ASSESSING VISUOSPATIAL NEGLECT IN CHILDREN WITH BRAIN INJURY

A Dissertation

by

ANDREA CHRISTINE WAHLBERG

Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Chair of Committee,	Cynthia Riccio
Committee Members,	William Rae
	Myeongsun Yoon
	Teresa Wilcox
Head of Department,	Victor Willson

August 2014

Major Subject: School Psychology

ABSTRACT

Visuospatial neglect (VSN), the failure to report, respond, or orient to novel or meaningful visual stimuli presented in a specific location, is a frequently occurring outcome following stroke. VSN can negatively impact the functions of daily life and is an important predictor for long term outcomes. The phenomenon is frequently studied in adult populations; however, the nature and incidence of VSN following childhood stroke is virtually unknown. Current research investigating the neuroanatomical correlates of VSN and hypothesized models of dysfunction all assume a fully mature brain and thus lack a developmental perspective. Similarly, current neuropsychological measures used to assess VSN are almost exclusively developed and normed with adult populations. While some individual adult tests have been modified for use with children, no standardized battery to assess VSN in young children currently exists. The present study investigated the reliability and validity of a five-task neuropsychological testing battery, the Pediatric Visuospatial Neglect Battery, developed at the Children's Hospital of Philadelphia (CHOP) to assess VSN in young children ages 2-6 following stroke.

Although there were some exceptions, the reliability estimates of task scores obtained from the present sample were generally low. With regard to criterion-related validity, sensitivity to detect brain injury was generally poor while specificity was high. Some of the low reliability and validity estimates were due to measurement problems of the calculated variables. These variables can be reexamined and likely improved in

future studies. In other instances, modifications to the tasks are recommended. Specific recommendations for improving the five existing tasks are provided as well as suggestions for additional tasks that could potentially be added to the battery in future administrations. Although somewhat disappointing, low initial reliability and validity estimates are part and parcel to test development. This study represents an important first step in developing a standardized battery to detect VSN in children. With refinement and additional testing, the Pediatric Visuospatial Neglect Battery may soon become an excellent instrument for investigating the VSN phenomenon in children.

DEDICATION

To my family, Sergey, Sashenka, Mom and Dad.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Cynthia Riccio, Ph.D. and my committee members, William Rae, Ph.D., Myeongsun Yoon, Ph.D., and Teresa Wilcox, Ph.D. at Texas A&M University for their support and guidance throughout the course of this research and preparation of this manuscript. I would like to especially thank Sabrina Smith, M.D., Ph.D. and members of the Stroke Team from the Children's Hospital of Philadelphia for their enthusiastic support in the use of their data set.

I would also like to thank each of my professors at Texas A&M University. Their commitment to teaching and dedication to their students has provided a rich learning environment and has equipped me with the expertise to pursue my passion in the field of pediatric neuropsychology. Most importantly, I wish to thank the children and families who participated in this research project. The time and effort they dedicated to the project will hopefully help improve the lives of many more children and families in the future.

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CHAPTER I

INTRODUCTION

Each year approximately 795,000 individuals suffer from a stroke in the United States (American Heart Association [AHA], 2012). The risk of stroke increases with age, and approximately 75% of individuals who experience a stroke are age 65 and older (Centers for Disease Control and Prevention [CDC], 2012). Because the majority of stroke cases occur in the adult population, this disorder is often thought of as an "adult disorder" or a disorder of "old age"; however, stroke also occurs in infants, young children and adolescents. In the United States the overall incidence of stroke in children ages 0-15 years is 6.4 in 100,000, and the prevalence of perinatal strokes (occurring at ≤ 28 days of life or in utero) is 29 per 100,000 live births (AHA, 2012). While it may be surprising to find that stroke occurs at such young ages, there is evidence to suggest that these estimates are actually low, and that the true incidence of pediatric stroke may be twice as high as the data suggest (Agrawal, Johnston, Wu, Sidney, & Fullerton, 2009).

What is Neglect?

Commonly occurring and frequently studied outcomes of stroke in adults and children include motor weakness, verbal difficulties, memory problems, and emotional and behavioral changes. One particularly important phenomenon, *unilateral neglect* or just *neglect*, the "failure to report, respond, or orient to novel or meaningful stimuli presented in a specific location" (Heilman, Watson, & Valenstein, 2012, p. 296), is also a potential outcome following stroke but receives less attention in the literature. In their review of published reports of neglect following stroke in adults, Bowen, McKenna, and Tallis (1999) found the incidence of neglect to vary between 13 and 82%; they concluded that an accurate estimate of its occurrence could not be determined. The reason for the tremendous variability is due in part to the heterogeneous nature of the disorder, and in part due to measurement issues such as participant selection and the nature and timing of the assessments. The incidence of neglect following stroke in children is also unknown and, to date, only a handful of studies examining neglect in children have been conducted.

Although some studies suggest that neglect occurs quite frequently following stroke (Stone, Wilson, Wroot, & Halligan, 1991), it is often not assessed or diagnosed properly and is rarely the focus of rehabilitation efforts. The lack of attention paid to neglect following stroke is unfortunate because it has been found to be an extremely important predictor of future functional outcomes (Azouvi et al., 2002; Buxbaum et al., 2004; Jehkonen, Laihosalo, & Kettunen, 2006). The true incidence of neglect is unknown, it potentially occurs quite frequently, it is often overlooked and under diagnosed, and it is a very powerful predictor of future outcomes. For these reasons, it certainly deserves increased attention in both the adult and pediatric literature.

What is Visuospatial Neglect?

It is now widely accepted that unilateral neglect is not a unitary disorder, and clinical manifestations can vary dramatically along multiple dimensions including modality, spatial representation, and range/structure of space (Halligan, Fink, Marshall, & Vallar, 2003; Heilman et al., 2012; Ting et al., 2011). The term neglect is a general term that encompasses all dimensions. *Visuospatial neglect* (VSN) is a specific form of neglect that specifically involves the neglect of visual stimuli in surrounding space. Within the neglect literature, VSN is probably one of the most frequently studied types of neglect. VSN is of particular importance because it can dramatically impact day-to-day functioning (i.e., attending to environmental stimuli, maneuvering in space, driving an automobile, and so on). Unfortunately, due to inconsistencies in the literature with respect to definitions of neglect and the lack of characterization of its various subtypes, the prevalence of VSN specifically is unclear. Again, this is especially true for children as the research on neglect generally and VSN specifically following pediatric stroke is extremely sparse.

Statement and Significance of the Problem

We know that infants, children, and adolescents experience stroke, and that unilateral neglect in general, and VSN specifically, are potential negative outcomes of stroke; however, the nature and incidence of VSN in children is largely unknown. Unfortunately the current literature on these phenomena occurring in children leaves us with more questions than answers. The first problem is with terminology. We are unable to quantify the occurrence or study the nature of VSN in children because within the literature, terminology is often poorly defined and inconsistently used, and neglect subtypes are inadequately characterized.

The second problem is with assessment. No standardized and validated test battery has been developed for assessment of neglect or VSN specifically in children. Currently, clinicians and researchers are relying largely on individual child measures or measures selected and modified from adult batteries. Adequate normative data on younger populations do not exist.

The third and most significant problem is the lack of research on this phenomenon as it occurs in children. There are simply not enough studies on children with VSN to draw any unequivocal conclusions about the disorder. The overwhelming majority of research on VSN and neglect in general has focused on the adult population, completely ignoring a developmental perspective. While this makes intuitive sense because neglect secondary to brain injury caused by stroke does occur most frequently in the older adult population, it does not excuse the lack of research conducted with the pediatric population. On the contrary, the paucity of research in this area makes it a critical area for study.

Normative and clinical data from studies conducted on the adult population largely assume a fully developed, mature adult brain. Unlike the adult brain, the brain of an infant, child, or adolescent is in a state of development, sometimes rapid development. Developmental factors such as maturation of the corpus callosum, hemisphere specialization, and crossover effects complicate the normative data considerably-even before clinical cases are considered. Injury during periods of development may have markedly different sequelae that potentially affect other structures and processes as they develop. The possibility of various deleterious outcomes carries with it tremendously important implications for treatment and recovery of neglect. The study of VSN and neglect in children with brain injury is incredibly complex, and despite this greater complexity, unfortunately the research is very sparse.

An Identified Need

Research elucidating this complex phenomenon in children should begin by clearly defining associated terminology and adequately characterizing the various subtypes of neglect. A standardized test battery for use with a pediatric population should be developed and validated with adequate sensitivity and specificity to differentiate children with VSN from healthy children. Lesion analysis should be conducted to determine what structures are affected in cases of VSN. Comparisons of multiple outcome measures should be made between children with VSN and healthy controls and also within the group of children with VSN to determine the effects of numerous intervening task variables and individual characteristics. Follow up studies with frequent and short intervals are necessary to better understand how early VSN might be affected by the developing brain's natural plasticity. Longitudinal studies are needed to determine the functional outcomes and other long-term effects of VSN following pediatric stroke. Finally, interventions for VSN must be developed and their effectiveness evaluated for rehabilitation purposes.

Purpose and Research Goals

Although much research is needed in the field of neglect and VSN in children, the present study was necessarily more limited in scope. The purpose of the current research study was to validate a neuropsychological test battery that can detect VSN in young children who have experienced stroke. VSN is of particular interest because the true incidence of the disorder is unknown, potentially occurs quite frequently, dramatically affects day-to-day functioning, and is a very powerful predictor of future outcomes.

Specific Research Questions of the Study

1. How reliable are the scores generated by the individual tasks that make up the five-task battery?
    a. What is the reliability of the line bisection scores
        i. of the normative sample?
        ii. of the sample of children with brain injury?
    b. What is the reliability of the feature visual search task scores
        i. of the normative sample?
        ii. of the sample of children with brain injury?
    c. What is the reliability of the conjunction visual search task scores
        i. of the normative sample?
        ii. of the sample of children with brain injury?
    d. What is the reliability of the extinction task scores

i. of the normative sample?

ii. of the sample of children with brain injury?

2. Do the scores offer adequate criterion-related validity?

   a. Are the outcome variables of certain visuospatial neglect tasks better able to "predict" brain injury? If so which ones?

   b. Results of which tasks have the greatest decision (sensitivity and specificity) accuracy?

CHAPTER II

LITERATURE REVIEW

To adequately orient the reader to the phenomenon of VSN, a conceptual overview of neglect and VSN is presented. Neuroanatomical correlates implicated in the disorder and hypothesized models of dysfunction are discussed. This conceptual overview is followed by a thorough review of instruments currently used to assess VSN with special attention paid to the five tasks that comprise the Pediatric Visuospatial Neglect Battery developed at the Children's Hospital of Philadelphia (CHOP). Task variables and individual characteristics that affect performance are thoroughly discussed. Because this study is specific to measuring VSN as it occurs in children, literature that discusses the phenomenon and its assessment within a developmental context is highlighted; however, due to the lack of research in this area, it is necessary to begin more broadly.

Neglect

In its most general definition, neglect is the "failure to report, respond, or orient to novel or meaningful stimuli presented in a specific location, when this failure cannot be attributed to either sensory or motor defects" (Heilman et al., 2012, p. 296). While neglect can occur in one or both hemispaces (e.g., left or right visual field), it occurs more frequently and is often more severe in the hemispace contralateral to the side of the cerebral lesion (Heilman et al., 2012; Ting et al., 2011; Weintraub & Mesulam, 1988). In fact numerous studies use this "contralesional space" distinction in their definitions of neglect (see Azouvi et al., 2006; Behrmann, Ebert, & Black, 2004; Heilman, Watson, & Valenstein, 2003; Trauner, 2003; Verfaellie & Heilman, 2006). Neglect also occurs more frequently and is often more severe following injury to the right hemisphere than injury to the left hemisphere (Azouvi et al., 2006; Beis et al., 2004; Bowen et al., 1999; Weintraub & Mesulam, 1988). In the adult literature, this lateralization of neglect is a hallmark of the disorder, and will be discussed extensively. Very recent evidence in pediatric literature however, suggests differences in functional lateralization between the mature and immature brain. Specifically, children with right hemisphere damage display contralateral neglect similar to adults; however, children with left hemisphere damage display bilateral difficulties (Thareja, Ballantyne, & Trauner, 2012).

It is now widely accepted that *neglect* is not a unitary disorder (Azouvi et al., 2006; Heilman et al., 2012; Ting et al., 2011; Verfaellie & Heilman, 2006). Its clinical manifestations can vary along several dimensions (modality, spatial representation, and range of space), which also vary by person, point of time, and assessment method. Unfortunately, much of the literature fails to adequately describe the broad term *neglect* by its specific variants. Instead, terms such as *neglect*, *visual neglect*, *visuospatial neglect*, *hemispatial neglect*, *unilateral neglect*, and *visual inattention* are used loosely and interchangeably (Ting et al., 2011). This can cause confusion and misinterpretation of findings, and may limit applicability and clinical utility. For theoretical and practical purposes, the various types or forms of neglect should be considered on a case by case basis and clearly specified within each study. Despite this recommendation, poorly defined terms and limited descriptions will persist; therefore, it is important that the reader be informed of the various distinctions inherent in the complex disorder of neglect. In much of the theoretical literature, neglect is frequently conceptualized along the following dimensions: modality, spatial representation, and range/structure of space.

Modality

Perhaps one of the most important dimensions of neglect to consider is modality. Neglect can first be divided into sensory (input, afferent, attentional) neglect and premotor (output, efferent, or intentional) neglect (Heilman et al., 2012). *Sensory neglect* or inattention refers to a "deficit in awareness of stimuli presented contralateral to a lesion that does not involve sensory projection systems or the primary cortical sensory areas to which they project" (Heilman et al., 2012, p. 296). Sensory neglect can be further subdivided into tactile/somatosensory, auditory, and visual or visuospatial neglect. An individual with sensory neglect that is tactile, for example, may not be aware of tactile contact to the hand contralateral to the injury. Deficits can occur in one or multiple modalities (Barrett, Edmondson-Jones, & Hall, 2010; Sinnett, Juncadella, Rafal, Azanon, & Soto-Faraco, 2007).

Premotor, or output, neglect is characterized by the failure to orientate the limbs toward contralesional hemispace despite awareness of the stimulus and the strength to respond. Heilman et al. (2012) call this failure to respond in the absence of unawareness or weakness, *action-intentional neglect*, and have identified five subtypes: *akinesia*, the failure of initiation of movement that cannot be attributed to dysfunction in upper or lower motor neuron systems or unawareness of the stimulus; *motor extinction,* the presence of contralesional akinesia when both limbs are moved simultaneously, but not when they are moved independently; *hypokinesia*, initiating action responses after an abnormally long delay; *motor impersistence,* the inability to sustain an act; and *allokinesia,* movement of the incorrect extremity or movement in the incorrect direction. Although sometimes occurring together, disassociations between sensory and premotor neglect have been widely documented (Bisiach, Geminiani, Berti, & Rusconi, 1990; Heilman et al., 2012; Làdavas, Umiltà, Ziani, & Brogi, 1993; Verfaellie & Heilman, 2006) and thus are generally conceptualized separately. A clear modality distinction therefore should always be made.

Spatial Representation

Another dimension to consider when defining neglect is spatial representation. This variant depends on a specific frame of reference, either egocentric or allocentric. *Egocentric* (self or body-referenced) neglect is described as failure to orientate or attend to stimuli in one hemispace (left or right) with respect to the individual. For example, a person with *left egocentric visuospatial neglect* who is sitting, facing, and looking forward at a table might not attend to items on the left side of the table or anything to the left of his body's midline. Alternatively, spatial position can be independent of the lateral position of the observer. *Allocentric* (stimulus or object-referenced) neglect is a type of neglect where lateralized deficits are spatially defined in terms of an object's position relative to another object. One side of an object may be ignored irrespective of the position of the object in relation to the person (Halligan et al., 2003). For example, a person with *left allocentric visuospatial neglect* who is sitting, facing, and looking forward at a table attends to all items on both the left and right halves of the table, but might neglect the left half of one or more objects irrespective of their position on the table. While some evidence supports a strong association between egocentric and allocentric neglect (Rorden et al., 2012), disassociations have been found (Bickerton, Samson, Williamson, & Humphreys, 2011; Kleinman et al., 2007; Marsh & Hillis, 2008), and so again clear distinctions are essential. The spatial representation variation of neglect is further complicated by the term *hemispace*. Hemispace is a complex term because it is also defined differently according to specific points of reference. More specifically, it can be defined in terms of a visual half field, head hemispace, or trunk/body hemispace (Heilman, Bowers, Valenstein, & Watson, 1987). If the eyes, head, and body are all facing directly forward, such that the midsagittal planes are aligned, then these three structures are parallel, and all three hemispatial fields are congruent. However, if the eyes are shifted in one direction, or if the head is turned to one side, then the hemispaces are no longer congruent, and thus specific distinctions must be made as to which hemispace is being considered.

Range/Structure of Space

When discussing issues of attention and neglect, seamless Euclidian space is often divided into three regions: personal space, peripersonal space, and extrapersonal space. *Personal* space is the space of the body's surface. Typical manifestations of *personal neglect* include failure to shave or groom one side of the face, failure to adjust glasses on one side of the face, and failure to notice the position of or use appropriately limbs on one side of the body (Halligan et al., 2003). *Peripersonal* (near) space is the space within arm's reach. *Extrapersonal* (far) space is the space that is beyond arm's reach. Verfaellie and Heilman (2006) reserve the term *hemispatial neglect* to peripersonal and extrapersonal neglect exclusive of personal neglect. Again, dissociations between neglect in these structures of space have been found (Berti & Frassinetti, 2000; Halligan & Marshall, 1991); thus, clear distinction is important.

Visuospatial Neglect

With the general term neglect and its variants more clearly explained, it is now permissible to discuss VSN specifically. Generally stated, VSN is the neglect of one-half of visual space (Heilman et al., 2012). Individuals with VSN may fail to read parts of a word or sentence, may write or draw on only one side of a page, or may fail to eat the food on one side of their plate. It should be noted that the term neglect is embedded within the term VSN, and thus the general neglect definition as stated previously still applies. VSN has also been termed hemispatial neglect, visuospatial agnosia, hemispatial agnosia, spatial neglect, and unilateral spatial neglect (Heilman et al., 2012). Each of these terms possesses certain nuances with very specific implications, which unfortunately are often ignored or poorly characterized in the literature. With respect to the three dimensions of neglect described previously, the term VSN clearly implies sensory (or input) neglect of visual or visuospatial stimuli, but the other two dimensions (spatial representation and range/structure of space) are left unspecified. In the majority of studies reviewed here, VSN is most often conceptualized and assessed (although not specifically termed) as egocentric and as occurring in peripersonal space. By definition these two specific variants are not fixed, so it is often up to the reader to differentiate the types of VSN when it is not clearly stated. Recent studies have begun investigating these different dimensions of VSN (i.e., egocentric vs allocentric neglect and peripersonal vs extrapersonal neglect), and in effect making accurate terminology more important.

Anatomical Correlates of VSN

To better understand the complexities of VSN, it is important to consider the neurological correlates associated with the disorder. Determining the structures and functions implicated in VSN is a difficult task. First, individuals with VSN often have extensive brain damage making precise anatomical correlations nearly impossible. Secondly, individuals with VSN often have other additional cognitive impairments which hinders the assessment of pure VSN. The nature and timing of the assessments can be problematic as well because some individuals with VSN show only mild symptoms sensitive to certain tests and/or rapid recovery. Finally, the lack of clear and specific classification of neglect subtypes can lead to overgeneralization of the neural basis of VSN (Ting et al., 2011).

Brain imaging studies utilizing functional magnetic resonance imaging (fMRI), positron emission tomography (PET), perfusion weighted imaging (PWI), and diffusion weighted imaging (DWI) have identified several regions serving visuospatial attention that are implicated in VSN: the inferior parietal lobe, the temporal parietal junction, the superior temporal gyrus, and the frontal lobe, including the medial and inferior frontal gyri (see Ting et al., 2011). Specific cortical areas have been implicated in various types of VSN. For instance, portions of the dorsal stream of visual processing, including the right supramarginal gyrus, are involved in spatial encoding and are implicated in egocentric neglect, whereas parts of the ventral stream including the posterior inferior temporal gyrus are involved in allocentric encoding and thus allocentric neglect (Medina et al., 2009). Grimsen, Hildebrandt, and Fahle (2008) also found allocentric impairment linked to ventral regions (near the parahippocampal gyrus) and egocentric impairment associated with damage to premotor cortex involving the frontal eye fields. Personal neglect is associated with damage to right inferior parietal regions (supramarginal gyrus, post-central gyrus and especially the white matter medial to them), whereas extrapersonal neglect is associated with damage to a circuit of right frontal (ventral premotor cortex and middle frontal gyrus) and superior temporal regions (Committeri et al., 2007).

While correlations between cortical areas and neglect typology appear to provide a straightforward solution for the disorder's heterogeneous manifestations, recent evidence suggests that cortical damage alone may be insufficient to cause neglect, and that disconnection of subcortical white matter tracks may provide a better explanation. With the advent of diffusion tensor imaging (DTI), specific white matter tracts in the fronto-parietal network have been implicated in VSN (Doricchi, Thiebaut de Schotten, Tomaiuolo, & Bartolomeo, 2008). Specifically, the white matter fronto-parietal pathways that link parietal and frontal areas including the superior longitudinal fasciculus (SLF) and the arcuate fasciculus (AF), and more ventral pathways such as the inferior longitudinal fasciculus (ILF) and the occipital frontal fasciculus (IFOF) have been implicated in neglect (Bird et al., 2006; He, et al., 2007; Leibovitch, et al., 1998; Urbanski et al., 2008; Urbanski et al., 2011). Interestingly, the areas of damage in these fibers has been localized to the white matter beneath the temporal-parietal junction (Leibovitch et al., 1998) and the supramargynal gyrus (Doricchi & Tomaiulolo, 2003), (previously implicated cortical areas). The 2008 and 2011 studies conducted by Urbanski et al. were some of the first to use DTI tractography in individuals with neglect secondary to vascular brain injury. More studies are needed before firm conclusions can be drawn about the nature and location of specific white matter disconnections and the variants of neglect.

Seemingly, subcortical damage to white matter tracks is the clear culprit in the VSN puzzle; however, findings from cortical perfusion studies offer yet another possibility. Recent studies using PWI, suggest that VSN is associated with hypoperfusion of the overlying cortex rather than cortical or subcortical damage alone (Hillis et al., 2005). Hillis et al. posits that cortical hypoperfusion rather than subcortical infarct is the likely cause of neglect because in their study, no significant association between subcortical lesion site and the presence or type of neglect was found, and because reperfusion of the cortex resulted in recovery of function despite the continued presence of the subcortical infarct. This finding provides additional insight yet is still relevant to the disconnection theory because it supports the idea that subcortical disruption of parietal-frontal connections may cause neglect by reducing functional activity in the entire cortical-subcortical parietal frontal network (Doricchi et al., 2008).

Hypothesized Models of Dysfunction

Any attempt to understand neglect must necessarily involve the consistent finding of its greater frequency and severity following injury to the right as opposed to the left hemisphere. This lateralization is a hallmark of neglect and has helped inform the following widely-cited neurocognitive models of spatial attention and neglect. Mesulam (1981) proposed a very influential model that suggested spatial attention was a distributed function mediated by a network of cortical areas rather than a specialized function of the parietal lobes. According to Mesulam (1999), three cortical regions subserve spatial attention: the posterior parietal cortex along the intraparietal sulcus, dorsal frontal cortex near the frontal eye field, and the medial frontal cortex near the anterior cingulated cortex. It was suggested that damage to any of these core nodes of the attention network will result in unilateral spatial neglect. Perhaps the most influential idea of his theory was that space is asymmetrically represented. The right hemisphere controls attentional orienting in both hemispaces (both contralaterally and ipsilaterally), whereas the left hemisphere controls attentional orienting mainly in the right hemispace (contralaterally). This functional organization implies that injury to the left hemisphere results in maintained attentional orienting to both hemispaces due to the intact right hemisphere; whereas, injury to the right hemisphere results in attention being directed only toward the right hemispace by the intact left hemisphere. This asymmetrical model explains the greater frequency of neglect following right as opposed to left hemisphere injury.

Corbetta, Kincade, and Shulman (2002) proposed a dorsal-ventral fronto-parietal model of attention, a novel model evolving from the Mesulam model. In this model, the dorsal attentional network (DAN) is bilateral and connects the superior parietal lobes and the intraparietal sulci with the dorsal frontal lobes, including the frontal eye fields. The DAN mediates stimulus and response selection and is involved in goal-directed, top-down attentional selection. The ventral attentional network (VAN) is lateralized to the right hemisphere and links the temporal parietal junction, inferior parietal lobe, and ventral frontal lobe. The VAN mediates alerting and reorienting toward novel sensory events, and is associated with stimulus-driven, bottom-up attention. Corbetta et al. (2002) suggest that VSN is associated with a bottom-up attentional deficit, which overlaps with the implicated structures (of the right lateralized VAN) and may help explain the higher incidence of VSN following right hemisphere damage.

Common to these models of attention are two very important ideas: 1) widely distributed networks connecting various cortical areas serving attention and 2) right lateralization. Each of these models is in part supported by the neuroanatomical findings discussed previously. Namely, that VSN can result from damage to fronto-parietal connections in the right hemisphere, which are important for orienting of spatial attention, arousal, and other related functions. Doricchi et al. (2008) did a particularly nice job connecting neuroanatomical findings to existing theory. They suggest that functional disruption of different networks could be associated with different types of neglect, and may result from damage to different white matter bundles, from damage to different points along the same bundle, or from the combination of disconnection and damage to different cortical modules. Again, it should be noted that these hypothesized models of dysfunction stem from studies on adults and imply a fully mature brain. Currently, no model of VSN from a developmental perspective has been put forth. For purposes of this study, these two general aspects of the above models will conceptually form the base of the present investigation.

Assessment of VSN

What follows is a review of various neuropsychological tests that purport to measure VSN in children. Because most of these measures were adapted from adult tests and most of the normative and clinical data come from adults, findings in the adult population must necessarily be presented. The Pediatric Visuospatial Neglect Battery under investigation in the present study consists of five neuropsychological tests (line bisection, cancellation, feature visual search, conjunction visual search, and extinction). These tests will be the focus of the review and will be presented first. They will be described in detail with respect to purpose, administration, and interpretation. Findings on normal healthy adults and children will be presented first with special attention paid to the multiple task variations and individual characteristics that affect performance. Next, findings from clinical and experimental neuropsychological studies involving adults and children with neglect and brain injury will be presented, again with special attention paid to the variables that affect performance. Following the review of these five neuropsychological tests, other popular measures of VSN will be discussed briefly.

The Line Bisection Task

The line bisection task is a paper and pencil test that is widely used among clinicians and researchers to detect neglect in individuals with brain injury. Its simplicity and ability to effectively discriminate between individuals experiencing neglect following brain injury and healthy controls, makes it a quick and effective assessment tool. Although variations exist, in its most common form, the subject is presented with a white sheet of paper (often presented in landscape orientation) consisting only of a black horizontal line drawn across the center of the page. The subject is then asked to visually estimate the midpoint of the horizontal line by making a small vertical mark with a pencil. To score the line bisection task, the administrator precisely measures the distance between the participant's small vertical mark and the true midpoint (veridical center) of the horizontal stimulus line. This distance is referred to as *deviation from center* or *midpoint displacement*. In some instances the line bisection task is administered multiple times, and an average deviation from center score is calculated.

Line bisection performance in healthy individuals and individuals with brain injury. The line bisection task is a widely used instrument, and thus a considerable amount of research using the task has been conducted. Unfortunately, the reported findings on line bisection performance of healthy individuals are largely inconsistent and substantial variability exists between the studies. Jewell and McCourt

(2000) conducted a meta-analysis of 73 line bisection studies, which included 2,191 healthy individuals. The results of the study indicated a significant leftward bisection error in neurologically normal individuals with an overall effect size ranging between -0.37 and -0.44. This phenomenon has been termed *pseudoneglect*. In neuroimaging studies of healthy adults, superior portions of the right posterior parietal cortex and postcentral sulcus were highly active during bisection tasks (Revill, Karnath, & Rorden, 2011). Also, disruption of the posterior parietal cortex via brain stimulation produced performance indicative of contralateral neglect on line bisection in healthy adults (Fierro et al., 2000).

Line bisection performance of individuals with brain injury differs from that of healthy controls. Midpoint deviation toward the ipsilesional side of an injury suggests an attention, orientation, or representational bias, and hence potential VSN. Due to its greater frequency and severity, the vast majority of studies investigate left neglect following injury to the right hemisphere. The most important general finding on line bisection performance is that individuals with left hemispatial neglect following right hemisphere injury display a rightward shift in the perceived midpoint of horizontal lines. This finding has been replicated so consistently that it is used diagnostically (see Wilson, Cockburn, & Halligan, 1987).

Task variables affecting line bisection performance. There are numerous variations of the line bisection task that affect line bisection performance in both healthy individuals and individuals with brain injury. The task variables affecting performance that are studied most frequently in the literature are discussed here.

Line length. The stimulus lines in the line bisection task can vary in length. While perhaps seemingly trivial, these differences have been shown to produce different outcomes in healthy individuals. Research suggests that performance deteriorates (i.e., deviation from center increases) with increased line length in both healthy adults (Azouvi et al., 2006; Chokron & Imbert, 1993; Luh, 1995; Manning, Halligan, & Marshall, 1990; Mozer, Halligan, & Marshall, 1997) and in healthy children (Dennis et al., 2005; Van Vugt, Fransen, Creten, & Paquier, 2000). Some suggest that the variability of displacements is actually proportional to line length (Mozer et al., 1997). Direction of the deviation is less clear. In children, a significant leftward shift of the subjective midpoint occurred as line length increased (Van Vugt et al., 2000); however, the adult literature is largely inconsistent and appears to be affected by other intervening variables. Some have found no clear left/right differences in performance with changes in line length (Manning et al., 1990; Nichelli, Rinaldi, & Cubelli, 1989).

Much like their healthy counterparts, accuracy tends to decrease with increasingly longer lines in adults with neglect secondary to brain injury (Halligan & Marshall, 1989; Marshall & Halligan, 1989). Interestingly, evidence has been found in adults for a paradoxical “crossover” effect, where individuals with neglect tend to bisect average and long lines to the right of center, but begin to displace bisection marks increasingly leftward as the lines become smaller, and bisect extremely short lines to the left of true center (Halligan & Marshall, 1988; Halligan & Marshall, 1989; Ishiai, Koyama, Seki, Hayashi, & Izumi, 2006; Marshall & Halligan, 1989). No studies evaluating the effect of line length on line bisection performance in children with brain injury or neglect were found.

Line placement. The placement of the stimulus line may also play a role in normative performance on the line bisection task. Head and body midline are traditionally used to divide space into two half-fields producing slightly overlapping left and right hemifields. In most administrations the stimulus line is placed on a flat surface directly at the subject's body midline. However, some line bisection studies have shifted the stimulus line to left and right of body midline with varying outcomes. Nichelli et al. (1989) found that normal adults displaced the midpoint toward the end opposite to the side of hemispace presentation, a phenomenon called *body midline attraction*. McCourt and Jewell (1999) and Reuter-Lorenz, Kinsbourne, and Moscovitch (1990) found the opposite: subjects made leftward errors with left hemispace presentation, and rightward errors with right hemispace presentation. Others have found that the position of the lines with respect to the body or the page on which they are drawn has little effect in healthy adults (Mozer et al., 1997). Van Vugt et al. (2000) found that healthy children do not necessarily display body midline attraction in their line bisections. They found that on lines presented in the center and to the left of center a significant leftward shift of midpoint occurred; however when lines were presented to the right children displayed a non-significant rightward displacement.

In adults with neglect, presenting lines in different hemispaces may influence line bisection. Specifically, lines placed in left hemispace increase bisection error toward the right, while placing lines in right hemispace significantly reduced the amount of rightward deviation (Nichelli et al., 1989; Samuelsson, 1990). However, Reuter-Lorenz and Posner (1990) found no effect for side of line presentation on magnitude or direction of bisection in individuals with right hemisphere damage. No studies evaluating the effect of line placement on line bisection performance in children with brain injury or neglect were found.

Directional scanning. In most administrations of the line bisection task, examinees are permitted to manually and visually inspect the stimulus line in an uncontrolled and untimed manner. Because individuals may adopt systematic scanning strategies when bisecting lines, it is important to determine if this scanning behavior affects the perceived midpoint. Attempts have been made to control scanning behavior by controlling initial starting position of the hand or eyes, by requiring certain directional hand movements across the stimulus line, or by having the examinee watch the examiner trace a line from left to right or right to left prior to bisecting it. These experimental manipulations have led to mixed findings. Reuter-Lorenz and Posner (1990) found no effects for directional scanning in healthy adults; whereas Chokron, Bartolomeo, Perenin, Helft, and Imbert (1998) found leftward errors when lines were visually scanned from left-to-right and found rightward errors when lines were scanned from right-to-left. Similar patterns were observed in children using a pen in either a left or right starting position (Dobler et al., 2001). Some researchers have suggested that reading habits may play a role in directional scanning and thus midpoint perception, as subjects who read text from left-to-right tend to err left and subjects who read text from right-to-left tend to err right (Chokron & Imbert, 1993).

Using an infrared eye monitoring instrument, the eye movements of an adult with neglect were found to be directed to the right end of the line without any scanning or leftward eye movement back to the center of the line (Kim, Anderson, & Heilman, 1997). This scanning behavior was markedly different from healthy adults who initially orient to the left end of the line, scan rightward, then look leftward to the center. When given an explicit request to start the exploration of the line from the left side, individuals with neglect tended to reduce the amount of error in their bisections (Samuelsson, 1990). No studies evaluating the effect of scanning direction on line bisection performance in children with brain injury or neglect were found.

Spatial location. Traditionally, the pencil and paper line bisection task is administered while the examinee is seated at a table with the stimulus line(s) within arm's reach. This administration procedure necessarily takes place in peripersonal (or near) space. The line bisection task has also been performed in extrapersonal (or far) space by projecting the stimulus line onto a far wall and allowing the examinee to use a laser pointer to bisect the line. The line bisection performance of healthy adults does not appear to differ between near and far space, and again appears to reveal a slightly leftward bias (Aimola, Schindler, Simone, & Venneri, 2012). Performance in near and far space might be affected by gender, however, as women were more accurate in the near condition than the far, and men were more accurate in the far condition than the near (Stancey & Turner, 2010). No studies that examine extrapersonal bisection performance in children were found.

Unlike their healthy counterparts, the line bisection performance of individuals with brain injury does appear to be affected by spatial location. While a mean rightward deviation in line bisection performance was present in both near and far space for individuals with right hemisphere injury displaying neglect, the deviations were significantly greater in near space than in far space (Aimola et al., 2012). No studies evaluating the effects of spatial location on line bisection performance in children with brain injury or neglect were found.

Individual variables affecting line bisection performance. In addition to variations in the line bisection task itself, line bisection performance is also affected by various characteristics of the individual. The most frequently studied individual variables affecting line bisection performance are discussed here.

Handedness/laterality. Handedness is the most commonly used indicator of lateralization of cerebral dominance, which is known to affect performance on a variety of cognitive and perceptual tasks, yet many studies fail to disclose subject handedness (Jewell & McCourt, 2000). Handedness, defined as preferred hand, can include left (sinistrals), right (dextrals), or ambidextrous. In adults, both dextrals and sinistrals tend to err leftward of center, with sinistrals erring farther to the left than dextrals. (Luh, 1995; Scarisbrick, Tweedy, & Kuslansky, 1987). Bradshaw, Nettleton, Wilson, and Bradshaw (1987) found similar effects for accuracy in preschool children with sinistrals displaying larger bisection errors than dextrals. Dobler et al. (2001) found sinistral children (ages 6-7) erred to the left and dextral children erred to the right. In children, handedness appears to have an interaction effect with stimulus position (Van Vugt et al.,

2000) and hand used to perform the task (Bradshaw et al., 1987). More specifically, dextral preschoolers tended to bisect lines to the left regardless of hand used, while sinistral preschoolers bisected to the right when using their right hand and to the left when using their left hand, a phenomenon termed *symmetrical neglect* (Bradshaw et al., 1987).

Hand used. A distinction must be made between handedness and hand used. Although a person may have a natural hand preference, this may or may not have been the hand that they used to perform the line bisection task. In clinical studies involving individuals with brain injury, hemiparesis or hemiplegia may prevent the use of a preferred hand. In research studies, experimenter manipulation may force the use of a non-preferred hand. Alternatively, a person may be ambidextrous with regard to handedness, but would necessarily be required to use only one hand while performing the manual bisection task. Because the line bisection task requires unilateral limb use, which itself imposes an asymmetry of cerebral activation, it is necessary to study the effect of hand used. The literature becomes increasing complex and inconsistent when hand used is a manipulated variable. This seems to be especially true in the developmental literature where lateralization and motor effects have a particularly strong influence (Dellatolas, Coutin, & De Agostini, 1996).

Meta-analytical findings suggest that individuals err to the left of true center regardless of hand used to perform the task; however, individuals err farther left when the left hand is used than when the right hand is used (Jewell & McCourt, 2000). Other studies found no significant differences between left and right hand used (Dellatolas, Vanluchene, & Coutin, 1996). In children, hand used seems to have strikingly similar performance effects to handedness. Children (ages 7-12) who used their right hand to bisect lines were more accurate overall. Bradshaw et al. (1987) found that sinistral preschoolers bisect to the right of center when using their non-preferred right hand, and to the left of center when using their preferred left hand, whereas hand used did not affect the performance of dextral preschoolers, who consistently bisected to the left.

Age. Age appears to have a significant effect on line bisection performance. In children aged 7-12 years, Van Vugt et al. (2000) found significantly increasing accuracy with increasing age. In younger children (ages 4-8), performance seems to be affected by handedness and hand used. Symmetrical neglect (bisecting to the left when using the left hand and bisecting to the right when using the right hand) appears to be strongest in very young children (Bradshaw, Spataro, Harris, & Nettleton, 1988; Dellatolas, Coutin, et al., 1996; Failla, Sheppard, & Bradshaw, 2003), but has also been found in elementary age children (Sampaio, Gouarir, & Mvondo, 1995). After childhood, a leftward trend occurs in young and middle aged adults followed by a suppressed or even reversed (rightward shift) trend in the elderly (Dellatolas, Vanluchene, et al., 1996; Failla et al., 2003; Fujii, Fukatsu, Yamadori, & Kimura, 1995; Schmitz & Peigneux, 2011). This shift at the oldest ages has been attributed to the normal aging process and decline in processes associated with the right hemisphere. The age effect suggests the potential for additional variables to exert their influence as development progresses. For instance, some of the age effects might be attributed to educational level or reading and math ability. As mentioned previously, Chokron and Imbert (1993) found that bisection performance was related to the direction of text reading. With regard to math, Cattaneo, Fantino, Mancini, Mattioli, and Vallar (2012) found that the mental number line modulates the representation of visual and haptic space on the line bisection task.

Sex. The majority of studies examining the influence of sex on line bisection performance report non-significant effects (Jewell & McCourt, 2000); however, some studies have concluded that males and females perform differently on the line bisection task. For example, Roig and Cicero (1994) found that males err more to the left than females. The findings are less consistent with children. Van Vugt et al. (2000) found significant sex biases such that girls presented with a rightward bias, where boys displayed a non-significant but leftward bias. Others have found no sex differences in children (Dobler et al., 2001).

Brain injury. In most studies individuals were treated as cohesive "injury" or "neglect" groups. Very few studies were found that investigate various injury effects on line bisection performance. This is likely due to small sample sizes and the time and expense associated with imaging studies. Despite these limitations, some preliminary findings have been made. Lesion size does not appear to correlate with line bisection performance in adults with neglect (Aimola et al., 2012; Saj, Honoré, Braem, Bernati, & Rousseaux, 2012). Although there appears to be a slight recovery effect in some individuals, Saj et al. detected a significant rightward bias on the line bisection task at approximately 1 and 2 months post stroke. No studies were found that evaluate the type of brain injury on line bisection performance in children with brain injury or neglect.

Reliability and validity of the line bisection task. Most research studies investigating line bisection performance do not report reliability, often because multiple repeated measures are not taken or are not the focus of the study. When reported however, line bisection administrations seem to have fairly good reliability. Luh (1995) administered the line bisection task with 15 lines presented on a single stimulus page (three columns and five rows). Although this resulted in various line placements (left, right and center), Luh found the overall test reliability of the line bisection administration to be .75.

Most studies investigating the validity of the line bisection task, report external validity, more specifically, decision based criterion-related validity. In their 2007 study, Lindell et al. administered a neuropsychological test battery consisting of 19 separate tests, and found that the line bisection test and the complex line bisection test were two of the most sensitive measures of neglect. In their line bisection task, the participant had to estimate the center of three horizontal lines (each 20.4mm) presented in a staircase fashion. This test was able to positively detect 38% of the neglect cases. In the complex line bisection test, twelve horizontal lines were spaced in a mirror image (six lines on each half of the paper). In the upper half of the paper, three pairs of 63 mm lines were placed in a pyramid fashion. In the lower half of the paper three pairs of lines of different lengths (63 mm, 123 mm, and 185 mm) were placed the same distance from the center of the page. This complex line bisection task, which manipulated line placement and length, was even more sensitive, and was able to positively detect 48% of neglect cases. In a separate study, Azouvi et al. (2002) found that among adults with right hemisphere injury, the line bisection task was able to positively identify neglect in 38% of individuals when a 20 cm line was used, and 19% when a 5 mm line was used.

The Cancellation Task

Like line bisection tasks, cancellation tasks are generally pencil and paper tests. Both structured and random cancellation tasks have been used in traditional IQ tests and in other instruments as measures of processing speed and visual attention. Similar to the line bisection task, multiple stimulus and administration variations exist for the cancellation task. Task variations and their effects will be discussed in detail below; however, in its most traditional form, the cancellation task consists of a stimulus page of multiple target items and distracters (usually shapes, symbols, animals, objects, or letters) placed on a table in front of an examinee. The target and distracter items are pseudo-randomly arranged so that an (approximately) equal number of target items appear on the left and right sides and top and bottom half of the stimulus page. The examiner asks the examinee to identify and cross out (cancel) all the target items with a pencil. After the examinee indicates that they have finished cancelling all of the target items on the stimulus page or after the allotted time has expired, the examiner removes the page and calculates the total number of target objects cancelled. This raw score is then converted into a standard score based on age or grade-level norms. Additional analyses can be conducted as needed including number of targets cancelled in various quadrants, re-cancellations, location of initial target cancelled, or cancellation search strategy (Laurent-Vannier, Chevignard, Pradat-Diehl, Abada, & De Agostini, 2006;

Laurent-Vannier, Pradat-Diehl, Chevignard, Abada, & Agostini, 2003; Manly et al., 2009; Thareja et al., 2012).

Cancellation performance in healthy individuals. Normative data suggest that in general, healthy adults (Azouvi et al., 2006) and children (Laurent-Vannier et al., 2003; Laurent-Vannier et al., 2006; Thareja et al., 2012) make no (or very few) omission errors on untimed administrations of cancellation tasks. Commission errors are also infrequent (Thareja et al., 2012). Accuracy increases with age as very young children (less than 4 years old) tend to make slightly more omission errors than older children (ages 4-8) (Laurent-Vannier et al., 2003; Laurent-Vannier et al., 2006). Omission errors that do occur in healthy individuals generally happen with the same frequency on the left and right sides of the stimulus page (Aimola et al., 2012; Azouvi et al., 2006; Thompson, Ewing-Cobbs, Fletcher, & Miner, 1991). Healthy adults tend to begin the cancellation task on the left side of the stimulus page (Azouvi et al., 2006) as do healthy children aged over 6 years (Laurent-Vannier et al., 2003; Thareja et al., 2012), and generally proceed from left to right across the page (Thareja et al., 2012). Younger children (aged 3 – 6 years) tend to begin cancelling targets in the middle of the page, and very young children do not display a left/right bias in initial target cancelled (Laurent-Vannier et al., 2003). It is unclear if cancellation starting points differ in cultures where text is not read from left to right. Search organization is efficient in healthy individuals with consecutive cancellations occurring within close proximity and very infrequent re-cancellation behavior (Manly et al., 2009). Poor (but non-lateralized) performance on the cancellation task is often interpreted as indicative of a general attention problem (Laurent-Vannier et al., 2006); however, lateralized performance can indicate neglect or another visual deficit.

Variables affecting cancellation performance in healthy individuals. Similar to the line bisection task, numerous variables affect cancellation performance. The most frequently studied task variables and individual characteristics affecting cancellation performance are discussed here.

Structured vs. random tasks. In structured cancellation tasks, both target and distracter items are equally spaced and lined up in multiple columns and rows. The subject can employ any visual search strategy he wishes, but often will scan a row from left to right (or a column from top to bottom) searching and cancelling target items as he comes across them. The Bells test (Gauthier, Dehaut, & Joanette, 1989) is a frequently used structured cancellation task for adults consisting of 35 black ink bells and 280 distracter items pseudo-randomly arranged in seven columns. The teddy bear and letter cancellation tasks are other examples of structured cancellation tasks more frequently used with younger examinees. Random cancellation tasks are similar to structured tasks in that the examinee is asked to search for target items among a page of distracter items; however, in random tasks the items are not neatly arranged in rows and columns. Again, examinees can use any search strategy they find helpful, but visual scanning of neatly aligned rows or columns is not possible in random cancellation tasks. The star cancellation task from the Behavioral Inattention Test (BIT; Wilson, Cockburn, & Halligan, 1987) is a frequently used random cancellation task that consists of 56 small target stars and distracter items which consist of large stars, letters, and short words pseudo-randomly arranged on a stimulus page. When comparing the performance of healthy individuals on structured and random cancellations tasks, the findings are mixed. In healthy children, Thareja et al. (2012) found no significant performance difference between structured and randomized tasks. Normative data from the Wechsler Intelligence Scale for Children, Fourth Edition (WISC-IV; Wechsler, 2003) further suggest very little difference between the two cancellation tasks. In healthy children, mean process scores were slightly higher for the structured task.

Target and distracter type/number. Target and distracter items appearing on the stimulus page may be any number of shapes, symbols, animals, objects, letters, words, or a combination of these. The Bells test consists of 315 target bells and distracter objects including guitars, apples, keys, birds, and horses. The Letter Cancellation from the BIT consists of rows of uppercase target letters embedded in a structured array of uppercase distracter letters. The Star cancellation test (also from the BIT) uses short words as distracters pseudo-randomly arranged among stars of various sizes. The teddy bear cancellation task was specifically developed for use with young children (Laurent-Vannier et al., 2003). It consists of 15 teddy bear targets equally distributed in five columns and surrounded by 60 distracter items (dolls, cars, and candy). In the present review, only two studies were found that compared normative performance on various cancellation tasks with different target and distracter items. Interestingly, target and distracter type tends to affect cancellation performance. Both healthy children (Thareja et al., 2012) and adults (Lindell et al., 2007) perform better on cancellation tasks that use shapes rather than letters.

Peripersonal (near) vs. extrapersonal (far) space. Traditionally, the pencil and paper cancellation task is administered while the examinee is seated at a table with the stimulus page within arm's reach. This administration procedure necessarily takes place in peripersonal space. The cancellation task also has been performed in extrapersonal space by projecting the stimulus page onto a far wall and allowing the examinee to use a laser pointer to cancel target items. Cancellation performance of healthy adults appears to be the same for near and far space cancellation tasks, both testing situations revealing non-lateralized (balanced) search performance (Aimola et al., 2012). No studies examining the effect of near vs far space on children's cancellation performance were found.

Age. Although the research examining age effects on cancellation performance is not completely consistent, some general trends have emerged on some performance outcome variables. In healthy individuals, very young children show less accurate performance overall, but little to no lateralized (left vs right) cancellation performance (Laurent-Vannier et al., 2003). In middle childhood, a leftward deviation of initial targets cancelled begins to develop (Laurent-Vannier et al., 2006) and persists throughout adulthood (Azouvi et al., 2006). No significant age differences were found on location of total omissions.

Sex, handedness, SES, time of day. In healthy children, no statistically significant differences on sex, handedness, or SES were observed on number of omissions, location of omissions, or location of initial targets cancelled (Laurent-Vannier et al., 2006). However, the high SES group showed a tendency toward significance in location of initial targets cancelled with these children displaying greater leftward displacement. The authors suggested this finding may be attributed to high SES children having more opportunities to read at an earlier age. Interestingly, time of day does appear to have an effect in children, with cancellation performance being faster and more accurate in the morning (Rana, Rishi, & Sinha, 1996).

Cancellation performance in individuals with brain injury and neglect. In addition to their use with healthy individuals in measures of general intelligence and processing speed, cancellation tasks also owe much of their popularity to clinical and experimental neuropsychology and are used extensively in cases of suspected neglect and attention deficits. While poor cancellation performance is often indicative of a general attentional problem, lateralized performance on the cancellation task is a consistent finding in individuals with neglect secondary to brain injury. Unfortunately, a single raw cancellation score is insufficient to measure lateralized performance, and thus neglect. Structured observation of the cancellation task provides rich information on lateralized deficits and is warranted in cases of suspected neglect. Location of initial target(s) cancelled, location of total targets cancelled (a measure of lateralization of omissions), order of target cancellation, scanning pattern, speed, and re-cancellation of previously cancelled targets are additional outcome measures that can add valuable information in cases of suspected neglect (Laurent-Vannier et al., 2003; Laurent-Vannier et al., 2006; Manly et al., 2009; Ting et al., 2011). In fact, research suggests that many of these outcome measures are more sensitive to neglect than the final raw cancellation score (Azouvi et al., 2002; Manly et al., 2009).

Total omissions. Although insufficient to detect VSN, a raw total omission score does provide some useful information on attention. In general, both adults (Azouvi et al., 2002; Manly et al., 2009) and children (Laurent-Vannier et al., 2006; Thareja et al., 2012) suffering from neglect secondary to unilateral brain injury tend to make more total omission errors than healthy individuals. On average, children and adults with right hemisphere injury tend to make more total omissions than individuals with left hemisphere injury (Azouvi et al., 2006; Laurent-Vannier et al., 2006).

Location of initial target cancelled. The literature consistently finds that the location of the initial target cancelled, a measure of lateralized performance, is a very sensitive measure of neglect. More specifically, adults and children with right hemisphere injuries and left neglect tend to cancel their initial target on the right side of the stimulus page (Azouvi et al., 2002; Azouvi et al., 2006; Laurent-Vannier et al., 2003; Laurent-Vannier et al., 2006; Manly et al., 2009; Nurmi, et al., 2010). Children with left hemisphere injury begin their search in the middle of the stimulus page twice as frequently as age-matched controls (Thareja et al., 2012). The performance of individuals with brain injury is markedly different from healthy controls who generally begin cancelling items on the left side of the stimulus page (Azouvi et al., 2006; Thareja et al., 2012).

Location of omissions. Location of omissions is another measure of lateralization, or left-right performance bias. It also appears to be a relatively good measure of neglect, with adults suffering from neglect tending to locate and cancel more targets on the side of the stimulus page ipsilesional to the site of injury, and tending to make more omission errors on the side of the page contralesional to the site of injury (Azouvi et al., 2002; Manly et al., 2009). The same trend was found in children (Thareja et al., 2012). Upon closer analysis, Manly et al. noted a right-left detection rate gradient in adults with left hemisphere neglect whereby targets in the far right were the most frequently detected (i.e., cancelled), followed by those in the near right, near left, and finally far left. A right-lateralized performance bias has also been found in children with right hemisphere injury (Ferro & Martins, 1990; Laurent-Vannier et al., 2003; Laurent-Vannier et al., 2006). This lateralized cancellation performance is different from healthy individuals who do not display a left or right bias in location of omissions.

Speed. Cancellation speed was significantly slower in adults with right hemisphere injury when compared to healthy controls (Azouvi et al., 2002; Manly et al., 2009). In children, individuals with brain injury, regardless of hemisphere, were significantly slower than healthy controls (Thareja et al., 2012). Also, individuals with right hemisphere injury displayed significantly greater slowing as the task progressed and slowed as target location moved farther away from the far right side of the stimulus page (Manly et al., 2009).

Search organization and re-cancellation. Search organization is a measure of search efficiency derived by calculating the distance between two consecutive cancellations (Manly et al., 2009). While healthy adults tend to make consecutive cancellations near each other, adults with brain injury tend to make consecutive cancellations farther apart or 'jump around' the stimulus page (Manly et al., 2009). Thareja et al. (2012) also found erratic search performance in children with brain injury;

however, structured search arrays improved the search performance in children with right hemisphere injury (but not left hemisphere injury). Re-cancellation of previously cancelled targets occurs infrequently in healthy adults; however, it occurs frequently in adults with right hemisphere injury. In their study, Manly et al. (2009) found that 83% of adults with right hemisphere injury re-cancelled targets at a mean rate of 8.17 times.

Risk factors affecting cancellation performance. Lesion-symptom mapping suggests that cancellation performance is related to damage to fronto-parietal areas including the middle frontal gyrus, pre-and postcentral gyrus and the posterior parietal cortex (Vossel et al., 2011). In adults with right hemisphere injury, there was a significant positive correlation between lesion volume and lateralized (rightward bias) performance on the Bells cancellation test in near (but not far) space (Aimola et al., 2012). Time since injury also appears to have an effect on cancellation performance, suggesting the potential for recovery. In a study of adults with right hemisphere injury, Kettunen, Nurmi, Dastidar and Jehkonen (2012) found that the rightward cancellation biases observed in the acute period decreased significantly at 6 month follow-up, although mild residual rightward attentional biases persisted. Manly et al. (2009) found omissions and rightward biases were significantly greater in the acute period. However, there is evidence to suggest no improvement in omission rate over shorter periods of recovery (Saj et al., 2012). Case studies involving children reveal similar findings where target detection improved over time (Ferro & Martins, 1990). In some pediatric cases, mild deficits still persisted including continued use of a right to left scanning strategy and greater omission errors during periods of fatigue or when managing another simultaneous task (Laurent-Vannier et al., 2003).

Reliability and validity of the cancellation task. In their 2007 study examining the clinical assessment of hemispatial neglect, Lindell et al. (2007) found that cancellation tasks, including the star cancellation and letter cancellation tests taken from the BIT, and the random shape cancellation and random letter cancellation tests (Weintraub & Mesulam, 1988), were among the most sensitive tests for detecting neglect. Of these four cancellation tasks, random shape cancellation was the most sensitive, positively detecting 52% of the neglect cases. This task consisted of a stimulus sheet containing 60 target shapes located pseudorandomly, but equally across the left and right sides, among distracter shapes. The star cancellation test was able to positively detect 41% of neglect cases. In this task the participant was given a stimulus sheet with 56 small stars (which are the target items) and distracter items which consisted of large stars, letters, and short words. The random letter cancellation test and the letter cancellation test were able to positively detect 36% and 32% of neglect cases, respectively. The letter cancellation test consisted of five rows of 34 upper case letters presented on a rectangular page. The participant was asked to scan, locate, and cross out, forty target stimuli, which appeared equally on each side of the page, from distracter letters. The random letter cancellation test also had the participant detect target stimuli (the letter A) among distracter letters, but in this test the letters appeared in a scattered formation rather than in structured rows. The cancellation tasks described in Lindell et al.'s (2007) study used total number of omissions as the outcome score, and despite its good sensitivity, numerous other studies suggest that location of initial target cancelled is much more sensitive (Manly et al., 2009), and may actually be the most sensitive measure to detect neglect (Azouvi et al., 2002).

Feature and Conjunction Visual Search Tasks

Unlike “cancellation” and “line bisection”, “visual search” is not usually the name of a particular test, but rather an umbrella term used to describe various types of tasks that involve visual scanning or searching often via uniquely designed computer paradigms. Cancellation tests are sometimes referred to as types of visual search tasks, but in the present review they are treated separately. As described above, cancellation tasks are traditionally pencil and paper tasks where individuals are required to manually cancel multiple target items randomly arranged on a stimulus page of distracters. Alternatively, visual search tasks, as conceptualized here, are tasks that involve visually searching an array of distracters for a single target item that may or may not share some common features with the distracters. In this task, multiple trials are often administered where individuals are presented with target present or target absent displays and are required to identify the presence of and/or localize the target.

Treisman’s seminal Feature Integration Theory (FIT, Treisman & Gelade, 1980) proposed that visual search tasks could be dichotomized into two categories: preattentive processing tasks and attentive processing tasks. *Preattentive* processing occurs in parallel across the visual field and involves the search for a single distinct and basic feature such as color, shape, or size. Searching for a single target item such as a red object embedded in a field of blue objects is an example of a preattentive processing task. Reaction times are assumed to be independent of the number of distracter items present in the display. The interpretation is that feature search can be executed effortlessly and without attention as the target “pops out” in this type of search, and so is unaffected by a larger display with more distracters (Behrmann et al., 2004). Preattentive tasks are also referred to as *parallel, disjunctive, simple,* or *feature* search tasks.

Attentive processing tasks involve more complex perceptual processes and require discrimination between multiple combined features. An example of an attentive processing task is searching for a target item (e.g., a red circle) among a field of distracters that may share some but not all of the same features as the target item (e.g., red squares, blue circles, blue squares). Unlike in the preattentive visual search, targets in the attentive visual search do not readily “pop out”, but instead must be carefully discriminated. Because the entire display must be searched from item to item, or serially, until the target item is located, reactions times for attentive search tasks are positively related to the number of items in the display. Attentive tasks are also referred to as *serial, difficult,* or *conjunction* search tasks.

Although both feature and conjunction visual search tasks can be administered via a variety of formats, computerized administration has become increasingly popular. In computerized administrations, visual stimulus arrays are displayed on a computer monitor and the examinee is instructed to press certain keys to indicate the presence of and/or location of a target. A predetermined number of target present and target absent trials can be administered either randomly or in a specified order with the location of the target varying between trials. Often experimental trials are preceded by learning trials to ensure the examinee understands the task. Computerized administrations allow for instant and accurate scoring of responses and recording of reaction times. Some advanced computer systems can also observe and record eye saccades and visual scanning behavior.

Feature and conjunction visual search performance in healthy adults and children. Consistent with FIT, research on visual search tasks does suggest differences in performance depending on the preattentive or attentive nature of the task. In feature (preattentive) search, the breadth of attention is wide, and the slope of the search function relating response time to display size is flat in both healthy adults (Treisman & Souther, 1985) and children (Karatekin & Asarnow, 1998). This flat slope in both target present (regardless of location) and target absent trials, suggests that an exhaustive search is performed. Research on healthy individuals appears to support the notion of a flat slope relating response time to display size in both target present and target absent trials of feature visual search (Karatekin, Lazareff, & Asarnow, 1999).

According to FIT, attention is narrowed down and items are searched serially in conjunction (attentive) visual search tasks. In these tasks the search function relating response time to display size has a positive linear slope in both healthy adults (Treisman & Souther, 1985) and children (Karatekin & Asarnow, 1998), and search rates differ depending between target present and target absent trials. Specifically, in conjunction tasks, search rates for target absent trials are about twice as long as in target present displays, suggesting a self-terminating search when the target item is found (Snodgrass

& Townsend, 1980). No difference was found in serial search rates for targets appearing in the left or right hemifields of normal individuals (Arguin, Joanette, & Cavanagh, 1990). Adult neuroimaging data suggest that visual search causes activation of the anterior insula, anterior cingulate cortex, and right basal ganglia (Revill et al., 2011).

Feature and conjunction search performance in individuals with brain injury. It has been hypothesized that if unilateral neglect arises from a deficit of attention, then the performance of individuals with VSN should differ from controls on conjunction (attentive) but not feature (preattentive) search tasks. Furthermore, their performance on feature search tasks should not be affected by display size and should be identical for targets presented on both contralesional and ipsilesional sides. In contrast, the performance of individuals with VSN should be impaired on conjunction (attentive) search tasks, particularly when targets appear on the contralesional side, and performance should deteriorate as display size increases. Unfortunately, a clear consensus in the literature consistent with these hypotheses does not exist.

Some research supports the notion that feature search is preserved in adults and children with brain injury and/or neglect (Arguin, Joanette, & Cavanagh, 1993; Esterman, 2000; Schatz, Craft, Koby, & DeBaun, 2004); while other studies have found that feature search performance is negatively affected by injury and/or neglect (Behrmann et al., 2004; Eglin, Robertson, & Knight, 1989; Pavlovskaya, Ring, Groswasser, & Hochstein, 2002; Riddoch & Humphreys, 1987). The research on conjunction search performance in adults and children with brain injury is much more consistent and generally shows that accuracy and RTs are negatively impacted in cases of neglect (Aglioti, Smania, Barbieri, & Corbetta, 1997; Arguin et al., 1993; Behrmann et al., 2004; Eglin et al., 1989; Eglin, Roberson, & Knight, 1991; Esterman, 2000; Karatekin et al., 1999; Pavlovskaya et al., 2002; Riddoch & Humphreys, 1987; Schatz et al., 2004). This finding has been interpreted by some as a delay in feature integration (Karatekin et al., 1999).

Additional findings indicate varied performance on visual search tasks when targets are presented in different hemispaces. While it appears there is no difference in detecting targets located in left vs right hemispace in healthy controls (Arguin et al., 1990) the majority of findings suggest that visual search performance of adults and children is affected by unilateral brain injury, and is worse when targets appear in contralesional space vs ipsilesional space (Aglioti et al., 1997; Arguin et al., 1993; Behrmann et al., 2004; Eglin et al., 1991; Esterman, 2000; Pavlovskaya et al., 2002; Riddoch & Humphreys, 1987; Schatz et al., 2004).

The Extinction Task

As individuals with neglect improve, they become able to correctly detect and localize stimuli contralateral to their lesion; however, when presented with bilateral simultaneous stimuli they often fail to report contralesional stimuli (Heilman et al., 2012). This phenomenon is called “extinction to double simultaneous stimulation” or simply “extinction”. Like neglect, extinction can occur in visual, auditory, tactile, or a combination of these modalities (multimodal extinction). Extinction is most severe when the bilateral simultaneous stimuli are presented on opposite sides of midline, but can also occur when both stimuli are presented on the same side of the head or in the same hemifield. In this instance, the stimulus that is closer to the contralesional side is extinguished (Heilman et al., 2012). Many researchers deem extinction to be closely related or a milder form of neglect often manifested during recovery periods (Geeraerts, Lafosse, Vandenbussche, & Verfaillie, 2005; Heilman et al., 2012), while others suggest they are dissociable syndromes related to different neural substrates (Vossel et al., 2011). The similarities and distinctions between neglect and extinction phenomena continue to be hotly debated topics.

Extinction tasks are frequently included in neglect batteries (see Beis et al., 2004; Buxbaum et al., 2004) because they can detect what is often considered to be a closely related or mild form of neglect (Geeraerts et al., 2005; Heilman et al., 2012). Assessing extinction must by definition involve the presentation of more than one stimulus. Beyond that constant caveat, the task can vary widely. For example, to assess tactile extinction, an individual’s hands or cheeks located on opposite sides of body midline may be simultaneously stimulated, whereas to assess auditory extinction, a tone might be presented to the left or right side of an individual’s head. In cases of suspected multimodal extinction, the modalities are tested simultaneously. For example, a tone might be paired with a visual stimulus and presented bilaterally. Although these various testing modalities are interesting, the present review is concerned only with assessing extinction to visual stimuli. Even with this narrowed specification, a wide variety of visual extinction tasks exist.

Extinction tasks and computer paradigm variation. In neurological exams, one traditional assessment of VSN/extinction is the finger wiggle test. In this test the examiner places her hands a short distance away from either side of an individual's head and takes turns wiggling her left and right index finger independently (unilateral stimulus) and simultaneously (bilateral stimuli). Often finger puppets are used with young children. The individual is asked to identify and/or localize the finger (or puppet) that wiggles. Alternatively, neuropsychological assessments for extinction can involve computer testing paradigms that alternate unilateral and bilateral target presentation in left and/or right hemifields. Targets are flashed on computer displays and the individual is asked to identify the presence of and/or localize the target via specific button presses. Various error scores for unilateral/bilateral, target present/target absent, and left/right presentation trials are calculated (Baylis, Gore, Rodriguez, & Shisler, 2001; Bonato, Priftis, Marenzi, Umilta, & Zorzi, 2010; Muller-Oehring et al., 2009; Umarova et al., 2011; Vossel et al., 2011).

Unlike traditional paper and pencil tests such as the line bisection and cancellation tests, computerized visual extinction tasks vary considerably, and are often uniquely created for individual research studies. In the present review of computerized visual extinction tasks, several important task variations were identified. First, computer paradigms differed with respect to unilateral/bilateral target presentation. Some used purely bilateral target displays, while others contained alternating bilateral and unilateral trials. Secondly, the paradigms differed with respect to location of target presentation. Most tasks presented bilateral targets with one appearing in each hemifield (or side of the head); however, because individuals may also extinguish one of two targets presented in the same hemifield (Heilman et al., 2012), some tasks presented bilateral targets in the same hemifield. Third, by definition extinction occurs with simultaneous bilateral targets; however, some researchers have investigated non-simultaneous bilateral target presentation (a temporal order of judgment task). More specifically, the contralesional target may either precede or follow the ipsilesional target by a certain time interval. Another paradigm difference is the presence or absence of cueing prior to target presentation. Many extinction tasks present a cue (often a blinking object) prior to the target in an effort to orient attention. Cueing paradigms can be further modified by interspersing false cue trials among the true cue trials. Another difference is that some computer paradigms test only for the presence or absence of bilateral targets in an otherwise blank display, while some incorporate distracter items. Finally, some paradigms test only a single modality, while others test multiple modalities (e.g., presenting a visual stimulus on the right side while simultaneously presenting a tactile stimulus on the left side). Unfortunately, task variations are rarely manipulated variables directly compared within the same study. Instead a single extinction task is usually created to test theory or examine group differences; therefore, detecting the effects of all the various paradigms is nearly impossible.

Extinction performance in healthy individuals and in individuals with brain injury. Normal subjects do not extinguish simultaneous bilateral stimuli. They are able to detect the presence of multiple stimuli presented simultaneously in opposite hemispaces (Heilman et al., 2012; Vossel et al., 2011). When compared to healthy controls, individuals with visual extinction secondary to brain injury display impaired performance of detecting a stimulus presented in contralesional space when it is simultaneously presented with a stimulus in ipsilesional space (Baylis et al., 2001; Baylis, Simon, Baylis, & Rorden, 2002; Vossel et al., 2011; Vuilleumier & Rafal, 2000). Similar "extinction-like" findings have been noted in individuals with neglect (Schurmann, Grumbt, Heide, & Verleger, 2003; Vuilleumier & Rafal, 2000).

In addition to the general finding stated above, some researchers have investigated various nuances of the extinction phenomenon. In temporal order of judgment tasks, individuals with right hemisphere brain lesions required the contralesional stimulus to lead the ipsilesional stimulus to achieve the point of subjective simultaneity (Baylis et al., 2002; Sinnett et al., 2007). Di Pellegrino, Basso, and Frassinetti (1997) found impairment in detecting a contralesional stimulus both when preceding and following an ipsilesional stimulus. Individuals with visual extinction made significantly more temporal binding errors (reporting the stimulus that precedes or follows the target as being the target) for contralesional than ipsilesional stimuli and more binding errors than healthy controls (Arend, Rafal, & Ward, 2011). In cued paradigms, an increase in missing responses for right visual cue/left visual target, was observed in individuals with neglect and a response delay for the same trial was observed in individuals with brain injury both with and without neglect (Schurmann et al., 2003). In dual-task conditions that recruit additional attentional resources, individuals with unilateral stroke displayed dramatic failure to report contralesional-sided targets (Bonato et al., 2010) during bilateral simultaneous stimulation.

Visual extinction has a neuroanatomical correlate within the right inferior parietal cortex which is different than the damage of the fronto-parietal brain areas associated with standard neglect test-specific (i.e., BIT subtests) lesion patterns (Vossel et al., 2011). Additionally, individuals with extinction display increased activation of the left prefrontal cortex. This activation pattern is different from individuals with neglect and healthy controls (Umarova et al., 2011).

The Behavioral Inattention Test

The BIT consists of six paper and pencil tests (line crossing, letter cancellation, star cancellation, figure copying, line bisection, and free drawing) and nine behavioral tests (picture scanning, telephone dialing, menu reading, article reading, telling and setting time, coin sorting, address and sentence copying, map navigation, and card sorting). While the BIT appears to have good predictive validity in adult neglect populations (Azouvi et al., 2006; Hartman-Maeir & Katz, 1995), many of the subtests are not appropriate for use with young children. In the present review, no studies were found that used the BIT with children with VSN or other types of neglect.

The Catherine Bergego Scale

The Catherine Bergego Scale (CBS; Azouvi, Marchal, Samuel, & Morin, 1996) is a 10-item checklist of functional performance in activities of daily living including grooming and shaving, dressing, eating, cleaning the face after eating, spontaneous gaze, knowledge of parts of the body, auditory attention, collision with objects, navigation, and locating items. The CBS also includes a measure of anosognosia (i.e., unawareness of the disorder) which has been shown to be an important indicator of neglect severity (Azouvi et al., 1996; Gialanella & Mattioli, 1992). The CBS appears to have good validity, sensitivity, and reliability (Azouvi et al., 1996; Azouvi et al., 2002) in adult studies; however, like the BIT, some of the subtests are inappropriate for use with young children. Furthermore, these tests are not specific to VSN and instead are more likely to detect other subtypes of neglect (i.e., personal neglect, auditory neglect, output/intentional neglect). In the present review, no studies were found that used the CBS with children with VSN or other types of neglect.

Drawing and Copying Tasks

Both free drawing and copying tasks can elicit the neglect phenomenon (Lezak, Howieson, Loring, Hannay, & Fischer, 2004). For this reason, both tasks are often found in batteries assessing general neglect or VSN specifically. For example the BIT has both representational drawing (clock face, man or woman, and butterfly) and figure and shape copying (star, cube, and daisy) tasks. Each of these tasks are bilateral in nature, either bilaterally symmetrical or having left and right sided details that are different but equally important. Copying tasks appear to be more sensitive at detecting inattention than drawing tasks (Lezak et al., 2004).

The clock face drawing was originally used to detect unilateral visuospatial inattention thought to be associated with right parietal dysfunction (Lezak et al., 2004). However, research suggests that it is a far more complex task involving multiple cerebral regions that is also sensitive in detecting other abilities including receptive language, numerical knowledge, working memory, and executive (planning and organizing) functions (Freedman et al., 1994). For instance, in a study of developmentally normal children, neglect for the upper left quadrant was detected, but was thought to be due to poor planning rather than true VSN (Cohen, Ricci, Kibby, & Edmonds, 2000). So, while drawing and copying task appear to have good sensitivity to detect neglect in adults and older children, the lack of specificity to detect neglect in young individuals calls into question the validity of the clock face task when used for this specific purpose. Furthermore, using the clock face task for very young children does not make intuitive sense as numerical knowledge, conceptualization of time, planning ability, and graphomotor skills are not yet fully developed.

Reading and Writing Tasks

Two reading tasks appear on the BIT: Menu Reading and Article Reading. On the Menu Reading task, the individual is presented with a large folded card containing two columns of five food items each on both sides of the center fold. Food items consist of one and two words printed in large font. For the Article Reading task, the individual is presented with two articles about political economies. The stimulus page consists of three columns of print a little larger than newspaper print. Menu Reading was able to identify 65% of individuals with visual inattention, while Article Reading identified 38% (Halligan, Cockburn, & Wilson, 1991).

The Indented Paragraph Reading Test (IPRT; Caplan, 1987) is another measure of visual inattention/neglect. In this task, the individual is presented with a block of text and asked to read it orally. Neither the left or right margins are flush, with the left margins indented at multiple varying lengths. The examiner records omission and commission errors, reading rate, and the first word read on each line. In Caplan’s original study, 78% of individuals with damage to the left hemisphere were able to read the passage without error, and only 53% of individuals with right hemisphere injuries were able to read the passage perfectly.

The Address/Sentence test is a writing/copying task found in the BIT. It is a very simple task that requires the individual to copy a four-line address and a three-line sentence. Words appearing on the far left and right of the sentence copy task are words that could be easily omitted without affecting the meaning of the sentence. In a group of individuals with right hemisphere injury, 65% were unable to pass this test (Halligan et al., 1991). While both the reading and writing tasks appear to have good sensitivity to detect VSN in adults, neither test is appropriate for very young children (ages 2-6) as reading and writing skills have yet to be fully developed.

Summary

We know that infants, children, and adolescents experience stroke, and that unilateral neglect in general, and VSN specifically, are potential negative outcomes of stroke; however, the nature and incidence of VSN in children is largely unknown. Uncertainty surrounding the phenomenon of VSN in children is due in large part to three limitations of the current literature: 1) the inconsistent usage and characterization of neglect terminology/typology; 2) the lack of a standardized and validated test battery for the assessment of VSN in children; and 3) lack of research on VSN from a developmental perspective.

Studying VSN in children is critically important because injury during periods of development may have markedly different sequelae that potentially affect other structures and processes as they develop. The possibility of various deleterious outcomes carries with it tremendously important implications for treatment and recovery of neglect. The study of VSN and neglect in children with brain injury is incredibly complex, and despite this greater complexity, unfortunately the research is very sparse. The present study is important to the field of VSN and sheds light on how to assess this intricate phenomenon.

Although much research is needed in the field of neglect and VSN in children, the present study was necessarily more limited in scope. The purpose of the current research study was to validate the Pediatric Visuospatial Neglect Battery developed at CHOP that purports to assess VSN in young children who have experienced stroke. VSN is of particular interest because the true incidence of the disorder is unknown, potentially occurs quite frequently, dramatically affects day-to-day functioning, and is a very powerful predictor of future outcomes. The present study examined the reliability and validity of the scores of the five tasks of the Pediatric Visuospatial Neglect Battery that was administered to a group of children with brain injury and healthy controls ages 2-6 years. Reliability analyses of the individual task scores were performed. Validity analyses including sensitivity and specificity analyses were also performed.

Implications

A well-validated and standardized neuropsychological test battery capable of detecting VSN in children is essential. Accurate assessment of VSN is a necessary first step to proper diagnosis, thoughtful treatment planning, and effective rehabilitation. While this is critically important for any individual suffering from a stroke, it may be even more important for very young individuals. From a developmental perspective, VSN occurring in an immature brain could potentially have deleterious effects on many other brain structures and functions as development progresses. Additionally, effective and timely rehabilitation may have a tremendously positive impact due to the plasticity of the developing brain. For these reasons, this validation study is a critically important addition to the literature base.

CHAPTER III

METHODS

This research study was a cross-sectional study using previously collected data from CHOP. All data were collected under strict adherence to study protocol, under the close supervision of the principal investigators, and according to CHOP Institutional Review Board (IRB) guidelines. Use of the existing data set was approved by the Texas A&M University IRB as well. The focus of the study was on the determination of the psychometric properties given the scores generated by the five individual tasks of the Pediatric Visuospatial Neglect Battery.

Participants

Eligible study participants included all individuals from birth through 6 years who were admitted to the Children's Hospital of Philadelphia (CHOP) for treatment (n = 3), or who had a history (n = 17), of arterial ischemic stroke (AIS), focal cerebral hemorrhage, or surgical resection. Children with a history of meningoencephalitis, hypoxic-ischemic encephalopathy, cardiac arrest, in utero drug exposure, bilateral lesions, severe closed head trauma and other conditions that might have resulted in global brain injury were excluded from participation in the study. Eligible participants were identified through the neurology consultation service, attending physicians of the stroke team, outpatient neurology clinic schedules, the pre-existing stroke database, or upon referral to study investigators by the Neurology Division or other divisions within CHOP. The diagnosis of stroke or other brain injury was confirmed by review of the brain MRI or CT scan which was performed previously for clinical purposes. The size and location of injury also was evaluated. Following diagnosis and clinical care, eligible participants were invited to participate in the research study by one of the investigators.

Control participants (n = 59) were age-matched healthy children recruited from CHOP Primary Care Centers and Kids First Practices via the CHOP Pediatric Research Consortium. Control participants also included the children of friends and neighbors of the study investigators and staff. Children of staff members within the Division of Neurology and Radiology were excluded from participation. Parents of the control participants were asked to complete a control eligibility survey to ensure that the child was neurologically and developmentally normal. Children with a history of stroke, cerebral palsy, seizures, meningoencephalitis, developmental delay, attention deficit hyperactivity disorder, psychiatric conditions, prior brain surgery, congenital heart disease, malignancy, ventriculoperitoneal shunt, head trauma resulting in loss of consciousness, prematurity (less than 35 weeks gestation), or any other condition which put the child at risk for neurodevelopmental disability, as well as children requiring occupational, physical, or speech therapy or special education for neurologic indications, were not be eligible to participate as controls. Efforts were made to recruit both male and female children from all ethnic/racial backgrounds. All study participants were required to be fluent (with respect to age) in English. Demographic information is presented in Table 1.

Table 1
Demographics

	Control	Injury	Total
Age Group			
2-4	28 (47%)	12 (60%)	40 (51%)
5-6	31 (53%)	8 (40%)	39 (49%)
Gender			
Male	36 (61%)	11 (55%)	47 (59%)
Female	23 (39%)	9 (45%)	32 (41%)
Hemisphere of Injury			
Right		6 (30%)	6 (30%)
Left		14 (70%)	14 (70%)
Race/Ethnicity			
White	27 (46%)	14 (70%)	41 (52%)
Black	24 (41%)	4 (20%)	28 (35%)
Other	8 (13%)	2 (10%)	10 (13%)

The injury group had approximately equal numbers of males and females although most children were Caucasian and belonged to the younger age group. Within the injury group, more than twice as many children had left hemisphere injury as compared to right hemisphere injury. Attempts were made to match the control group for age, gender, and race/ethnicity; however, this was not always possible. The control group is slightly older, has more males, and is comprised of fewer Caucasian children than the injury group.

Procedures

Following informed consent, data collection began and included demographic information (age, race/ethnicity, gender, education level, and handedness), clinical information (diagnoses, type and location of injury, age at time of injury, MRI findings, neurologic symptoms, neonatal and past medical history) and information regarding treatment (medications and interventions) and recovery. Five neuropsychological tests (line bisection, cancellation, feature visual search, conjunction visual search, and extinction) were then administered and are described in detail below. For acute patients admitted and treated at CHOP and enrolled in the study (*n* = 3), initial assessment was performed at bedside within 10 days of stroke diagnosis or surgery. Repeat testing occurred as an outpatient in the Neurology Clinic or in the child's home approximately 1 month and 6 months following the stroke or surgery. Those children with a history of AIS, cerebral hemorrhage, or focal brain resection (*n* = 17) were assessed in a single testing session in the Neurology Clinic at CHOP or in the child's home.

Control subjects (*n* = 59) were assessed in a single testing session in their CHOP Primary Care Center, Kids First Practice, Neurology Clinic, or in their home. Neuropsychological supervision for the data acquisition was provided by the Neuropsychological Core of the Clinical and Translational Research Center (CTRC) at CHOP and The University of Pennsylvania. Participants received a gift card for their time, and travel expenses were reimbursed.

Measures

The neuropsychological test battery investigated in this study consists of five individual tasks: line bisection, cancellation, feature visual search, conjunction visual search, and extinction. What follows here is a brief description of the measures, how they were administered, and the 36 outcome variables recorded for analysis. See Table 2 for a summarized variable list. All measures were administered in standardized format according to the research protocol under IRB approval.

Line Bisection

Participants were seated at a table and given a single sheet of white paper with a single black line 200 mm long printed horizontally across the middle of the page. The participants were instructed to bisect the line at its midpoint using a pencil. Following a demonstration trial, 20 experiment trials were administered. The deviation of the participant’s bisection line from true center was measured (in mm) for each of the twenty trials. Two outcome variables frequently used in studies of neglect (Azouvi et al., 2006; Manning et al., 1990; Mozer et al., 1997; Halligan & Marshall, 1989; Marshall & Halligan, 1989) were analyzed for the line bisection task: mean deviation from center (LineMD) and standard deviation of the deviation scores (LineSD).

Cancellation Task

Participants were again seated at a table and given a single black and white stimulus page consisting of 16 target object (apples) pseudorandomly arranged among

32 distracter objects (16 panda bears and 16 wrapped presents). The array was random, not structured; however, the target objects were distributed equally across the page in four general areas: far left, near left, near right, and far right. They were also distributed equally across the top, middle, and bottom of the stimulus page. The participants were given a pencil and were instructed to cross out every apple that they saw on the paper. The task was administered once and was untimed. The examiner had a copy of the stimulus page, and recorded the order in which the participant cancelled the target objects. Eight outcome variables previously determined to be sensitive to detecting neglect (Azouvi et al., 2006; Laurent-Vannier et al., 2006; Manly et al., 2009; Thareja et al., 2012) were analyzed for the cancellation task: total number of targets cancelled (CaRawTot), location of initial target cancelled (CaLocInt), total number of targets cancelled in far left space (CaRawFL), total number of targets cancelled in near left space (CaRawNL), total number of targets cancelled in near right space (CaRawNR), total number of targets cancelled in far right space (CaRawFR), cancellation order(CaOrder), and organization of cancellation search strategy (CaOrg).

The CaOrder variable attempts to quantify the order of target cancellations. The reverse rank order (16 for the 1^{st} target cancelled, 15 for the 2^{nd} target cancelled, etc…) is multiplied by the column weight (-2 = far left; -1 = near left; 1 = near right; 2 = far right). These products are added together to give an indication of the cancellation order. A large negative number indicates that many of the initial targets were cancelled on the left half of the stimulus page and later targets were cancelled on the right half of the stimulus page, whereas a large positive number indicates that many of the initial targets were cancelled on the right half of the stimulus page and later targets were cancelled on the left half of the page.

The CaOrg variable attempts to quantify search strategy and is an indicator of organized or random cancellation patterns. The location of consecutive cancellations is examined to determine how far and how often the examinee "jumped" across the stimulus page. Consecutive cancellations belonging to the same area (e.g., 1st cancellation in near left space to 2nd cancellation in near left space) are assigned a 0. Consecutive cancellations belonging to adjacent areas (e.g., 3rd cancellation in near right space to 4th cancellation in far right space) are assigned a 1, while consecutive cancellations on opposite sides of the page (e.g., 5th cancellation in far left space to 6th cancellation in far right space) are assigned a 3. The sum of these consecutive cancellation scores is the CaOrg variable score. A small score indicates an organized search strategy with little distance, or "jumping", between consecutive cancellations, while a large score indicates a random search strategy with much jumping around.

Feature Visual Search Task

Participants were seated in front of a computer monitor. Twenty-five objects arranged in a 5 x 5 grid were displayed on the computer screen, one target object (a red circle) and 24 distracter objects (blue squares). The participant was instructed to visually scan the monitor and determine if the target object (a red circle) was present. If so, they were to press a computer key labeled "yes". If no red circle was present on the screen (i.e., if there were only blue squares), they were instructed to press a computer key labeled “no”. Participants were instructed to do this as quickly and accurately as possible. Six practice trials were administered followed by 24 experiment trials. The location of the red circle changed (or was not present) for each trial. In eight of the trials the target appeared on the left half of the screen, in eight trials the target appeared on the right, and in eight trials the target did not appear at all. These conditions were named “left”, “right”, and “catch”, respectively. In target present conditions, the search targets appeared equally on the top and bottom portion of the search area.

The 24 trials were randomly arranged, but were presented in the same order for all participants. E-Prime computer software was used to administer, score, and electronically record the data for this task. Accuracy, reaction time, and difference in left vs right target detection are frequently studied variables in the neglect literature (Aglioti et al., 1997; Arguin et al., 1993; Behrmann et al., 2004; Eglin et al., 1989; Eglin et al., 1991; Esterman, 2000; Karatekin et al., 1999; Pavlovskaya et al., 2002; Riddoch & Humphreys, 1987; Schatz et al., 2004) and so were collected here. Eight outcome variables were analyzed for the feature visual search task: total number of correct responses for all conditions (FeRawTot), number of correct responses when the target appeared on the left (FeRawL), number of correct responses when the target appeared on the right (FeRawR), number of correct responses when the target was absent, also called the “catch” condition (FeRawC), overall mean reaction time for all conditions (FeMRT), and mean reaction times for each condition (FeLRT, FeRRT, and FeCRT).

Conjunction Visual Search Task

Participants were again seated in front of a computer monitor, and again 25 objects were displayed in a 5 x 5 grid arrangement. Like before, the participant was instructed to search for a red circle (the target object) among a screen of distracter objects; however, this time the distracters shared some common features with the target. The distracters consisted of blue squares, red squares, and blue circles. The participant was instructed to press “yes” if they saw a red circle and “no” if they did not see a red circle as quickly and accurately as possible. Six practice trials were administered and followed by 24 experiment trials. The location of the red circle changed (or was not present) for each trial. In eight of the trials the target appeared on the left half of the screen, in eight trials the target appeared on the right, and in eight trials the target did not appear at all. Again, these conditions were named “left”, “right”, and “catch”, respectively. In target present conditions, the search targets appeared equally on the top and bottom portion of the search area.

The 24 trials were randomly arranged, but were presented in the same order for all participants. E-Prime computer software was used to administer, score, and electronically record the data for this task. Similar to feature visual search, accuracy, reaction time, and difference in left vs right target detection are frequently studied variables in the neglect literature and were collected here. Again, eight outcome variables were analyzed for the conjunction visual search task: total number of correct responses for all conditions (CjRawTot), number of correct responses when the target appeared on the left (CjRawL), number of correct responses when the target appeared on the right (CjRawR), number of correct responses when the target was absent, the “catch” condition (CjRawC), overall mean reaction time for all conditions (CjMRT), and mean reaction times for each condition (CjLRT, CjRRT, CjCRT).

Extinction Task

Participants were seated in front of a single computer monitor. Two circles were quickly flashed on the screen, one on the left and one on the right side. The participant was instructed to search for the red circle (the target object) and determine if it was present and if so, where it was located. Participants were instructed to make the following button presses as quickly and accurately as possible: press“1” if the red circle appeared on the left; “2” if there were two red circles; “3” if the red circle appeared on the right; and “4” if there were no red circles. Thirty-two experiment trials were administered following learning trials. In 8 trials the target was presented on the right, in 8 trials the target was presented on the left, in 8 trials the target was presented on both the right and the left, and in 8 trials the target was absent (only two distractor objects were presented on the monitor). These four distinct conditions were named, “right”, “left”, “both”, and “catch”, respectively.

The 32 trials were presented in random order, but the order remained the same for all participants. Again, E-Prime software was used to administer, score and record the data for this computerized task. Accuracy and reaction time for target detection in the four conditions (left, right, both, catch) are frequently measured variables in extinction studies of neglect (Bonato et al., 2010; Muller-Oehring et al., 2009; Schurmann et al.,

2003) and were measured in the present study. Ten outcome variables were analyzed for the extinction task: total number of correct responses for all conditions (ExRawTot), number of correct responses when the target appeared on the left (ExRawL), number of correct responses when the target appeared on the right (ExRawR), number of correct responses when the target appeared on both the left and right (ExRawB), number of correct responses when the target was absent, the "catch" condition (ExRawC), overall mean reaction time for all conditions (ExMRT), and mean reaction times for each condition (ExLRT, ExRRT, ExBRT, and ExCRT).

Table 2
Variable List

Line Bisection Task	
LineMD	Mean deviation of bisection mark from true center (mean of 20 trials)
LineSD	Standard deviation of the 20 line bisection trials
Cancellation Task	
CaRawTot	Total number of targets cancelled (raw score out of 16)
CaRawFL	Number of targets cancelled in far left (raw score out of 4)
CaRawNL	Number of targets cancelled in near left (raw score out of 4)
CaRawNR	Number of targets cancelled in near right (raw score out of 4)
CaRawFR	Number of targets cancelled in far right (raw score out of 4)
CaLocInt	Location of initial target cancelled using column weights: far left (-2), near left (-1), near right (1), far right (2)
CaOrder	Order of cancellation score using the sum of the products of order rank weight (16 for 1st target cancelled…1 for the 16th target cancelled) multiplied by column weight (far left = -2, near left = -1, near right = 1, and far right = 2)
CaOrg	A measure of cancellation search strategy using the sum of the column weight (-2, -1, 1, or 2) differences between consecutive cancelled targets

Table 2 Continued

Feature Visual Search Task	
FeRawTot	Total number of correct responses for all conditions (raw score out of 24)
FeRawL	Number of correct responses when target was presented on the left (raw score out of 8)
FeRawR	Number of correct responses when target was presented on the right (raw score out of 8)
FeRawC	Number of correct responses when target was absent, “catch” condition (raw score out of 8)
FeMRT	Overall mean reaction time for all 24 trials
FeLRT	Mean reaction time when target was presented on the left
FeRRT	Mean reaction time when target was presented on the right
FeCRT	Mean reaction time when target was absent, “catch” condition
Conjunction Visual Search Task	
CjRawTot	Total number of correct responses for all conditions (raw score out of 24)
CjRawL	Number of correct responses when target was presented on the left (raw score out of 8)
CjRawR	Number of correct responses when target was presented on the right (raw score out of 8)
CjRawC	Number of correct responses when target was absent, “catch” condition (raw score out of 8)
CjMRT	Overall mean reaction time for all 24 trials
CjLRT	Mean reaction time when target was presented on the left
CjRRT	Mean reaction time when target was presented on the right
CjCRT	Mean reaction time when target was absent, “catch” condition
Extinction Task	
ExRawTot	Total number of correct responses for all conditions (raw score out of 32)
ExRawL	Number of correct responses when target was presented on the left (raw score out of 8)
ExRawR	Number of correct responses when target was presented on the right (raw score out of 8)
ExRawB	Number of correct responses when target was presented on both the left and right (raw score out of 8)

Table 2 Continued

ExRawC	Number of correct responses when target was absent, “catch” condition (raw score out of 8)
ExMRT	Overall mean reaction time for all 32 trials
ExLRT	Mean reaction time when target was presented on the left
ExRRT	Mean reaction time when target was presented on the right
ExBRT	Mean reaction time when target was presented on both the left and right
ExCRT	Mean reaction time when target was absent, “catch” condition

Data Analyses

Thirty-six performance outcome variables (listed above in Table 2) for the five neuropsychological tasks were calculated from the collected data (line bisection = 2 variables; cancellation = 8 variables; feature visual search = 8 variables; conjunction visual search = 8 variables; extinction = 10 variables). Reliability analyses were conducted on four of the five battery tasks. Reliability analysis of the cancellation task scores could not be performed because it was treated as a single item and only one administration was given. Cronbach’s alpha was used as a measure of internal consistency for the line bisection task, and Kuder-Richardson coefficient 20 (KR20) was used for the two visual search tasks and the extinction task. Reliability coefficients for the normative group and for the individuals with brain injury were calculated separately and as a whole group. For the validity analyses, the age-specific normative data generated from the control subjects for each of the outcome variables was used to convert the scores of all participants into Z scores.

Participants were considered to have normal or abnormal performance on a particular outcome variable depending on their Z score for that variable. Scores falling within two standard deviations of the normative mean (-2.00 < Z score < 2.00) were considered normal performance, and scores falling outside this range were considered abnormal performance. Directionality was important for some of the variables (those measuring raw scores or reaction times). Z scores of the raw score variables that fell below the 2 SD cutoff, were considered abnormally low and were termed VSN behavior, those scores that were 2 SD above the mean (indicating above average performance) were not considered to be neglect behavior. Similarly, reaction time scores that were 2 SD above (slower than) the mean were termed VSN behavior, while reaction times that fell 2 SD below (faster than) the mean were not considered VSN behavior. Other outcome variables measured lateralization, so large deviations in either direction were deemed VSN behavior. For these variables, scores of 2 SD above the mean indicated significant rightward deviation, and scores of 2 SD below the mean indicated significant leftward deviation. To assess criterion-related validity, decision accuracy was calculated using sensitivity and specificity analyses to determine how well each task variable “predicted” the “outcome” of brain injury.

Research Questions and Hypotheses

Research Question 1

How reliable are the scores generated by the individual tasks that make up the five-task battery?

a. What is the reliability of the line bisection scores

    i. of the normative sample?

    ii. of the sample of children with brain injury?

b. What is the reliability of the feature visual search task scores

    i. of the normative sample?

    ii. of the sample of children with brain injury?

c. What is the reliability of the conjunction visual search task scores

    i. of the normative sample?

    ii. of the sample of children with brain injury?

d. What is the reliability of the extinction task scores

    i. of the normative sample?

    ii. of the sample of children with brain injury?

Hypothesis 1

For the individual tasks where reliability analyses are possible (all but cancellation) it was hypothesized that the reliability coefficients would be at least .70, indicating "adequate" reliability (Standards for Educational and Psychological Testing, 1999). To test this hypothesis, Cronbach's alpha was calculated for the 20 trials of the line bisection task. The KR20 coefficient was calculated for both visual search tasks and the extinction task, as these tasks were comprised of dichotomous (pass/fail) items. Reliability coefficients for the normative group and for the individuals with brain injury were calculated separately.

Research Question 2

Do the scores offer adequate criterion-related validity?

a. Are the outcome variables of certain visuospatial neglect tasks better able to "predict" brain injury? If so which ones?

b. Results of which tasks have the greatest decision (sensitivity and specificity) accuracy?

Hypothesis 2

It was hypothesized that each of the five VSN tasks will have at least one outcome variable that offers adequate criterion-related validity as measured by both sensitivity and specificity ratios. The outcome variables for each of the five tasks that were hypothesized to have the greatest decision accuracy were: LineMD - Mean deviation from center; CaLocInt - Location of initial target object cancelled; FeRawL – Number of correct responses (in the feature visual search task) when the target was presented on the left; CjRawL – Number of correct responses (in the conjunction visual search task) when the target was presented on the left; ExRawB – Number of correct responses (in the extinction task) when targets appeared on both the left and right. It was also hypothesized that the cancellation variable CaLocInt (location of initial target object cancelled) would have the greatest decision accuracy of all 36 outcome variables and thus would be the best predictor of brain injury. To test these hypotheses, sensitivity and specificity analyses were conducted for each of the outcome variables.

CHAPTER IV

RESULTS

Reliability Analyses

The first hypothesis of this research study was that each task in the Pediatric Visuospatial Neglect Battery would produce scores of adequate (.70) or higher temporal reliability. This level was selected because according to the Standards for Educational and Psychological Testing (1999), reliability coefficients of .70 indicate “adequate” reliability, and this was deemed to be a minimum acceptable threshold. Four of the five battery tasks were subject to this analysis. The cancellation task was a single trial and single administration; therefore, reliability analysis could not be conducted on this particular task. Estimates of internal consistency (Cronbach’s alpha and Kuder-Richardson 20 coefficient) were calculated for the line bisection, feature visual search, conjunction visual search, and extinction tasks because each of these tasks consisted of multiple trials/items. The neglect literature suggests significant group differences on these tasks; therefore, in addition to an overall reliability estimate for each task, an attempt was made to calculate score reliability for both healthy controls and children with brain injury separately. Unfortunately, the sample size of children with brain injury in the present study is extremely small. Because reliability estimates can be unstable with small samples (Yurdugul, 2008), caution is required in the interpretation of these results.

Line Bisection Task

Twenty line bisection trials were administered according to the standardized guidelines described previously. Incomplete trials and trials that were not completed correctly (i.e., multiple bisection marks or scribbles) were noted for qualitative purposes, but were excluded from the reliability analysis. Additional trials to make up for excluded trials were not administered, thus some cases had less than 20 trials. The scores of 75 participants were included in the line bisection reliability analysis (control group = 58; individuals with brain injury = 17). Four participants from the youngest age group were unable to understand the instructions and/or adequately perform a single trial, thus were excluded. Item covariances were calculated and Cronbach's alpha was used as a measure of internal consistency. Reliability coefficients for various numbers of trials were calculated. This method prevented the exclusion of an entire case that may have had only a single erroneous trial and provided insight into the optimal number of trials. Because the trials were identical repeated measures, reliability analysis with varying number of trials was used instead of generalizability analysis to determine the optimal number of trials.

As expected, there were significant positive correlations between the 20 line bisection trials. The correlation matrix for the line bisection task is provided in Table 3 below. Internal consistency of the repeated line bisection trial scores was high and varied with age and group membership (control, right hemisphere injury, and left hemisphere injury). Cronbach's alpha was calculated for the entire 2-6 year old study sample, but due to hypothesized differences between age groups, alpha also was calculated separately for the children aged 2-4 years and the children aged 5-6 years. The injury group was also separated into children with left hemisphere injury and children with right hemisphere injury. Unfortunately, the sample size of these groups was extremely small. Although alpha is reported here for these specific groups, caution should be taken when interpreting the alpha coefficients of small samples as these estimates can be unstable (Yurdugul, 2008). Table 4, Table 5, and Table 6 display Cronbach's alpha for various numbers of trials for all children (ages 2-6), and children ages 2-4 and ages 5-6, respectively.

Table 3

Correlation Matrix for the Line Bisection Task (20 Trials, All Participants)

	Trial																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	-																			
2	.55**	-																		
3	.48**	.60**	-																	
4	.52**	.47**	.64**	-																
5	.42**	.49**	.38**	.65**	-															
6	.35**	.35**	.50**	.68**	.65**	-														
7	.20	.19	.33**	.50**	.54**	.76**	-													
8	.48**	.61**	.58**	.54**	.54**	.56**	.54**	-												
9	.39**	.50**	.47**	.65**	.62**	.63**	.61**	.70**	-											
10	.42**	.46**	.49**	.67**	.53**	.66**	.56**	.66**	.70**	-										
11	.35**	.42**	.54**	.55**	.45**	.69**	.70**	.65**	.69**	.64**	-									
12	.23*	.27*	.36**	.44**	.43**	.55**	.49**	.49**	.54**	.47**	.66**	-								
13	.42**	.51**	.59**	.57**	.52**	.55**	.50**	.63**	.63**	.64**	.72**	.65**	-							
14	.42**	.44**	.65**	.63**	.52**	.72**	.65**	.59**	.64**	.62**	.73**	.54**	.65**	-						
15	.28*	.27*	.39**	.40**	.31**	.54**	.58**	.46**	.54**	.49**	.65**	.75**	.68**	.66**	-					
16	.41**	.34**	.59**	.64**	.46**	.56**	.48**	.57**	.57**	.53**	.56**	.60**	.61**	.64**	.67**	-				
17	.30*	.27*	.40**	.61**	.43**	.57**	.45**	.46**	.58**	.59**	.62**	.56**	.54**	.44**	.53**	.63**	-			
18	.51**	.43**	.68**	.65**	.54**	.63**	.59**	.67**	.64**	.58**	.54**	.57**	.57**	.64**	.66**	.76**	.60**	-		
19	.41**	.49**	.63**	.68**	.62**	.65**	.65**	.61**	.66**	.61**	.64**	.66**	.66**	.63**	.65**	.64**	.65**	.73**	-	
20	.36**	.31*	.56**	.64**	.50**	.44**	.38**	.29*	.46**	.29*	.63**	.68**	.63**	.56**	.69**	.58**	.54**	.53**	.52**	-

** Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

Table 4
Cronbach's Alpha for the Line Bisection Task for All Children (Ages 2-6)

Number of Trials	Control Group		Individuals with Injury (Right or Left Hemisphere)		Individuals with Right Hemisphere Injury		Individuals with Left Hemisphere Injury		All Participants	
	n =	α =	*n* =	α =	*n* =	α =	*n* =	α =	*n* =	α =
2	58	.74	17	.49	5	.71	12	.34	75	.71
3	58	.78	17	.66	5	.79	12	.55	75	.78
4	57	.82	16	.74	5	.84	11	.67	73	.82
5	57	.83	16	.81	5	.85	11	.74	73	.84
6	57	.84	16	.85	5	.85	11	.79	73	.86
7	57	.84	16	.87	5	.87	11	.83	73	.87
8	56	.87	16	.89	5	.89	11	.85	72	.89
9	56	.89	16	.91	5	.87	11	.86	72	.91
10	56	.91	16	.92	5	.84	11	.88	72	.92
11	56	.91	16	.93	5	.88	11	.89	72	.93
12	56	.92	16	.93	5	.90	11	.89	72	.93
13	56	.93	16	.93	5	.92	11	.90	72	.94
14	56	.93	16	.94	5	.93	11	.90	72	.94
15	56	.94	16	.94	5	.94	11	.90	72	.95
16	56	.94	16	.94	5	.94	11	.91	72	.95
17	56	.94	16	.95	5	.92	11	.92	72	.95
18	56	.95	15	.97	5	.93	10	.95	71	.96
19	54	.96	14	.97	5	.93	9	.96	68	.97
20	45	.94	12	.97	5	.94	7	.97	57	.96

Table 5

Cronbach's Alpha for the Line Bisection Task for Children Ages 2-4

Number of Trials	Control Group		Individuals with Injury (Right or Left Hemisphere)		Individuals with Right Hemisphere Injury*		Individuals with Left Hemisphere Injury		All Participants	
	n =	α =	*n* =	α =	*n* =	α =	*n* =	α =	*n* =	α =
2	27	.70	9	.37	1		8	.42	36	.70
3	27	.78	9	.69	1		8	.73	36	.82
4	26	.82	8	.75	1		7	.80	34	.84
5	26	.81	8	.82	1		7	.85	34	.86
6	26	.82	8	.86	1		7	.89	34	.88
7	26	.84	8	.88	1		7	.90	34	.89
8	25	.89	8	.90	1		7	.91	33	.92
9	25	.90	8	.90	1		7	.92	33	.93
10	25	.91	8	.92	1		7	.93	33	.94
11	25	.92	8	.93	1		7	.93	33	.94
12	25	.92	8	.92	1		7	.92	33	.94
13	25	.93	8	.92	1		7	.93	33	.94
14	25	.94	8	.92	1		7	.93	33	.95
15	25	.94	8	.92	1		7	.92	33	.95
16	25	.94	8	.93	1		7	.93	33	.95
17	25	.95	8	.94	1		7	.94	33	.96
18	25	.95	7	.96	1		6	.97	32	.96
19	23	.96	6	.97	1		5	.98	29	.97
20	19	.95	5	.98	1		4	.98	24	.96

* There was only one participant age 2-4 with a right hemisphere injury who was able to complete the task; therefore, Cronbach's alpha could not be calculated.

Table 6
Cronbach's Alpha for the Line Bisection Task for Children Ages 5-6

Number of Trials	Control Group		Individuals with Injury (Right or Left Hemisphere)		Individuals with Right Hemisphere Injury		Individuals with Left Hemisphere Injury*		All Participants	
	n =	α =	*n* =	α =	*n* =	α =	*n* =	α =	*n* =	α =
2	31	.74	8	.68	4	.95	4	.23	39	.69
3	31	.73	8	.63	4	.93	4	-.55	39	.69
4	31	.79	8	.73	4	.94	4	-1.06	39	.77
5	31	.81	8	.77	4	.95	4	-2.30	39	.80
6	31	.84	8	.80	4	.93	4	-1.57	39	.82
7	31	.77	8	.84	4	.93	4	-.34	39	.80
8	31	.77	8	.88	4	.94	4	.06	39	.82
9	31	.81	8	.90	4	.92	4	.37	39	.86
10	31	.82	8	.90	4	.89	4	.27	39	.86
11	31	.84	8	.92	4	.91	4	.42	39	.88
12	31	.86	8	.93	4	.93	4	.60	39	.90
13	31	.87	8	.94	4	.94	4	.65	39	.91
14	31	.89	8	.95	4	.95	4	.69	39	.92
15	31	.90	8	.96	4	.96	4	.74	39	.93
16	31	.91	8	.96	4	.96	4	.78	39	.94
17	31	.90	8	.96	4	.95	4	.82	39	.93
18	31	.90	8	.97	4	.95	4	.83	39	.94
19	31	.90	8	.97	4	.96	4	.84	39	.94
20	26	.92	7	.97	4	.96	3	.86	33	.94

* The negative values are due to a negative average covariance among items. This violates reliability model assumptions.

Overall, good to excellent reliability ($\alpha > .80$) was achieved across all ages and groups for the 20-trial line bisection task. In most instances alpha remained above .80 even when less than 20 trials were administered. Children ages 5-6 were generally able to complete all the trials, occasionally making erroneous bisections on just one trial. However, children ages 2-4 had more erroneous bisections which generally occurred in the final quarter of the 20-trial task.

Feature Visual Search Task

The feature visual search task was administered according to standardized guidelines described previously. The 24 item responses were scored as either correct or incorrect. Responses not made within the interval time limit of 8,000 ms, were scored as incorrect. Five participants were unable to complete this task according to administration guidelines. Four of these five participants were in the youngest age group. One additional case was completed but eliminated due to a computer error with the time interval limit. The scores of 73 participants were included in this reliability analysis (control group = 56; individuals with brain injury = 17; ages 2-4 = 36; ages 5-6 = 37). The 24-item correlation matrix is provided in Table 7 below. In the matrix, “R” indicates that for that particular trail/item the target was presented on the right side of the monitor (in right hemispace); “L” indicates the target was presented on the left side; and “C” indicates the catch condition, or that the target was absent.

Table 7

Correlation Matrix for the Feature Visual Search Task (24 Items; Left, Right and Catch Conditions; All Participants)

	1 R	2 R	3 C	4 L	5 C	6 R	7 C	8 L	9 C	10 L	11 C	12 R
1 R	-											
2 R	-.03	-										
3 C	-.05	-.05	-									
4 L	-.03	-.03	.29*	-								
5 C	-.05	-.05	.79**	.29*	-							
6 R	.[a]	.[a]	.[a]	.[a]	.[a]	-						
7 C	-.05	.29*	.36**	-.05	.36**	.[a]	-					
8 L	-.02	.70**	-.03	-.02	-.03	.[a]	.44**	-				
9 C	-.04	.33**	.41**	-.04	.17	.[a]	.41**	.49**	-			
10 L	-.02	-.02	-.03	-.02	-.03	.[a]	-.03	-.01	-.03	-		
11 C	-.04	-.04	.41**	-.04	.17	.[a]	.17	-.03	.47**	-.03	-	
12 R	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	-
13 R	-.06	-.06	-.10	.21	-.10	.[a]	-.10	-.04	-.08	-.04	-.08	.[a]
14 C	-.05	-.05	.14	.29*	.14	.[a]	.14	-.03	.17	-.03	.17	.[a]
15 L	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]
16 C	-.03	-.03	.22	-.03	.22	.[a]	.22	-.02	.25*	.57**	.25*	.[a]
17 R	-.03	-.03	.22	.39**	.22	.[a]	-.06	-.02	-.05	-.02	-.05	.[a]
18 R	.16	-.07	-.11	-.07	-.11	.[a]	-.11	-.05	-.10	-.05	-.10	.[a]
19 L	-.02	-.02	-.03	-.02	-.03	.[a]	-.03	-.01	.49**	-.01	-.03	.[a]
20 L	.26*	-.05	-.08	.26*	.12	.[a]	-.08	-.04	-.07	-.04	-.07	.[a]
21 L	-.02	-.02	-.03	-.02	-.03	.[a]	-.03	-.01	-.03	-.01	-.03	.[a]
22 C	-.05	.29*	.14	.29*	.14	.[a]	.14	.44**	.17	-.03	-.07	.[a]
23 R	-.02	-.02	-.03	-.02	-.03	.[a]	-.03	-.01	-.03	-.01	-.03	.[a]
24 L	-.05	.29*	.14	-.05	.14	.[a]	-.07	-.03	-.07	-.03	-.07	.[a]

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).
[a] Cannot be computed because at least one of the variables is constant (all participants passed this item).

Table 7 Continued

	13 R	14 C	15 L	16 C	17 R	18 R	19 L	20 L	21 L	22 C	23 R	24 L
1 R												
2 R												
3 C												
4 L												
5 C												
6 R												
7 C												
8 L												
9 C												
10 L												
11 C												
12 R												
13 R	-											
14 C	.43**	-										
15 L	.[a]	.[a]	-									
16 C	-.07	.22	.[a]	-								
17 R	.15	-.06	.[a]	-.04	-							
18 R	.22	.04	.[a]	-.09	-.09	-						
19 L	-.04	-.03	.[a]	-.02	-.02	-.05	-					
20 L	.21	.31**	.[a]	-.06	-.06	.43**	-.04	-				
21 L	-.04	-.03	.[a]	-.02	-.02	.28*	-.01	-.04	-			
22 C	-.10	-.07	.[a]	-.06	.22	-.11	-.03	-.08	-.03	-		
23 R	-.04	-.03	.[a]	-.02	-.02	-.05	-.01	-.04	-.01	-.03	-	
24 L	-.10	-.07	.[a]	-.06	-.06	.04	-.03	.12	-.03	-.07	-.03	-

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).
[a] Cannot be computed because at least one of the variables is constant (all participants passed this item).

The correlation matrix reveals both positive and negative item correlations with varying degrees of significance. Although positive correlations were expected between items of the same condition (e.g., items with targets presented on the right would correlate with other items with targets presented on the right), this was not necessarily the case. Target absent or "catch" condition trials generally had positive correlations with each other, some of which were significant; however, this was not the case for the left and right conditions. Some items belonging to the left or right condition had very low or negative correlations with other items of that same condition. These negative item correlations resulted in low or in some cases negative (when the average covariance was negative) reliability coefficients.

Since all items were dichotomous (pass/fail), the Kuder-Richardson Formula 20 (KR20) was used as a measure of internal consistency. A composite score was generated for the entire 24-item feature visual search task, but because the items were not necessarily parallel, separate reliability analyses were also conducted treating each of the three conditions (right, left, and catch) as separate "scales". Interestingly, some research suggests no performance difference in detecting targets located in left vs right hemispace for healthy controls (Arguin et al., 1990). Taking this finding into account, the KR20 coefficient was also calculated for a comprehensive "target present" condition which included both the left and right conditions, essentially treating them as a single combined scale. Score reliability for the entire task and for the four scales was calculated for the entire sample and separately for the control and injury group. The KR20 coefficients for the feature visual search task are reported in Table 8 below.

Table 8

Kuder-Richardson 20 Coefficients for the Feature Visual Search Task

	Full Task All Conditions (24 items)	Right Condition Only (8 items)	Left Condition Only (8 items)	Target Present Condition (Both Left and Right 16 items)	Catch Condition Only (8 items)
All Participants (n = 73)	.52	.12	.07	.32	.70
Control Group (n = 56)	.44	.23	-.02[a]	.38	.41
Injury Group (n = 17)	.65	-.42[a]	.29	.11	.86

[a] The negative KR20 coefficients violate reliability model assumptions. This is due to negative average covariance among the items.

Overall, the results of the reliability analysis for the feature visual search task yielded poor score reliability. The KR20 coefficients for the full 24-item task were low. Even when the task was broken down into four scales, reliability of the scores was still generally low, particularly in the left and right conditions. Slight increases in reliability estimates were obtained for all participants and healthy controls when the left and right conditions were combined into a single target present condition. The reliability analysis for the right and left only conditions actually yielded two negative KR20 coefficients. This violates reliability model assumptions and is due to negative average covariance among the items as described above. Another contributing factor to the low reliability coefficients is the low score variance caused by near perfect test performance. As mentioned previously, the feature search task is often called the “easy” search task, because target items “pop” out amongst distracters and are relatively easy to find. In this administration, the average total raw score across all participants was 22.90 out of 24, indeed suggesting a very easy test.

The KR20 coefficients of the catch (target absent) condition were somewhat higher. The scores of the injury group indicated good (KR20 = .86) reliability, and the scores for all participants as a whole indicated adequate reliability (KR20 = .70). The catch condition yielded a lower mean scale score for all participants than either the right or left condition. This suggests the items were slightly more difficult, and perfect or near perfect scores were not as easily obtained. This resulted in greater score variance, which in combination with higher correlations between individual catch items, resulted in higher KR20 coefficients, particularly among children with brain injury.

Conjunction Visual Search Task

The conjunction visual search task was administered according to standardized guidelines described above. The 24 item responses were scored as either correct or incorrect. Responses not made within the interval time limit of 8,000 ms, were scored as incorrect. Fourteen participants were unable to complete this task according to administration guidelines. All but one was in the youngest age group. One additional case was completed but eliminated due to a computer error with the time interval limit. The scores of 64 participants were included in this reliability analysis (control group = 52; individuals with brain injury = 12; ages 2-4 = 27; ages 5-6 = 37). Similar to the feature visual search task, since all items were dichotomous (pass/fail), KR20 was used as a measure of internal consistency. A composite score was generated for the entire 24-item conjunction visual search task, but because the items were not necessarily parallel, separate analyses were also conducted treating each of the three conditions (right, left, and catch) as separate “scales”. Again, the right and left conditions were also combined to create a comprehensive “target present” scale for additional analysis. Score reliability was calculated for the entire sample and separately for the control and injury groups. The correlation matrix for the 24-item conjunction visual search task and the KR20 coefficients are reported in Table 9 and Table 10, respectively.

Table 9

Correlation Matrix for the Conjunction Visual Search Task (24 Items; Left, Right and Catch Conditions; All Participants)

	1 L	2 R	3 R	4 C	5 C	6 L	7 R	8 L	9 C	10 R	11 C	12 R
1 L	-											
2 R	.20	-										
3 R	.08	.14	-									
4 C	.01	-.12	-.03	-								
5 C	-.06	-.11	.01	.37**	-							
6 L	.20	.22	.11	.05	.19	-						
7 R	-.01	.02	.17	-.01	-.01	-.11	-					
8 L	.05	.11	.14	-.03	.16	.06	.17	-				
9 C	-.03	.06	-.17	.49**	.43**	.12	-.12	-.14	-			
10 R	.11	.29*	.20	-.07	.03	.30*	.21	.28*	-.10	-		
11 C	-.03	-.04	-.05	.15	.04	.12	.04	-.14	.34**	.25	-	
12 R	-.09	.20	.16	.10	-.10	.16	.14	.14	.08	.17	.18	-
13 L	-.03	.07	.17	.00	.21	.18	-.05	.20	-.02	-.01	-.21	.01
14 L	.16	.06	.13	-.03	-.04	-.06	.22	-.07	-.06	.10	-.25*	.00
15 R	.07	.11	.04	-.22	.18	.07	-.02	-.02	-.02	.09	-.02	-.16
16 L	.10	.19	.36**	-.07	.07	.25*	-.01	-.12	.03	.11	.03	.00
17 C	-.01	.14	.00	.10	.13	.33**	-.02	-.06	.33**	.10	.08	-.07
18 R	.01	.19	.23	-.19	-.03	.15	.08	-.21	.03	.38**	.15	.10
19 L	.09	.06	.35**	-.03	.04	.02	.14	-.07	-.06	.18	.04	.00
20 C	-.09	-.17	.04	.32*	.18	.16	-.26*	-.10	.29*	.01	.08	.03
21 C	.07	-.17	-.07	.53**	.27*	-.02	.14	-.02	.39**	-.07	.49**	.13
22 L	.20	.09	.14	-.12	.06	.48**	-.05	.03	.06	.29*	-.04	.20
23 C	.13	.06	.17	-.01	.04	.14	-.09	.18	.11	.35**	.24	-.05
24 R	.23	.06	.08	.15	.14	.31*	.13	-.05	.12	.07	-.10	.08

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Table 9 Continued

	13 L	14 L	15 R	16 L	17 C	18 R	19 L	20 C	21 C	22 L	23 C	24 R
1 L												
2 R												
3 R												
4 C												
5 C												
6 L												
7 R												
8 L												
9 C												
10 R												
11 C												
12 R												
13 L	-											
14 L	-.04	-										
15 R	.10	.18	-									
16 L	.19	.07	.21	-								
17 C	.17	.01	.04	.23	-							
18 R	.00	.27*	.10	.29*	.10	-						
19 L	.04	.22	.18	.37**	.01	.17	-					
20 C	.01	.09	-.06	.10	.28*	.10	.18	-				
21 C	.01	-.10	-.06	.00	-.07	-.11	-.10	.23	-			
22 L	.07	.15	-.08	.08	.26*	.29*	.24	.11	-.17	-		
23 C	.10	-.08	-.05	.12	.17	.26*	.04	.20	.20	.06	-	
24 R	.25*	.14	.29*	.37**	.20	.03	.34**	.18	.08	.16	.11	-

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Similar to the results of the feature visual search task, the correlation matrix for the conjunction visual search task also reveals both positive and negative item correlations with varying degrees of significance. Strong positive correlations were expected between item pairs of the same condition; however, again, this was not always the case. Like the scores of the feature visual search task, target absent or "catch" condition trials generally had positive correlations with each other, some of which were significant. But again, some items in the left and right conditions had very weak or even negative correlations with other items of that same condition. When compared to the feature visual search task however, these negative correlations occurred far less frequently in the conjunction task. These negative item pair correlations did produce low reliability estimates; however, unlike in the feature visual search task, the average covariance of the conjunction visual search task was positive for all groups and conditions, thus all of the KR20 coefficients remained positive.

Table 10
Kuder-Richardson 20 Coefficients for the Conjunction Visual Search Task

	Full Task All Conditions (24 items)	Right Condition Only (8 items)	Left Condition Only (8 items)	Target Present (Left and Right 16 items)	Catch Condition Only (8 items)
All Participants (n = 64)	.68	.54	.48	.68	.71
Control Group (n = 52)	.68	.53	.40	.63	.74
Injury Group (n = 12)	.66	.60	.67	.78	.55

The results of the reliability analysis for the conjunction visual search task varied by condition. The KR20 coefficients for the full 24-item task were questionable (but approached adequate) across all groups (.66 - .68). These full-task coefficients were slightly higher than those of the feature visual search task. This increased reliability may be due in part to greater score variance reflected by more difficult test items. When compared to the feature visual search task which yielded a mean score of 22.90 out of 24, the overall mean score of the conjunction task was 18.66 out of 24. The whole group full-task score variances of the feature and conjunction tasks were 2.03 and 11.51, respectively.

When the task was broken down into four scales for each of the conditions (right, left, target present, and catch), reliability of the scores was still low (some approaching adequate) in the left and right conditions (.40 - .67), but again these coefficients were higher than those obtained from the feature visual search task. Similar to the results of the feature visual search task, the scores of the catch (target-absent) condition yielded some of the highest reliability coefficients. Scores for the entire sample (.71) and for the control group (.74) had acceptable reliability for the catch condition. Also similar to the feature search task, when the left and right conditions were combined into a single target present scale, reliability was improved across all groups. The scores obtained from the injury group for the combined target present condition produced the highest KR20 coefficient (.78) which very nearly fell into the “good” range.

Extinction Task

The 32 item responses were scored as either correct or incorrect. Responses not made within the interval time limit of 300 ms, were scored as incorrect. Nineteen participants were unable to complete this task according to administration guidelines. Seventeen of these children were in the youngest age group. The scores of 60 participants were included in this reliability analysis (control group = 48; individuals with brain injury = 12; ages 2-4 = 23; ages 5-6 = 37). The correlation matrix for the extinction task is provided below in Table 11. As with the visual search tasks, the “L”, “R”, and “C” written after the trial number indicates the location of the target presentation as left, right, and catch (target-absent), respectively. The “B” is unique to the extinction task and indicates that targets were presented on both the left and right side of the screen.

Table 11

Correlation Matrix for the Extinction Task (32 Items; Left, Right, Both, and Catch Conditions; All Participants)

	1 B	2 B	3 R	4 C	5 R	6 L	7 L	8 R	9 C	10 B	11 R	12 L	13 C	14 R	15 B	16 L
1 B	-															
2 B	.70**	-														
3 R	.15	-.06	-													
4 C	-.06	-.04	.17	-												
5 R	-.04	-.03	.29*	.21	-											
6 L	.48**	.70**	-.09	.28*	-.04	-										
7 L	-.05	-.03	.39**	-.08	-.06	-.05	-									
8 R	-.06	-.04	.17	.35**	.21	-.06	.16	-								
9 C	-.04	-.03	-.11	.21	-.05	-.04	.25	-.07	-							
10 B	-.03	-.02	.15	-.06	-.04	-.03	.32*	-.06	-.04	-						
11 R	-.06	-.04	.42**	.10	.18	-.06	.36**	.10	.18	.25	-					
12 L	-.07	-.05	.10	-.11	-.08	-.07	.11	.08	-.08	-.07	.22	-				
13 C	-.05	-.03	.05	-.08	-.06	-.05	.20	-.08	.25	-.05	-.09	-.10	-			
14 R	-.07	-.05	.10	-.11	.15	-.07	.32*	-.11	.15	.22	.22	.19	.11	-		
15 B	-.06	-.04	.01	.13	.21	-.06	-.08	.13	-.07	-.06	-.10	.08	-.08	-.11	-	
16 L	-.03	-.02	.15	-.06	-.04	-.03	-.05	-.06	-.04	-.03	.25	.22	-.05	-.07	-.06	-
17 C	-.04	-.03	-.11	-.07	-.05	-.04	-.06	-.07	-.05	-.04	-.08	.15	-.06	-.08	.48**	.38**
18 B	-.06	-.04	.33*	.13	-.07	-.06	.16	-.09	-.07	.28*	.10	.08	-.08	.27*	-.09	-.06
19 C	-.04	-.03	.29*	.21	.30*	-.04	-.06	.21	-.05	-.04	-.08	.15	-.06	.15	.21	-.04
20 R	-.05	-.03	.05	.16	-.06	-.05	.20	.65**	-.06	-.05	.13	.11	-.07	-.10	-.08	-.05
21 B	-.03	-.02	.15	-.06	-.04	-.03	.32*	-.06	-.04	.48**	.25	-.07	-.05	.22	-.06	-.03
22 R	-.06	-.04	.27*	.30*	.18	-.06	.13	.50**	-.08	-.06	.26*	.22	-.09	-.12	.10	.25
23 C	-.05	-.03	-.13	.40**	-.06	.32*	-.07	.40**	-.06	-.05	-.09	-.10	-.07	-.10	.16	-.05
24 L	-.06	-.04	-.01	.10	-.08	-.06	.36**	.10	.43**	-.06	.26*	.22	.13	.22	-.10	-.06
25 C	-.04	-.03	-.11	.21	-.05	-.04	.25	.21	.30*	-.04	-.08	-.08	.25	.15	-.07	-.04
26 B	-.06	-.04	.01	.13	-.07	-.06	-.08	-.09	-.07	-.06	-.10	-.11	-.08	-.11	-.09	-.06
27 L	-.05	-.03	-.13	.40**	-.06	-.05	-.07	.16	.55**	-.05	.13	.11	-.07	.11	-.08	-.05
28 L	-.04	-.03	.09	-.07	-.05	-.04	.25	.21	.30*	-.04	.18	.15	-.06	-.08	-.07	-.04
29 C	-.04	-.03	-.11	-.07	-.05	-.04	-.06	-.07	-.05	-.04	-.08	.15	.25	.15	-.07	-.04
30 L	-.02	-.02	-.06	-.04	-.03	-.02	-.03	-.04	-.03	-.02	-.04	-.05	-.03	-.05	-.04	-.02
31 B	-.06	-.04	.01	-.09	-.07	-.06	-.08	-.09	-.07	.28*	.10	.45**	-.08	.08	.13	.28*
32 R	-.06	-.04	.01	-.09	-.07	-.06	.40**	.13	.21	-.06	.10	.08	.16	.08	.35**	-.06

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Table 11 Continued

	17 C	18 B	19 C	20 R	21 B	22 R	23 C	24 L	25 C	26 B	27 L	28 L	29 C	30 L	31 B	32 R
1 B																
2 B																
3 R																
4 C																
5 R																
6 L																
7 L																
8 R																
9 C																
10 B																
11 R																
12 L																
13 C																
14 R																
15 B																
16 L																
17 C	-															
18 B	-.07	-														
19 C	-.05	.48**	-													
20 R	-.06	-.08	-.06	-												
21 B	-.04	.28*	-.04	-.05	-											
22 R	-.08	-.10	.18	.36**	-.06	-										
23 C	.25	-.08	-.06	.20	-.05	.13	-									
24 L	-.08	.10	.18	.13	-.06	.07	-.09	-								
25 C	-.05	-.07	-.05	.25	-.04	.18	.25	.18	-							
26 B	-.07	.13	-.07	-.08	.28*	-.10	-.08	-.10	-.07	-						
27 L	-.06	.16	.25	.20	-.05	.13	.20	.36**	.25	-.08	-					
28 L	-.05	-.07	-.05	.25	-.04	.18	-.06	.18	-.05	-.07	.25	-				
29 C	-.05	-.07	-.05	-.06	-.04	.18	-.06	-.08	-.05	-.07	-.06	-.05	-			
30 L	-.03	-.04	-.03	-.03	-.02	-.04	-.03	-.04	.57**	-.04	-.03	-.03	-.03	-		
31 B	.21	.13	.21	-.08	-.06	.10	-.08	.30*	-.07	-.09	.16	-.07	-.07	-.04	-	
32 R	.21	-.09	-.07	.16	-.06	.10	.16	.30*	.21	-.09	-.08	.21	-.07	-.04	-.09	-

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Similar to the results of both visual search tasks, the correlation matrix for the extinction task also reveals both positive and negative item correlations with varying degrees of significance. Again, strong positive correlations were expected between item pairs of the same condition; however, many item pairs of the same condition had weak or even negative correlations. Weak and/or negative correlations reduced reliability estimates across all groups and conditions.

Since all items were again dichotomous (pass/fail), the KR20 was used as a measure of internal consistency. A composite score was generated for the entire 32-item extinction task, but because the items were not necessarily parallel, separate analyses were also conducted treating each of the four conditions (right, left, both, and catch) as separate "scales". Score reliability was calculated for the entire sample and separately for the control and injury groups. Again, the sample sizes are incredibly small, particularly when separated into left and right hemisphere of injury groups. The KR20 coefficients are reported below in Table 12; however, caution should be used when interpreting the results as estimates can be highly unstable with very small samples.

Table 12
Kuder-Richardson 20 Coefficients for the Extinction Task

	Full Task All Conditions (32 items)	Right Condition Only (8 items)	Left Condition Only (8 items)	Both Condition Only (8 items)	Catch Condition Only (8 items)
All Participants (*n* = 60)	.62	.59	.40	.27	.33
Control Group (*n* = 48)	.51	.43	.18	.27	.30
Injury Group (*n* = 12)	.73	.83	.53	.16	.47

The results of the reliability analysis for the extinction task varied by condition, but overall were quite low. The scores of the full 32-item task and the 8-item right condition scale for children with brain injury produced adequate and good reliability estimates, respectively. Upon closer examination however, these estimates were heavily influenced by a single outlier producing most of the overall variance. Therefore, the estimates, particularly for the injury group, are likely inflated and should be interpreted with caution. The remaining KR20 coefficients all indicate poor score reliability. Unlike in the two visual search paradigms, the catch condition of the extinction task did not produce higher reliability estimates than the other conditions.

Validity Analyses

The second hypothesis of the present study stated that at least one of the outcome variables from each of the tasks would have adequate (.70) criterion-related validity. The present validity analysis focused specifically on the decision accuracy of the individual tasks via sensitivity and specificity analyses. *Sensitivity* measures how accurately the task variable predicts brain injury for those who actually have brain injury (in this case according to brain scans in the child's medical record). It is the proportion of "true positives" as determined by the task variable to all those who actually have a brain injury. *Specificity* measures how accurately the outcome variable predicts non-injury among those who do not have brain injury. It is the proportion of "true negatives" as determined by the task variable to all those who do not have a brain injury.

Although somewhat artificial, the 36 task outcome variables were used as "predictors" of brain injury. The literature suggests that VSN is a *possible* but not *certain* outcome of brain injury; therefore, it would have been far better to use the outcome variables as "predictors of a VSN diagnosis" as opposed to "predictors of brain injury". Unfortunately, this diagnostic information is not often available (as in the present study), while confirmation of brain injury based on brain scans is frequently available. Additionally, one of the largest problems associated with VSN is how frequently the deficit goes undiagnosed; therefore, using an official diagnosis of VSN as a criterion is incredibly problematic. Although somewhat imperfect in its approach, this initial validity analysis represents an important first step in the process of developing a standardized Pediatric Visuospatial Neglect Battery.

Line Bisection Task

The scores of 72 participants were included in the line bisection validity analysis (control group = 56; individuals with brain injury = 16). Seven participants from the youngest age group were unable to understand the instructions and/or adequately perform at least half of the trials, thus were excluded from the analysis. The scores of the two line bisection outcome variables (LineMD and Line SD) were converted to Z scores using the mean of the control group. A two standard deviation (SD) cutoff score is frequently used in educational and social science research to indicate above or below "average" performance. This 2 SD cutoff also was used here to indicate abnormal performance or "VSN behavior". As discussed in the literature review, adults with VSN tend to bisect lines further to the right than their healthy counterparts; however, children perform markedly different. Due to these differences, no directionality was imposed on the cutoff score for the LineMD variable; instead significant deviations either to the left (-) or to the right (+) of the control mean line bisection were considered abnormal and termed VSN behavior. Directionality was however imposed on the LineSD variable. This variable was intended to measure the variation of each individual child's 20 line bisection marks. Performance that had significantly more variation than that of healthy controls was considered to be abnormal and termed VSN behavior. Using the 2 SD cutoff score, both outcome variables of the line bisection task appear to have excellent (> .90) specificity, but poor sensitivity to predict brain injury among children. The sensitivity and specificity ratios are presented in Table 13 below.

Table 13
Sensitivity and Specificity Ratios for the Line Bisection Task

		Predictor Cutoff Score (SD Below Control Mean)					
		2 SD		1.5 SD		1 SD	
Task Variable	Descriptor	Sensitivity	Specificity	Sensitivity	Specificity	Sensitivity	Specificity
LineMD	Mean deviation of bisection mark from true center (mean of 20 trials)	.31	.95	.31	.89	.56	.86
LineSD	Standard deviation of the 20 line bisection trials	.06	.93	.06	.93	.38	.84

After the initial analysis, a what-if analysis was conducted to determine if lowering the cutoff score to 1.5 SD or 1 SD would improve the decision accuracy with respect to sensitivity and specificity. With the present sample, reducing the cutoff score to 1.5 SD had no effect on sensitivity, but slightly reduced the specificity of LineMD. It had no effect on either sensitivity or specificity for LineSD. When the 1 SD cutoff score was used, specificity of LineMD was slightly reduced again, but was accompanied by an increase in sensitivity. For the LineSD variable also, sensitivity increased and specificity decreased.

Cancellation Task

The scores of 73 participants were included in the cancellation validity analysis (control group = 57; individuals with brain injury = 16). Six participants from the youngest age group were unable to understand the instructions and/or adequately perform the task, thus were excluded from the analysis. The participant scores of the cancellation outcome variables were converted into Z scores based on the mean performance of the control group. Again a 2 SD cutoff score was initially used to differentiate abnormal performance from normal performance. For six of these eight cancellation variables (CaRawTot, CaRawFL, CaRaw,NL, CaRaw,NR, CaRawFR, and CaOrg), the direction of the deviation was important, and only negative deviations below the cutoff score (indicating performance significantly below the mean) were considered VSN behavior. For these six variables, any score that was significantly above the mean was not considered VSN behavior. The CaLocInt and CaOrder variables, are measures of the initial target cancelled and order of target cancellation, respectively. Because these are both variables of lateralized (left or right) performance, scores above +2 SD and below -2 SD were both considered abnormal performance and indicative of VSN behavior. Following the initial analysis using a 2 SD cutoff score, a what-if analysis using 1.5 and 1 SD cutoff scores was conducted. The results of the sensitivity and specificity analysis with these various cutoff scores are reported in Table 14 below.

Table 14

Sensitivity and Specificity Ratios for the Cancellation Task

		Predictor Cutoff Score (SD Below Control Mean)					
		2 SD		1.5 SD		1 SD	
Task Variable	Descriptor	Sensitivity	Specificity	Sensitivity	Specificity	Sensitivity	Specificity
CaRawTot	Total number of targets cancelled (raw score out of 16)	.06	.95	.19	.93	.19	.93
CaRawFL	Number of targets cancelled in far left (raw score out of 4)	.19	.88	.19	.88	.19	.88
CaRawNL	Number of targets cancelled in near left (raw score out of 4)	.19	.97	.19	.97	.38	.77
CaRawNR	Number of targets cancelled in near right (raw score out of 4)	.13	.95	.13	.95	.25	.72
CaRawFR	Number of targets cancelled in far right (raw score out of 4)	<.00	.97	<.00	.97	.13	.86
CaLocInt	Location of initial target cancelled using column weights: far left (-2), near left (-1), near right (1), far right (2)	<.00	1.00	.13	.84	.38	.46
CaOrder	Rank order weight (16 for 1st target cancelled…1 for the 16th target cancelled) multiplied by column weight (far left = -2, near left = -1, near right = 1, and far right = 2)	.13	.97	.19	.84	.44	.67
CaOrg	A measure of cancellation search strategy using the sum of the column weight (-2, -1, 1, or 2) differences between consecutive cancelled targets	<.00	1.00	<.00	1.00	.13	.97

The results of the sensitivity and specificity analysis indicate that all but two of the outcome variables of the cancellation task have adequate (> .70) to excellent (> .90) specificity at all SD cutoff levels. Sensitivity however was generally poor at all SD cutoff levels. As expected, when the cutoff score was reduced, sensitivity increased or remained unchanged, and specificity decreased or remained unchanged. The specificity of the CaLocInt and CaOrder variables fell to unacceptable levels when the cutoff score was reduced to 1 SD.

The literature suggests that the location of the initial target cancelled (CaLocInt) is a very sensitive measure of neglect (Azouvi et al., 2002; Manly et al., 2009), yet the ratios presented above in Table 14 do not support this previous finding. This difference may be caused by measurement error in this particular calculated variable. CaLocInt variable was intended to quantify the location of the initial target cancelled by assigning ordinal numbers to a specific location on the stimulus page. Although these variables were ordinal, they were treated as scale variables in the initial analysis. When the deviation from the control group's mode was used instead of Z score conversions of the control group's mean, dramatically different results were obtained. Table 15 below displays the sensitivity and specificity ratios when VSN behavior was defined as unit distance from the mode instead of SD from the mean.

Table 15

Sensitivity and Specificity of the CaLocInt Variable Using a Mode Cutoff Score

		Predictor Cutoff Score (Using Control Mode)					
		-2 (far left only)		-1 (far left or near left)		1 (far left, near left, or near right)	
		Sensitivity	Specificity	Sensitivity	Specificity	Sensitivity	Specificity
CaLocInt	Location of initial target cancelled using column weights: far left (-2), near left (-1), near right (1), far right (2)	.80	.37	.45	.56	.13	.84

The mode of the control group was -2 suggesting that most healthy children began the cancellation task on the far left side of the stimulus page. The -2 cutoff score implies that any individual who did not also obtain a -2 for this variable (who did not begin on the far left of the stimulus page), was considered to display VSN behavior. The -1 cutoff score means that any individual who did not obtain a -2 or a -1 (who did not begin on either the far left or near left of the stimulus page), was considered to display VSN behavior. Similarly, the 1 cutoff means that any individual who did not obtain a -2, -1, or 1 (who did not begin on the far left, near left, or near right) was considered to display neglect behavior. In this analysis, sensitivity was good at the most conservative cutoff score. When CaLocInt is measured this way, the ratio supports previous findings in the literature and suggests that this variable does a good job of detecting VSN behavior among children with brain injury. However, measuring CaLocInt in this manner also tends to over-detect VSN behavior among healthy children. As the mode cutoff score becomes less restrictive, sensitivity decreases and specificity increases.

Feature Visual Search Task

The scores of 74 participants were included in the feature visual search validity analysis (control group = 57; individuals with brain injury = 17). Five participants, three from the youngest (2 - 4 years) age group and two from the older (5 – 6 years) age group, were unable to understand the instructions and/or adequately perform the task, thus were excluded from the analysis. The participant scores of the feature visual search outcome variables were converted into Z scores, and a 2 SD cutoff score was used to determine abnormal performance. The direction of the deviation was important for all eight of the feature visual search variables. For those variables measuring the number of correct responses (FeRawTot, FeRawL, FeRawR, and FeRawC), only (negative) Z scores below the cutoff score (indicating performance significantly below the mean) were considered VSN behavior. Z scores above the (positive) 2 SD cutoff score (indicating performance significantly above the mean) were not considered VSN behavior. Conversely, for the four reaction time variables (FeMRT, FeLRT, FeRRT, and FeCRT), Z scores above the positive cutoff score were indicative of slower reaction times and were deemed VSN behavior, while Z scores below the negative cutoff score were indicative of faster responses and were not considered VSN. Following the initial analysis using a 2 SD cutoff score, a what-if analysis using 1.5 and 1 SD cutoff scores was conducted. The results of the sensitivity and specificity analysis using these various cutoff scores are reported in Table 16 below.

Table 16
Sensitivity and Specificity Ratios for the Feature Visual Search Task

		Predictor Cutoff Score (SD Below Control Mean)					
		2 SD		1.5 SD		1 SD	
Task Variable	Descriptor	Sensitivity	Specificity	Sensitivity	Specificity	Sensitivity	Specificity
FeRawTot	Total number of correct responses for all conditions (raw score out of 24)	.06	.95	.12	.93	.24	.88
FeRawL	Number of correct responses when target was presented on the left (raw score out of 8)	.06	.98	.18	.79	.18	.79
FeRawR	Number of correct responses when target was presented on the right (raw score out of 8)	<.00	.91	<.00	.91	<.00	.91
FeRawC	Number of correct responses when target was absent, "catch" condition (raw score out of 8)	.06	.98	.12	.93	.18	.93
FeMRT	Overall mean reaction time for all 24 trials	.06	.95	.06	.91	.35	.88
FeLRT	Mean reaction time when target was presented on the left	.06	.93	.12	.93	.24	.88
FeRRT	Mean reaction time when target was presented on the right	<.00	.95	.18	.95	.29	.88
FeCRT	Mean reaction time when target was absent, "catch" condition	.12	.93	.24	.90	.41	.88

The results of the sensitivity and specificity analysis indicate that all of the outcome variables of the feature visual search task have adequate (> .70) to excellent (> .90) specificity at all SD cutoff levels. Similar to the results of the line bisection and cancellation validity analyses, sensitivity of the feature visual search task was poor at all SD cutoff levels.

Conjunction Visual Search Task

The scores of 64 participants were included in the conjunction visual search validity analysis (control group = 52; individuals with brain injury = 12). Fifteen participants (thirteen from the youngest (2 - 4 years) age group and two from the older (5 – 6 years) age group were unable to understand the instructions and/or adequately perform the task, thus were excluded from the analysis. As with the feature visual search task, participant scores of the conjunction visual search outcome variables were converted into Z scores. An initial 2 SD cutoff score followed by a what-if analysis for less restrictive cutoff scores was used to determine abnormal performance. The direction of the deviation was important for all eight of the conjunction visual search variables. For those variables measuring the number of correct responses (CjRawTot, CjRawL, CjRawR, and CjRawC), only Z scores below the negative cutoff score were considered VSN behavior. Z scores above the positive cutoff score were not considered VSN behavior as they indicated above average performance. Conversely, for the four reaction time variables (CjMRT, CjLRT, CjRRT, and CjCRT), Z scores above the positive cutoff score were indicative of slower reaction times and were deemed VSN behavior, while Z scores below the negative cutoff score were indicative of faster responses and were not considered VSN. The results of the sensitivity and specificity analysis of the conjunction visual search task are reported below in Table 17.

Table 17
Sensitivity and Specificity Ratios for the Conjunction Visual Search Task

		Predictor Cutoff Score (SD Below Control Mean)					
		2 SD		1.5 SD		1 SD	
Task Outcome Variable	Descriptor	Sensitivity	Specificity	Sensitivity	Specificity	Sensitivity	Specificity
CjRawTot	Total number of correct responses for all conditions (raw score out of 24)	.08	.98	.08	.94	.33	.81
CjRawL	Number of correct responses when target was presented on the left (raw score out of 8)	.08	.96	.08	.96	.25	.83
CjRawR	Number of correct responses when target was presented on the right (raw score out of 8)	.17	.98	.17	.98	.25	.89
CjRawC	Number of correct responses when target was absent, "catch" condition (raw score out of 8)	<.00	.94	.33	.89	.33	.81
CjMRT	Overall mean reaction time for all 24 trials	.08	1.00	.08	.90	.17	.79
CjLRT	Mean reaction time when target was presented on the left	.08	.94	.08	.92	.08	.85
CjRRT	Mean reaction time when target was presented on the right	<.00	.96	<.00	.94	.17	.85
CjCRT	Mean reaction time when target was absent, "catch" condition	.08	.96	.08	.92	.25	.87

The results of the conjunction visual search validity analysis were similar to those of the feature visual search task. Adequate (> .70) to excellent (> .90) levels of specificity were obtained at all SD cutoff levels, while poor levels of sensitivity were obtained at all SD cutoff levels. As the SD cutoff score was made less restrictive, sensitivity increased and specificity decreased; however, the less restrictive cutoff score did not increase sensitivity to adequate levels for decision accuracy to predict brain injury.

Extinction Task

The scores of 60 participants were included in the extinction validity analysis (control group = 48; individuals with brain injury = 12). Nineteen participants (seventeen from the youngest (2 – 4 years) age group and two from the older (5 – 6 years) age group) were unable to understand the instructions and/or adequately perform the task, thus were excluded from the analysis. Again, raw scores of the outcome variables were converted into Z scores, and a 2 SD cutoff score was initially used and followed by a what-if analysis to determine abnormal performance. The direction of the deviation was important for all ten of the extinction task variables. For those five variables measuring the number of correct responses (ExRawTot, ExRawL, ExRawR, ExRawC, and ExRawB), only Z scores below the negative cutoff score were considered VSN behavior. Z scores above the positive cutoff score were not considered VSN behavior as they indicated above average performance. Conversely, for the five reaction time variables (ExMRT, ExLRT, ExRRT, ExCRT, and ExBRT), Z scores above the positive cutoff score were indicative of slower reaction times and were deemed VSN behavior, while Z scores below the negative cutoff score were indicative of faster responses and were not considered VSN. The results of the sensitivity and specificity analysis of the extinction task are reported below in Table 18.

Table 18

Sensitivity and Specificity Ratios for the Extinction Task

		Predictor Cutoff Score (SD Below Control Mean)					
		2 SD		1.5 SD		1 SD	
Task Outcome Variable	Descriptor	Sensitivity	Specificity	Sensitivity	Specificity	Sensitivity	Specificity
ExRawTot	Total number of correct responses for all conditions (raw score out of 32)	.25	.92	.25	.90	.42	.85
ExRawL	Number of correct responses when target was presented on the left (raw score out of 8)	.17	.92	.17	.92	.58	.73
ExRawR	Number of correct responses when target was presented on the right (raw score out of 8)	.17	.92	.17	.92	.17	.88
ExRawB	Number of correct responses when target was presented on both the left and right (raw score out of 8)	.33	.94	.33	.94	.33	.94
ExRawC	Number of correct responses when target was absent, "catch" condition (raw score out of 8)	.08	.88	.08	.88	.08	.88
ExMRT	Overall mean reaction time for all 32 trials	.08	.94	.17	.92	.33	.85
ExLRT	Mean reaction time when target was presented on the left	.17	.94	.33	.92	.50	.90
ExRRT	Mean reaction time when target was presented on the right	.08	.94	.08	.92	.17	.90
ExBRT	Mean reaction time when target was presented on both the left and right	<.00	.94	<.00	.92	.17	.85
ExCRT	Mean reaction time when target was absent, "catch" condition	<.00	.94	<.00	.94	.25	.88

The results of the extinction sensitivity and specificity analysis indicate that all but one of the outcome variables have good (> .80) to excellent (> .90) specificity at all

SD cutoff levels. The specificity of one variable, ExRawL, decreased from excellent to adequate when using the 1 SD cutoff score. Again, sensitivity of all of the variables remained low even when less restrictive cut scores were used. Interestingly, ExRawL had the overall greatest sensitivity of all the 36 variables in the study (.58), yet it still did not reach an adequate level for decision accuracy.

CHAPTER V

SUMMARY AND CONCLUSION

Discussion

The purpose of the current research study was to validate the Pediatric Visuospatial Neglect Battery developed at CHOP that purports to assess VSN in young children who have experienced stroke. VSN is of particular interest because the true incidence of the disorder is unknown, potentially occurs quite frequently, dramatically affects day-to-day functioning, and is a very powerful predictor of future outcomes. The study examined the reliability and validity of the scores of the battery's five tasks which were administered to a group of children with brain injury and healthy controls ages 2-6 years.

The first hypothesis stated that reliability estimates for the scores of all the tasks would reach at least adequate (.70) levels. This hypothesis was not confirmed. Although some of the reliability estimates of some of the task scores did reach or surpass the adequate threshold, most reliability coefficients did not. The second hypothesis stated that all five tasks would have at least one variable with adequate (.70) decision accuracy with respect to sensitivity and specificity. This hypothesis also stated which specific variables would be the best predictors of brain injury for each task and for the overall VSN battery. The second hypothesis was partially confirmed. Each task did not have at least one variable that reached adequate levels of decision accuracy with respect to both sensitivity and specificity. Although not reaching adequate sensitivity levels, the hypothesized LineMD and ExRawB variables had the greatest decision accuracy with respect to specificity for their respective tasks. The hypothesized CaLocInt, FeRawL, and CjRawL variables did not have the greatest decision accuracy for their tasks. Finally, the hypothesized CaLocInt variable was not the most powerful predictor of the 36 VSN battery variables.

Line Bisection Task

As hypothesized, good to excellent reliability was achieved across all ages and groups for the 20-trial line bisection task. This is consistent with previous findings in the literature (Luh, 1995). High levels of reliability were expected because this task is a repeated measure. With regard to validity, both of the line bisection variables (LineMD and LineSD) had good specificity, but poor sensitivity to predict brain injury. Prior studies have reported higher levels of line bisection sensitivity (Azouvi et al., 2002; Lindell et al., 2007); however, these studies were conducted with adult populations. When the cutoff score was reduced from 2 SD to 1 SD, specificity remained high and sensitivity increased. As hypothesized, the LineMD variable had the greatest decision accuracy of the line bisection task (at the 1 SD level); however, the decision accuracy for this variable did not reach adequate levels with respect to *both* sensitivity and specificity.

When compared to the adult studies, the results of the present study suggest that internal consistency of the line bisection scores may not be affected by age, but age might be an important factor in validity. As discussed previously, the adult literature paints a relatively clear picture of line bisection performance: Healthy adults tend to bisect lines slightly to the left of true center (Jewell & McCourt, 2000), while adults with brain injury show a deviation of midpoint perception in the direction ipsilesional to the hemisphere of injury (Wilson, et al., 1987). In child studies, the findings are equivocal and vary based on numerous factors. As discussed in the developmental literature reviewed above, lateralization and motor effects (handedness and hand used) have a particularly strong influence on performance, especially in very young children. When these normative variables are coupled with hemisphere of injury, size and location of the lesion, and especially recovery effects for children with brain injury, performance assessment becomes even more complex. It is reasonable to suspect that these factors have numerous interaction effects and might have reduced the validity estimates for both the LineMD and LineSD variables of the line bisection task.

Cancellation Task

Due to its nature as a single administration of a single item, the cancellation task did not lend itself to an analysis of internal consistency; however, validity analysis was possible. All eight of the outcome variables for the cancellation task had good to excellent specificity, but sensitivity was generally poor across all cancellation variables. Even when the initial 2 SD cutoff score was made less restrictive, sensitivity remained poor. This finding was not expected and is not consistent with the literature which purports that the cancellation task is a highly sensitive measure of neglect (Lindell et al., 2007). Interestingly, CaLocInt became a very sensitive measure at the initial cutoff when the control group's mode was used instead of the mean. This finding is consistent with the literature (Azouvi et al., 2002; Azouvi et al., 2006; Laurent-Vannier et al., 2003; Laurent-Vannier et al., 2006; Manly et al., 2009).

Poor sensitivity may be caused by several measurement issues present in the study. First, sampling error due to the small sample size may have reduced validity estimates. Secondly, low score variance of many of the variables likely reduced validity. The low score variance may be attributed to near perfect performance and by having too few items making up a variable outcome score. Five cancellation variables (CaRawTot, CaRawFL, CaRawNL, CaRawNR, and CaRawFR) all had near perfect mean scores. Additionally, four of these variables had a maximum raw score of only four, again with near perfect performance.

In addition to these measurement issues, poor sensitivity may be attributed to the inability of these calculated cancellation variables to adequately measure the VSN construct in very young children. Many findings replicated in the literature suggesting group differences in cancellation performance were not supported in this study. Although the focus of the present study was not to examine group differences, these discrepancies from the literature might suggest some problems in measuring VSN in very young children with these particular variables.

Feature Visual Search Task

Overall, the scores of the feature visual search task yielded poor reliability and sensitivity. The KR20 coefficients for the full 24-item task and for three of the scales (left, right, and the combined target present condition) were generally low and in some cases negative. Two of the KR20 coefficients of the catch condition were at or above the adequate level. With regard to validity, sensitivity was generally low at all SD cutoff levels, while specificity was generally high. No previous reliability or validity studies have been conducted using this particular feature visual search computer paradigm, so little comparison can be made to prior literature. However, the present finding that reliability estimates were slightly higher when the left and right conditions were combined into a single “target present” scale, seems to support the previous finding that the visual search performance of healthy controls is not affected by left or right target presentation (Arguin, et al., 1990).

Poor reliability and validity estimates were likely due to a combination of low score variance and negative correlations between item pairs. One plausible explanation for both of these issues is sampling error, a problem inherent in studies with small sample sizes such as this one. Low score variance was also likely caused by near perfect performance on the frequently termed “easy” search task. Weak or negative correlations between items belonging to the same conditions might also be caused by the items not measuring the same underlying construct. While multiple trials with target presentation on the same half of the computer screen seems to be almost a repeated measure which would produce strong positive correlations, there may be other factors at work. For instance, target presentation in various vertical locations (i.e., in the top, middle or bottom of the screen) may have played a role in reducing the correlation between items presented in the same horizontal location (i.e., on the same side of the screen). Interestingly, the target absent, or "catch" condition trials generally produced higher reliability coefficients. This may have been caused by greater score variance of a more difficult condition and/or stronger positive correlations among the items of this scale.

Conjunction Visual Search Task

Overall, the reliability coefficients for the conjunction visual search task were low to adequate. The highest estimates came from the catch condition and after the separate left and right conditions were combined into a single target present scale, again supporting the findings of Arguin, et al.'s (1990) study. On the whole, these reliability estimates were higher than those obtained from the scores of the feature visual search task. This is due in part to greater score variance of a more difficult task. Also, unlike the scores in the feature visual search task, the scores of the conjunction visual search task did not yield a negative average covariance among items. Despite these improvements over the feature visual search, some low and/or negative correlations were still present between item pairs belonging to the same condition. This unexpected result may again be due to sampling error or items not necessarily measuring the same underlying construct. With regard to validity, sensitivity was poor and specificity was high across all SD cutoff levels. These validity results were very similar to those of the feature visual search task.

Extinction Task

The extinction task, much like the two visual search paradigms, was uniquely created for this battery, thus no prior reliability and validity studies were available for comparison. While other extinction tasks do exist, there are often more differences than similarities between them making task comparisons virtually impossible. Overall, the scores of the present extinction task indicated poor reliability and validity. With respect to decision accuracy, sensitivity to detect VSN behavior among those with brain injury was low at all SD cutoff levels. Specificity was generally high. This task produced high mean scores and very small score variances across nearly all of the groups and conditions. Additionally, and much like in both visual search tasks, numerous low and negative item pair correlations were present between items of the same condition. This may be due to sampling error associated with the small sample size, or this may be the result of poor measurement of the underlying VSN and/or extinction construct.

One potential problem might be related to the placement of stimuli. In the finger wiggle task, a traditional neurological examination, the fingers are simultaneously presented on both sides of the head. In similar computer paradigms, objects are flashed on two monitors, one placed on each side of the head. However, in the present computerized extinction task, both targets were presented on a single monitor placed directly in front of the examinee. Although technically, the targets do appear on opposite sides of body midline, it can be argued that practically, the objects are both in front of the examinee as opposed to being in separate and distinct hemispaces. This may represent poor measurement of the extinction construct.

Limitations

The present study was the first attempt to examine the reliability and validity of the scores of the Pediatric Visuospatial Neglect Battery developed at CHOP. As expected and due to its exploratory nature, numerous limitations were present and warrant mention. Most importantly, the reported reliability and validity estimates may be unstable due to the small sample size. Also, the sample was taken from a single geographic area and not all racial/ethnic groups were well represented. The control group was not well matched with respect to age or race/ethnicity and was too small to examine the effects of handedness, hand used, and SES. The injury group was too small to examine intervening variables such as hemisphere of injury, site of injury, size of lesion, age at time of injury, and time since injury. With regard to instrument administration and scoring, fatigue effects (especially for those with brain injury) may have been present overall or within certain tasks. Some of the tasks were simply too difficult for some of the younger children to understand and/or perform. The three computerized tasks required complex button presses that also proved too difficult for some of the youngest children. Finally, many of the task variables had score ceilings that were far too low resulting in near perfect performance and low score variance.

Recommendations and Suggestions for Improving the Battery

Although the scores from this particular sample suggest some reliability and validity issues, this is often the case in the initial phases of test development. Reexamination and refinement of the tasks and calculated variables, coupled with retesting of a larger more diverse sample, will almost certainly improve the utility of the Pediatric Visuospatial Neglect Battery. The first general recommendation is to improve sensitivity, by utilizing a less restrictive cutoff score for some of the variables. In many instances reducing the cutoff score from 2 SD to 1 SD greatly improved sensitivity with little effect on specificity. A second recommendation is to simplify the response process for the computerized tasks. Instead of using a standard computer keyboard with overlays, a single panel with four large, clearly labeled buttons placed in front of the child might reduce measurement error. Or, as computer technology continues to improve, a touch sensitive screen may become available. A third recommendation is to continue to allow for deviations in both directions on variables measuring lateralized performance. While older definitions of VSN are still widely used, theoretical shifts as recent as 2012 allow for neglect in either hemispace, not necessarily contralesional space. Although lateralization in a specific direction might be anticipated by the examiner based on known hemisphere of injury, the instrument should be sensitive enough to detect VSN in either contralesional or ipsilesional space. This is especially true for children, where the added complexity of a developmental perspective (including hemisphere crossover, specialization, and reading effects) dramatically complicates the picture. In addition to these general recommendations, the following task-specific recommendations are suggested to improve the battery.

Line Bisection Task Recommendations

It is recommended that the number of line bisection trials be reduced from 20 trials. Largely because it is a repeated measure, internal consistency is still excellent with fewer line bisections. A 10-trial line bisection task administration still yields scores with good to excellent reliability, and may reduce fatigue among the youngest ages, thus allowing more children to complete the task.

Cancellation Task Recommendations

To address the problem of low score variance, it is recommended that more items be added to the CaRawFL, CaRawNL, CaRawNR, and CaRawFR variables, and the difficulty level of the task be increased. This can be accomplished easily in several ways, each supported by the literature. First, the stimulus page could be made larger with more targets and distractors to increase the omission error rate. Relatedly, the targets and distractors could be made more similar (like the stars test) to increase both the omission and commission error rates. A third option would be to impose a time limit.

It is also recommended that three of the variables, CaLocInt, CaOrder, and CaOrg be reexamined and perhaps recalculated differently. One suggestion is to simplify the CaOrg variable. Instead of attempting to measure search strategy via a calculated variable using rank order and column weights, a more parsimonious approach might be to examine the difference or improvement between a structured and random array. Literature suggests that changing the array has little effect on healthy individuals, but does affect performance of those with brain injury (Thareja et al., 2012). Secondly, CaLocInt should also be reexamined to determine whether using a mode score instead of a mean score is a better way to measure this potentially very powerful predictor. One final recommendation for the cancellation task is to add a new variable that captures performance speed. The literature suggests that cancellation performance of both healthy adults (Azouvi et al., 2002; Manly et al., 2009) and children (Thareja et al., 2012) is significantly faster than age-matched individuals with brain injury. An overall “time to complete” variable might improve the decision accuracy of the cancellation task.

Feature Visual Search Task Recommendations

To address the problem of low score variance due to near perfect performance, it is recommended that the score ceilings of the feature visual search variables be raised by increasing task difficulty. Unfortunately, this may not be possible here. As discussed in the literature review, reaction time in feature visual search tasks is independent of the size of the display and the number of distractors (Behrmann et al., 2004; Karatekin & Asarnow, 1998; Karatekin, et al., 1999; Treisman & Souther, 1985); therefore, reducing the interval time limit or using a larger monitor with more distractors to increase item difficulty would probably have little to no effect on performance. An alternative approach to improve reliability estimates is to attempt to alleviate the negative average covariance problem by increasing the number of items. This would allow researchers to create scales that account for both horizontal and vertical target presentation (i.e., left bottom, left top, right bottom, right top), effectively dividing the display into four quadrants instead of just two halves. These more precise scales would assist researchers in investigating the additional effect of vertical presentation on score reliability.

Conjunction Visual Search Task Recommendations

Research suggests that, unlike the feature visual search task, reaction time on this task *is* affected by display size; therefore, to increase task difficulty (and thus score variance) additional distractors can be added to the display, the display can be made larger, or a stricter time limit can be imposed. Alternatively, task difficulty can be increased by making the discrimination between the target and distractors more difficult. In addition to color and shape, a third integrative feature could be added to the objects. For instance the target and distractors could vary by size, or by a feature within the shape like a certain number of dots or lines. Any of these modifications should result in a more difficult task and perhaps greater score variance which might produce higher reliability and validity estimates. Secondly, and much like in the feature visual search task, many item pairs from the same conditions produced weak or negative correlations; therefore, increasing the number of trials and creating more precise scales to examine the effects of vertical placement may be beneficial here as well.

Extinction Task Recommendations

To address the low reliability and validity estimates of this task, it is recommended that the current computer paradigm be reevaluated to ensure accurate measurement of the extinction construct. The reliability and validity of this task's scores would likely be improved if the targets and distractors were presented on two separate monitors placed on each side of the examinee's head (or a certain number of degrees from center), rather than on a single monitor placed directly in front of the examinee. This would provide a more clear separation of the hemispaces, and thus the condition scale scores.

Future Research

Additional studies examining the psychometric properties of each of these five tasks should be conducted. Larger and more diverse samples are needed before any firm conclusions can be drawn about the reliability and validity of any of these tasks for use with children ages 2-6. An attempt was made to examine the effect of age and hemisphere of injury on reliability and validity estimates, but due to the small sample size these variables need to be reexamined. Research suggests that age, handedness, and hand used can affect performance of all individuals and especially young children. Additional variables affecting children with brain injury such as hemisphere of injury, lesion size, affected brain structures, and time since injury may have additional effects on performance, and so also need to be examined with a larger sample.

Future research should also make an effort to examine the age effect in greater detail. Due to early and rapid brain development, age should be broken down into extremely small increments (perhaps by months), because large categorical age groupings do not accurately capture developmental effects, but instead tend to muddy the water with inconsistent findings. Regarding battery refinements, future studies should consider adding additional tasks that might be easier for young children yet still supported in the literature. Drawing tasks or copying tasks like those found in the BIT, and verbal tasks such as describing a picture or naming foods appearing on a plate may also prove to be an excellent addition to the Pediatric Visuospatial Neglect Battery and should be investigated in future studies.

Future criterion-related validity studies should attempt to use “diagnosis of VSN” as the criterion predicted by the outcome variables as opposed to “brain injury” since not all individuals with brain injury display neglect behavior and since detection of VSN is the true purpose of the battery. Finally, future validity studies should seek convergent evidence to support the use of the battery. For example, scores of the Pediatric Visuospatial Neglect Battery should be compared to findings of a neurological exam, a rating scale such as the CBS, or parent, child, or teacher reports of neglect behavior.

Conclusion

We know that infants, children, and adolescents experience stroke, and that unilateral neglect in general, and VSN specifically, are potential negative outcomes of stroke; however, the nature and incidence of VSN in children is largely unknown. This is because the overwhelming majority of research on VSN and neglect in general has focused on the adult population, completely ignoring a developmental perspective. Neglect behavior dramatically affects day-to-day functioning and is a very powerful predictor of future outcomes; therefore, it is critically important that we learn to accurately identify and measure this complex phenomenon as it occurs in children.

The present study represents the first attempt to validate the Pediatric Visuospatial Neglect Battery developed at CHOP that purports to assess VSN in young children ages 2-6 who have experienced stroke. The five tasks of the battery (line bisection, cancellation, feature visual search, conjunction visual search, and extinction) were selected for inclusion based on findings in the literature suggesting group differences in performance on these measures. Despite the importance of a developmental perspective, only a very small portion of the literature on VSN is specific to children, and only a fraction of these child studies investigate the psychometric properties of the VSN tasks used in the studies. For these reasons, the development and refinement of the Pediatric Visuospatial Neglect Battery is an important contribution to the field of pediatric neuropsychology.

Although there were some exceptions, reliability and validity estimates of task scores obtained from the sample selected for study were generally low. It appears that some of the low estimates are due to measurement problems of the calculated variables. Fortunately these variables can be reexamined and likely improved in future studies. In other instances, slight to significant modifications to the tasks are recommended. Specific suggestions for improving the existing tasks were provided, as well as suggestions for additional task that could potentially be added to the battery in future administrations. Although somewhat disappointing, low initial reliability and validity estimates are part and parcel to test development. This study represents an important first step in developing a standardized and well-validated battery to detect VSN in children, and with refinement and future retesting the Pediatric Visuospatial Neglect Battery may soon become an excellent instrument for investigating the VSN phenomenon.

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