tasks we will conduct with your child involve: answering questions, putting blocks together, looking for missing objects in pictures, drawing lines between sequential objects, reacting to information presented on a computer screen, and repeating back orally presented information. We ask that your child provides his or her best performance on all the tests presented.

**Benefits of Participation**
There *may* be no direct benefits to your child from participating in this study. However, the information gained in this study will help us understand more about attention and concentration in children.

**Risks of Participation**
There are risks involved in all research studies. The risks associated with participating in this project are minimal; your child may experience some boredom, fatigue, or mild anxiety when completing the tests. Some of these tests are timed and will require your child to work fast.

**Cost /Compensation**
There **will not** be financial cost to your child to participate in this study. The study will take one and a half hours (1.5) of his/her time. Your child **will** be compensated for his/her time through receiving small gift. This compensation will be provided even if your child decides to withdraw from the experiment. *The University of Nevada, Las Vegas may not provide compensation or free medical care for an unanticipated injury sustained as a result of participating in this research study.*

**Contact Information**
If you have any questions or concerns about the study, you may contact Dr. Daniel N. Allen at the UNLV Psychology Department, (702) 895-0121 or Brandon Park at (702) 423-2816. For questions regarding the rights of research subjects, any complaints or comments regarding the manner in which the study is being conducted you may contact the UNLV Office for the Protection of Research Subjects at (702) 895-2794.

**Voluntary Participation**
Your child's participation in this study is voluntary. Your child may refuse to participate in this study or in any part of this study. If unable to complete the study, your child may withdraw at any time without prejudice to relations with the University of Nevada Las Vegas or the examiners. You and your child are encouraged to ask questions about this study at the beginning or any time during the research study.

**Confidentiality**
All information gathered in this study will be kept completely confidential. No reference will be made in written or oral materials that could link you or your child to this study. All records will be stored in a locked facility at UNLV for at least 3 years after completion of the study. After the storage time the information gathered will be shredded.

**Participant Consent**
I have read the above information and agree to have my child participate in this study. I am at least 18 years of age. A copy of this form has been given to me.

______________________________  ______________________________
Signature of Participant's Parent  Date

______________________________  ______________________________
Participant's Parent Name (Please Print)
APPENDIX B

ASSENT TO PARTICIPATE IN RESEARCH (ages 7-12)

Attention in Children

1. My name is Brandon Park from the University of Nevada Las Vegas (UNLV).

2. We are asking you to help in a research study because we are trying to learn more about how children pay attention when they are doing different things.

3. If you agree to be in this study you will be asked to put blocks together, look at pictures and numbers, answer questions, draw, and write. Some of the things we will ask you to do will be easier for you and some will be harder. Some of the tests will require you to do things as fast as you can. Is that okay?

4. During the study you might get tired or bored. However, if you need a break at any time we can stop and let you rest.

5. If you participate in the study, you will get a small gift to thank you for helping.

6. Please talk this over with your parents before you decide whether or not to participate. We will also ask your parents to give their permission for you to do this study. But even if your parents say “yes”, you can still decide not to do this.

7. If you don’t want to be in this study, you don’t have to. Being in this study is your choice, and no one will be upset if you don’t want to be in the study. Even if you change your mind later and want to stop it is okay. No matter what, you will still get your small gift.

8. You can ask any questions that you have about the study. If you have a question later that you didn’t think of now, you can call me at 538-4082 or have your parents call me.

9. Signing your name at the bottom means that you agree to be in this study. You and your parents will be given a copy of this form after you have signed it.

Print your name ___________________________ Date ______________

Sign your name ___________________________
APPENDIX C

ASSENT TO PARTICIPATE IN RESEARCH (ages 13-17)

Attention in Children

1. My name is Brandon Park from the University of Nevada Las Vegas (UNLV).

2. We are asking you to take part in a research study because we are trying to learn more about how adolescents pay attention when they are performing different tasks.

3. If you agree to be in this study you will be asked to put blocks together, look at pictures and numbers, answer questions, draw, and write. Some of the things we will ask you to do will be easy and some will be hard. Also, some of the tasks will require you to do things as fast as you can. Is that okay?

4. During the study you may get tired or bored. However, if you need to take a break at any time we can stop and let you rest.

5. If you do the study, you will get a small gift to thank you for helping.

6. Please talk this over with your parents before you decide whether or not to participate. We will also ask your parents to give their permission for you to do this study. But even if your parents say “yes” you can still decide not to do this.

7. If you don’t want to be in this study, you don’t have to. Being in this study is up to you and no one will be upset if you don’t want to be in the study. Even if you change your mind later on and want to stop it is okay. No matter what, you will still get your small gift.

8. You can ask any questions that you have about the study. If you have a question later that you didn’t think of now, you can call me at 538-4082 or have your parents call me.

9. Signing your name at the bottom means that you agree to be in this study. You and your parents will be given a copy of this form after you have signed it.

Print your name ______________________________ Date ______________________

Sign your name ________________________________
APPENDIX D

PRESS RELEASE

Brandon Park, a graduate student at the University of Nevada, Las Vegas, is conducting a study evaluating attention and memory in children and adolescents. If you have a child or adolescent between the ages of 9 and 17 years with healthy motor function, vision, and hearing, who speaks primarily English, then they may be eligible to participate. As compensation for participating they will receive small gift.

Parents are encouraged to contact Brandon Park at (707) 538-4082 for more information and to schedule an initial assessment. The assessment procedure consists of a brief interview and testing. This process usually lasts 1 to 1 1/2 (1.5) hours. This study is being supervised by a UNLV faculty advisor and primary investigator, Dr. Daniel N. Allen.

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APPENDIX E
Tables & Graphs

Table 3.
Glasgow Coma Scale

The GCS (Teasdale & Jennet, 1974) is scored between 3 and 15, 3 being the worst, and 15 the best. It is composed of three parameters: Best Eye Response, Best Verbal Response, and Best Motor Response, as given below:

**Best Eye Response. (4 points)**

<table>
<thead>
<tr>
<th>Response</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) No eye opening</td>
<td>1 point</td>
</tr>
<tr>
<td>b) Eye opening to pain</td>
<td>2 points</td>
</tr>
<tr>
<td>c) Eye opening to verbal command</td>
<td>3 points</td>
</tr>
<tr>
<td>d) Eyes open spontaneously</td>
<td>4 points</td>
</tr>
</tbody>
</table>

**Best Verbal Response. (5 points)**

<table>
<thead>
<tr>
<th>Response</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) No verbal response</td>
<td>1 point</td>
</tr>
<tr>
<td>b) Incomprehensible sounds</td>
<td>2 points</td>
</tr>
<tr>
<td>c) Inappropriate words</td>
<td>3 points</td>
</tr>
<tr>
<td>d) Confused</td>
<td>4 points</td>
</tr>
<tr>
<td>e) Orientated</td>
<td>5 points</td>
</tr>
</tbody>
</table>

**Best Motor Response. (6 points)**

<table>
<thead>
<tr>
<th>Response</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) No motor response</td>
<td>1 point</td>
</tr>
<tr>
<td>b) Extension to pain</td>
<td>2 points</td>
</tr>
<tr>
<td>c) Flexion to pain</td>
<td>3 points</td>
</tr>
<tr>
<td>d) Withdrawal from pain</td>
<td>4 points</td>
</tr>
<tr>
<td>e) Localizing pain</td>
<td>5 points</td>
</tr>
<tr>
<td>f) Obey Command</td>
<td>6 points</td>
</tr>
</tbody>
</table>
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